TECHNICAL REVIEW

ADAPTING DAIRY FARM SYSTEMS

ALTERNATE FEEDBASE AND FORAGE OPTIONS AND HERD MANAGEMENT INFRASTRUCTURE FOR DAIRY FARMS

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FOREWORD

Towards the end of 2019, Dairy Australia initiated the Adapting Dairy Farm Systems project to be conducted over 3-4 years. The impetus for this work, examining options for dairy farming systems away from grazing as the mainstay of herd nutrition, has come predominantly from our five dairying regions beyond southern Victoria and Tasmania.

Murray Dairy led the charge off the back of their Accelerating Change project (2015-2018) and the subsequent Future Focus – Regional Dairy Industry strategy for Murray Dairy in 2019. The Adapting Dairy Farm Systems projects reflects the significant challenges being placed on farm systems relying on a perennial pasture base whether they are irrigated or not. Farmers in multiple regions are responding with the structural alteration to their individual farm system with changes such as alternate forage crops, batch and year-round calving patterns, partial or total mixed rations and permanent feeding or housing infrastructure.

This review represents one of the foundational building blocks for the project. There was a need to explore, capture and summarise the available Australian and applicable overseas literature on alternate forages for dairy production, in addition to how feed may be stored, delivered and consumed with, or without, cattle housing. Our authors, Ray King and Steve Little, brought to this considerable task their deep experience in nutrition and dairy production along with their wide scientific training. Dairy Australia is indebted to both of them for the diligence and care with which this review has been undertaken. We also acknowledge the assistance of our peer review panel of Christie Ho, Dave Barber, Bill Wales, Scot McDonald and Ruairi McDonnell have provided to produce an accurate, encompassing and robust work.

This review should not be contemplated as a resource set apart. Rather, it should be considered as a pivotal component of related resources both in preparation (at the time of writing) and available for Australian dairy farmers and their advisers now. These aligned resources include results from the C4 Milk project (QDAF and Dairy Australia), the 2nd Edition Guidelines for Feedpads and Cattle Housing and the "Economic and Risk" project examining financial performance and decision making of intensive dairy systems (both in preparation and part of Adapting Dairy Farm Systems) plus the future research and demonstration output from the Murray Dairy Fodder for the Future project.

Finally, I wish to acknowledge the excellent project steerage for Adapting Dairy Farm Systems provided by Karen Romano (Project Leader) and Pheona Smoczynska (Project Manager). Their combined work is instrumental in delivering the resources from this undertaking. I trust you, the reader, find useful and very applicable information contained within this review.

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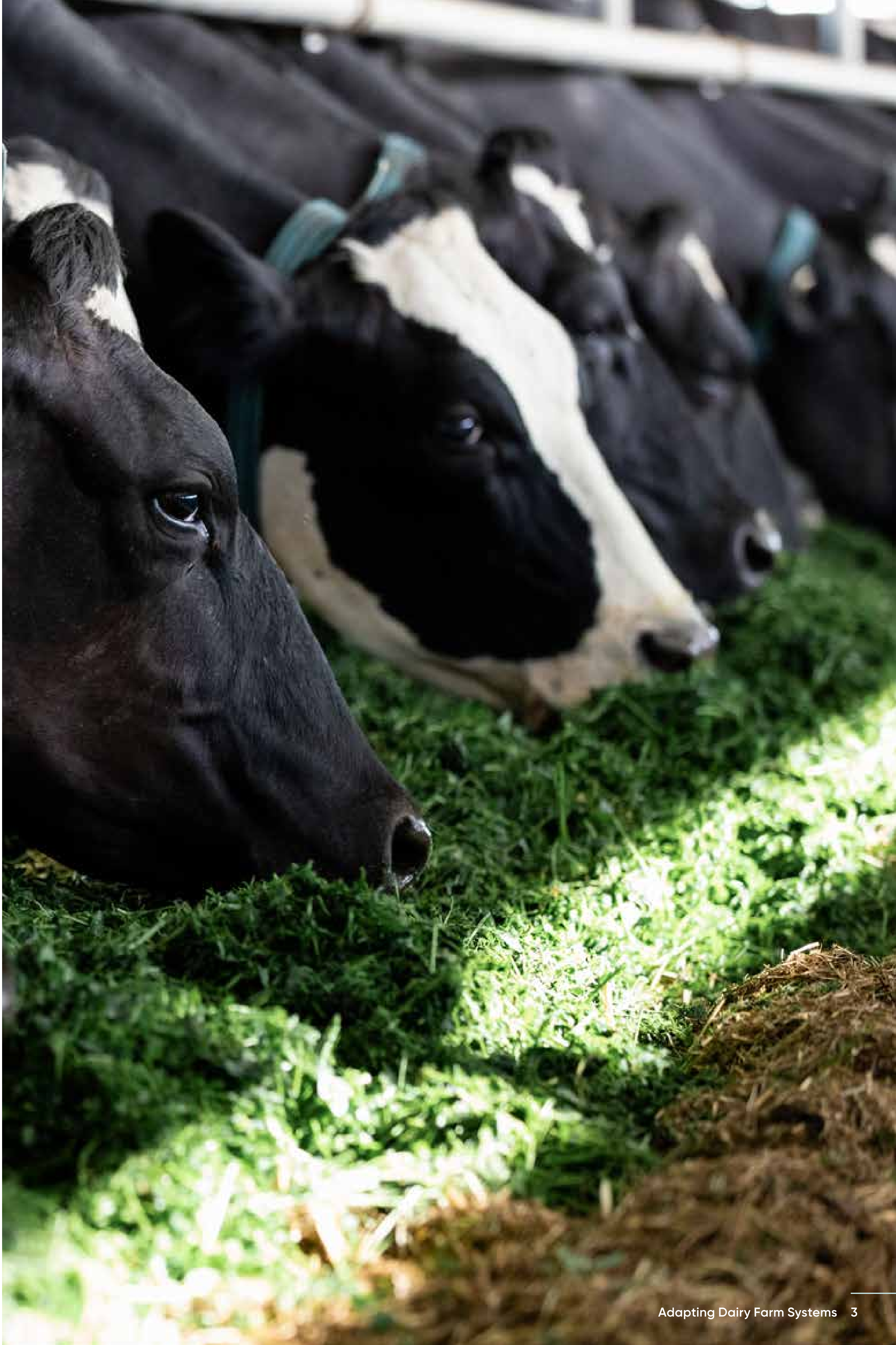


SHELLEYS

01

Technical Review: Alternate feedbase and forage options for dairy farms in Murray Dairy

Ray King

August 2021

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INTRODUCTION

Many dairy farms, particularly those in the Murray Dairy region have moved to a more intensive production system. Alongside these changes, farmers have been exploring alternate annual forage crop options as a replacement for perennial grasses that require water over the summer period. As irrigation water is likely to remain one of the most limiting resources in the Murray Dairy region in the future, a major challenge in this dairying area is to grow the maximum amount of quality dry matter per ML of water.

This review examines what is known about several forages that may be grown in the Murray Dairy region and compares their potential yield, agronomic requirements, water use efficiency, flexibility of use and their nutrient content for dairy cows. While yield is an important criterion for choosing dairy forages, it is only one factor in a complex system. The choice of forages must be considered on a whole-farm basis and include water use efficiency, nutritive value, cost of production and risk. Water use efficiency will often be the core of the forage decision making process of many dairy farmers in this region.

Because of the limited information that has been published on the performance of the various forage crops in the Murray Dairy region, this technical review has included relevant data on the forage crops that may have been derived from studies conducted elsewhere in Australia and overseas. Much of the information in this review has been based upon the excellent work conducted by the dairy research groups at the University of Sydney, University of Melbourne and the Departments of Agriculture in Victoria and Queensland over the past 10–20 years. The forage options that have been discussed in this technical review include, maize, sorghum, millet, lucerne and winter cereals, as well as multi-cropping systems. While this technical review concentrates on forages that would most likely be grown and fed to dairy cows, a summary of the role of concentrates and hay in the dairy cow ration has also been included.

In addition, this review has been limited to technical information and there has been no attempt to examine relative costs and returns of the various forage systems. There does not appear to be decision support tools available that may be used by industry to identify the optimum forage crop(s) to be grown, given current forage, water, and other input prices. Certainly, Grains Research and Development Corporation have initiated a program to optimise the return from at least six irrigated grains grown in the Southern Murray Darling Basin to maximise the dollar return per ML of water and have developed a new decision support tool ("Water Can Profit") that explores how gross margins of the various grain crops varies with input prices and grain yields.

As a result of this review, some gaps in our knowledge of these forages have been identified that may be worthy of further investment in Research, Development and Extension (RD&E). Future work should concentrate on the continued evolution of forage sources and the integration of alternate forage types into the farming system. In addition, the selection of forage sources must be flexible from year-to-year to account for different climatic conditions, water availability and production systems. The further development of double cropping systems and even triple cropping of some forages will become an increased part of the feedbase resource in these areas.

FORAGES GROWN IN THE MURRAY DAIRY REGION

This part of the Technical Review examines what is known about several forages that may be grown in the Murray Dairy region and compares their potential yield, agronomic requirements, water use efficiency, flexibility of use and their nutrient content for dairy cows. The forage options that have been discussed in this technical review include, maize, sorghum, millet, lucerne and winter cereals, as well as multi-cropping systems. While yield is an important criterion for choosing dairy forages, it is only one factor in a complex system and choice of forages must be considered on a whole-farm basis and include water use efficiency, nutritive value, cost of production and risk.

MAIZE

RELATIVE SCORE	
Yield	✓ ✓ ✓ ✓ ✓
Nutrient content	✓ ✓ ✓ ✓ ✓
Simple management	✓ ✓
Water use efficiency	✓ ✓ ✓ ✓ ✓
Versatility	✓ ✓ ✓
Reliability	✓ ✓ ✓

Background

Maize (Zea mays) is a multi-purpose cereal grain that can produce both grain and silage for livestock feeding. In Australia, maize is a minor summer crop with an annual average production of between 350,000 and 450,000 tonnes, with grain yields of about 10–20 t DM/ha (GRDC, 2017a). Most of the maize grown in Australia is sold on the domestic market to the food and stockfeed industries. Maize entering the food market ends up as breakfast cereal, snack foods, corn flour, etc. while the domestic stockfeed feed market includes grain as well as whole plant maize silage. Maize varieties used for stockfeed are chosen mainly for their potential for grain yield.

It is estimated that over the past few years, there has been an increase in the area sown in Australia to produce maize silage, mainly for the dairy industry. Maize provides a high yield of consistent forage and is higher yielding than most other crops grown for silage, making it an ideal choice as a silage crop in dairying regions in Australia. Overall, only 16% of Australian dairy farmers have sown maize in the last 5 years, but in the larger herds (above 500 cows), 30–45% of farmers sowed maize in the past 5 years (Dairy Australia, 2019a). In addition, increased areas have been sown for maize silage in the past couple of years as irrigation water has become very expensive to grow pasture and other crops.

AT A GLANCE:

- Maize yields of over 30 tonne DM/ha are possible but more common yields on dairy farms in northern Victoria are about 25 tonne DM/ha.
- Ideal sowing time varies between locations as soil temperature must be above 14°C.
- Maize silage is a high-quality forage supplement that is most effective in high producing cows in early/mid lactation.
- Maize is the most efficient crop for water utilisation.

R&D GAPS AND OPPORTUNITIES:

- Evaluate brown midrib (BMR) maize against existing forage varieties of maize if BMR maize is introduced to Australia.
- Comparative trials with other summer forages in northern Victoria.
- Yield and water use efficiency (WUE) on dairy farms in Murray Dairy region when BMP guidelines are strictly followed.
- Assess quality of maize silage when BMP guidelines are strictly followed.

Varieties

Selection of an appropriate maize hybrid in respect to time to maturity depends on potential yield and the growing season. The time to maturity is identified by the cumulative relative maturity (CRM) figure. In areas that are relatively cool such as around Mt Gambier, South Australia or in East Gippsland, Victoria the summers are relatively cool and thus a short to medium season hybrid of 95–110 CRM is the most appropriate, with longer season (120–130 CRM) varieties struggling to finish before late autumn. Note that the CRM value relates to the accumulated amount of 'growing degree days' required to mature, which is derived from average temperatures, and it does not mean it will be ready to harvest in 95 days.

BMR maize was first discovered in 1924 in Minnesota, USA as a natural mutation of regular dent maize. BMR varieties of maize have been used in the USA for the past 30 years or so and are likely to be introduced into Australia in the next couple of years. The benefit of the BMR maize, despite often a small reduction in yield, is that it has a lower lignin content which leads to greater NDF digestibility, dry matter intake and milk yield (Oba & Allen, 1999b).

Yields

Expected forage yields observed in commercial crops in Australia are usually up to 25 t DM/ha. Densley *et al.* (2006) has shown that reliable annual maize silage production of 30 t DM/ha was possible using a late maturing maize hybrid combined with a winter forage crop near Hamilton in the north island of New Zealand. Later, Minnee *et al*. (2009) confirmed that annual yields of forage crops (based upon maize) of around 45 t DM/ha were possible, provided water and nitrogen were plentiful and that the crop rotation was carefully designed to maximise solar radiation capture and utilisation. However, in both these research studies the observed yields were based on 'best' plot yields of crops and pasture. More common yields on commercial farms can approach 20–25 t DM/ha. Greenwood *et al.* (2008) reported maize silage yields on commercial farms in northern Victoria ranged from 19 t DM/ha when grown under flood irrigation to 21 t DM/ha when grown under centre pivot irrigation.

Sowing

Extensive details on the agronomic management of maize for grain in northern Australia are provided in the respective copy of GrowNotes, produced by Grains Research and Development Corporation (GRDC, 2017a). This technote highlights the main issues around the agronomy of maize, but more detailed information can be sought from the respective GrowNotes.

The growing season for maize is generally between about 100 and 150 days, from planting to harvest, with planting often beginning in mid-October through to early December. The season length will vary between about 115 days and 145 days, depending upon the hybrid/variety selected, seasonal conditions, location, and crop management, especially irrigation.

For a given region, the growing season is determined by the earliest sowing date and the latest harvest date. The earlier sowing date depends strictly on soil temperature which must be at least 12°C (but ideally at 14°C) at a sowing depth of 10cm for three consecutive days. For example, maize may be sown as early as mid-September on the north coast of NSW, mid-late October in northern Victoria and in East Gippsland and around the Mt Gambier district in early-mid November.

Maize should be grown on well-drained soils with neutral to mildly acidic pH and plant populations for silage production in irrigated crops should be about 80,000–900,000 seeds/ha. High plant densities are even more important if maize is sown early so that canopy closure can be achieved sooner, minimising opportunities for weeds to establish and maximising radiation absorption. The desirable distance between rows is 65 to 75cm.

Water use efficiency and fertiliser requirements

Maize has a high requirement for water due to its high yields of grain and total plant dry matter. Because of these high yields, maize is one of the more efficient users of water. Wood (2018) recorded up to 8 t DM/ML when using a sub-surface drip irrigation system. However, maize appears to be more sensitive to water restrictions than other forage crops and relative water use has increased as yields have increased.

The Water Use Efficiency (WUE) of an irrigated maize forage crop, expressed as kg DM/ha/mm total water required, is about 30kg DM/ha/mm (range 29-34) in on-farm studies conducted in northern Victoria (Greenwood *et al*., 2005). This compares very favourably with the WUE likely for perennial pastures (10–20kg DM/ha/mm) in a similar environment (Greenwood, 2003). Furthermore, Neal *et al*. (2011) found that the highest WUE for all the annual forages used by the dairy industry was in maize, at 42.9kg DM/ha/mm. However, the reduction in WUE in response to deficit irrigation is likely to be greatest in the high yielding summer forages such as maize. The maize crop uses about 70% of its water requirement during the 3 weeks either side of tasselling in the later part of growth. Thus, if irrigation water is limited, it is important to irrigate during this critical period.

The fertiliser and nutrient requirements of the maize crop may be estimated from the quantities of nutrients removed from a paddock when the maize forage crop is harvested. Kaiser *et al*. (2004) suggested that 25 t DM maize silage removed about 250kg nitrogen (N), 245,kg potassium (K) and 45kg phosphorus (P) when harvested. However, Callow (2013), when calculating the amount of nutrients removed for several forage crops, found that the amount of nutrients removed over the growing season were about 320kg N, 180kg K and 60kg P per hectare for a 25 t DM maize crop.

Harvesting

Maize is unlikely to be grazed and the crop is ready to harvest for fodder or silage, theoretically, about 10–14 days before physiological maturity, which will be about 3 to 4.5 months after planting.

Maize must be ensiled at the proper moisture content to get fermentation for preservation. But, determining when to harvest maize at the right whole plant moisture is difficult. The dilemma is finding an easily measured indicator that accurately correlates with moisture. Kernel milk line has been the most widely used indicator for determining when to harvest maize for silage, as it indicates the rate at which the crop is drying down. The milk line is a visual division between the yellowish colour of the seed coat at the bottom of the kernel and whitish colour of the seed towards the tip of the kernel. However, relying upon the milk line can be misleading as the actual moisture content of the plant varies between hybrids. It is much better to directly measure dry matter of the whole plant to identify the right time (about 30 to 32% DM) to harvest maize for silage. To do this you should sample each paddock by harvesting 15–20 plants and chopping them up, subsample and determine DM% by oven drying at 100°C for 24 hours or drying in a microwave for up to about 15 minutes.

Harvesting factors affecting the nutrient content of maize silage

Cutting height

Cutting maize silage at higher levels can be a tool for farmers to manage the dry matter of the crop. Since harvesting silage 25cm higher will generally increase the dry matter in the harvested crop by 2% units, farmers could use this to harvest earlier. Because maize silage generally dries down at a rate of about 0.5% units/day, this translates into harvesting approximately four days earlier. The decision to cut maize silage at higher levels is a farm-specific question and is likely influenced by several considerations.

The higher the cut height, the lower the yield but silage produced will be of better quality (Table 1). Conversely, the lower cut height will produce more silage, but at a lower quality. The better-quality maize silage would be fed to high producing cows to improve dry matter intake and milk yield, while the lower quality silage cut at a lower height could be fed to late lactation cows whose dry matter intake is less limited by gut fill, to promote improved body condition.

Table 1. Effect of cut height on nutrient content of maize silage. Summary of 11 cutting height studies by Wu and Roth (2016)

Nutrient content	Low chop height (Av. 20cm)	High chop height (Av. 50cm)
Dry matter (%)	38.1	40.3
Crude protein (%)	7.0	7.1
NDF (%)	41.6	38.6
Starch (%)	30.6	32.4
DM digestibility (%)	78.6	80.6
NDF digestibility (%)	50.6	54.0

Chop length

The optimum chop length for maize silage is not constant, but depends upon hybrid, dry matter concentration, processing, and sources of effective neutral detergent fibre (NDF) in the diet. The typical chop length is about 10–15mm, but shorter chop length silage can pack better in the silo/pit and can lead to less spoilage and better silage. However, shorter chop length may reduce the "effective" nature of the fibre in the rumen. Longer chop lengths of 25–30mm are sometimes used to produce a product called shredlage, where the particles are also "shredded" along the length as they are processed. This extra processing may improve starch digestibility and the effective fibre level.

Roller clearance

The typical maize forage harvester has both choppers and rollers to crack any grain. The rollers will increase total tract starch digestibility, decrease sorting, and cob refusal. Roller clearance can vary between 1 and 3mm and is dependent upon the vitreousness and moisture content of the kernel. The roller clearance should be tightened until all kernels are broken and there are no cob pieces greater than a fingertip. However, fine processing lowers machine output and increases the power requirement and fuel consumption.

The conservation process for maize must be carefully managed to minimise losses. Aerobic spoilage during storage can result in a loss of up to 10% and similarly, aerobic spoilage during feed out can result in an additional loss of up to 10%. The use of silage should be delayed until at least 3 weeks after ensiling to obtain adequate quality. The quality of silage still improves beyond 3 weeks and peaks at about 6 months after ensiling, with the optimum feed out period being between 2 and 6 months after ensiling.

Composition and nutrient content of maize silage

The composition of maize silage can be quite variable and will be affected by hybrid, environment, and management factors such as population density, maturity at harvest and subsequent processing. Maize silage provides not only energy and appreciable quantities of starch, but also fibre in the form of Neutral Detergent Fibre (NDF). As the corn plant matures, starch concentration increases, thereby diluting NDF concentration. The average composition of maize silage samples analysed by near infrared reflectance spectroscopy (NIRS) by a US commercial laboratory between 2000–2018 is shown in Table 2.

Table 2. Composition of maize silage (Mike Allen, Pers. comm.)

Nutrient content	No. samples	Mean	"Normal" range
Dry matter (%)	272,433	33.3	25.5–41.1
NDF (% DM)	270,531	43.5	37.6–49.5
30 hr *in vitro* NDF digestibility (%)	66,770	52.7	46.7–58.6
Starch (% DM)	236,266	31.8	24.4–39.2
In vitro starch digestibility (%)	44,721	69.8	47.2 –92.5

Table 3. Composition of maize silage samples collected in the 2018/19 season (Feedtest, 2020), between 2012 and 2019 (DPI Wagga, Richard Meyer, Pers. comm.) and in samples analysed by Forage Lab Australia at Bendigo (Trevor Dorman, Pers. comm.)

	Wagga		Feedtest		Forage Lab Australia	
	Mean	Range	Mean	Range	Mean	CV%
Dry matter (%)			33.0	22.0–52.1	42.4	56
NDF (% DM)	50.2	32.4–66.2	50.2	41.4–64.2	41.2	11
CP (% DM)	7.5	5.6–9.9	8.2	5.0–12.9	8.4	14
ME (MJ/kg)	10.3	7.8–11.9	10.2	8.4–11.6	11.3	5
Starch (%DM)					28.4	22

Local figures from samples submitted to Feedtest in Victoria, NSW DPI at Wagga or Forage Labs Australia at Bendigo indicate similar average nutrient content as well as the quite large range in values (Table 3).

NDF digestibility

NDF digestibility of maize silage may range from 30 to 60%, with many samples likely to be between 40 and 50%. NDF digestibility affects passage rate and dry matter intake with higher digestibility figures promoting greater voluntary feed intakes. Higher NDF digestibility of NDF in maize silage leads to improved animal performance and Oba and Allen (1999a) have estimated that each unit increase of NDF digestibility results in an increase of 0.17kg/day dry matter intake and an increase of 0.25kg/day in milk yield.

Starch digestibility

Maize is an advantageous source of starch for lactating dairy cows because the ruminal digestion of starch in maize is slower than starch digestion in some other cereal grains such as wheat and barley. The slower digestion of starch in maize helps cows maintain a more stable rumen pH and avoid the milk fat depression often seen when diets high in other forages are fed. This slower digestion of starch in maize is often very complementary to winter cereal grain digestion.

Maize silage that is more fermentable will have higher starch digestibility. Ensiling increases the *in vitro* digestibility of starch in maize silage. As the silage process progresses, *in vitro* starch digestion in maize silage increases, particularly over the first 3-4 weeks and more particularly when the grain has a high moisture content.

Conclusions

Maize silage is a high-quality forage supplement that is increasingly being successfully incorporated into dairy rations in Australia. The average composition of good quality maize silage is about 40% NDF with an *in vitro* NDF digestibility of about 55% (Mike Allen, Pers. comm.). In addition, it may contain between 25% and 35% starch.

The composition of maize silage can be quite variable and will be affected by hybrid, environment, and management factors such as maturity and dry matter at harvest, chop height, chop length and subsequent processing.

Good quality maize silage should be fed to cows during early lactation where it is most effective, improving dry matter intake and milk yield. Poorer quality maize silage could be restricted to feeding cows in later lactation where it may improve body condition without any major effect on milk yield (Mike Allen, Pers. comm.).

SORGHUM

RELATIVE SCORE	
Yield	✓ ✓ ✓ ✓
Nutrient content	✓ ✓ ✓
Simple management	✓ ✓ ✓
Water use efficiency	✓ ✓ ✓ ✓
Versatility	✓ ✓ ✓ ✓
Reliability	✓ ✓ ✓

Background

Sorghum is a popular forage crop used in livestock production systems capable of producing substantial quantities of feed during the warmer months of the year (Ellis, 2007). Sorghum is a feed source that can be grazed, ensiled, or made into hay. While it has been an established forage crop in Queensland for many years, the use of forage sorghum into the southern dairy farming systems has been more recent (Dairy Australia, 2018). In these systems, sorghum is often directly grazed during the growing season between November and April.

In comparison to maize, forage sorghum is generally lower in starch availability and higher in NDF, but the growing costs are considerably less, and the crop is much more forgiving than maize if growing conditions become challenging. Sorghum is best suited to farms with limited water resources where rainfall is a major driver of yield. The problem often faced with growing maize for silage is that it has large water requirements, whereas there is much less risk in growing sorghum as it requires less irrigated water, is far less demanding agronomically, but can still produce an acceptable crop.

Overall, 29% of Australian dairy farmers have sown sorghum in the last 5 years. But 40% of farmers in the Murray Dairy region have sown sorghum and even higher numbers of farmers have grown sorghum in the more northern dairy regions. Despite this general popularity of sorghum, the larger dairy farmers much prefer to sow maize ahead of sorghum and millet (Dairy Australia, 2019b).

AT A GLANCE:

- Forage sorghum covers a range of C4 summer forages including sudan grass (sudan x sudan), sorghum x sudan hybrids, sweet sorghums hybrids and BMR sorghums. Varieties should be chosen to match the nutrient requirements of the livestock and the feed gaps in the individual farm.
- Sorghum is sown later than other summer crops when soil temperature reaches 18°C.
- Sorghum, while often not reaching the yields of maize, can be grazed as well as harvested for silage.
- Sorghum also requires less close agronomic management than maize and tolerates water stress.
- The lower nutrient content of sorghum is less suited to high producing dairy cows.

R&D GAPS AND OPPORTUNITIES:

- Comparative trials with alternative types of sorghum and against maize in Murray Dairy region when BMP guidelines are followed.
- Further work on the growth and suitability of grain sorghums as a forage source for dairy cows is required.

Varieties

The term forage sorghum covers a range of C4 summer forages including:

- Sudan grass (sudan x sudan) which are early flowering. The sudan grass and sudan x sudan hybrids are dual-purpose varieties suitable for both grazing and silage/hay conservation. These varieties tolerate repeated heavy grazing with good recovery between grazing, as well as producing higher quality hay.
- Sorghum x sudan hybrids which are often late flowering are also dual-purpose varieties that can tolerate multiple grazings and/or silage cuts.
- Sweet sorghums hybrids are generally cut and are often preferred for silage production as they have been selected for once-a-year harvest. (Kaiser *et al.*, 2004).
- Sorghums that are bred to express the BMR genes. The BMR genes may reduce yields, but this is often outweighed by an increase in forage quality as it reduces lignin content.

In addition, there are sorghums that are grown for grain but have become more widely used as a silage crop in northern Australia. Grain-sorghum hybrids, which typically are shorter in height and have higher grain-to-forage ratios than forage types, are also viable options for use as a silage crop. Barber (2020) has recently demonstrated the potential for grain sorghums for silage production, yielding equivalent to, or surpassing dry matter yields of popular forage sorghum varieties. These grain type sorghums which include both white and red sorghum grain varieties have become more widely used as a silage crop in northern Australia, as well as more recently, in the Murray Dairy region.

Varieties have different traits, yields, quality, and growing characteristics and should be chosen to match the nutrient requirements of the livestock and the feed gaps in the individual farm.

When choosing a variety, it is recommended to consult an agronomist with experience in sorghum production in the local area. Seed suppliers can provide advice on their company varieties and often provide useful comparisons of characteristics between varieties to match the individual farmer needs.

Yields

With no limitation of water or nutrients, sorghum can produce up to 17–20 t DM/ha in commercial situations. Although sorghum does not have the same yield potential as maize, one of the main advantages of sorghum over maize is that sorghum can be direct grazed as well as harvested for silage.

Forage sorghum has an advantage over maize crops because it can have multiple cuts compared to the single cut option with maize. Irrigated forage sorghum crops have produced yields in northern Victoria ranging from 14–19 t DM/ha when cut three times, to 20–31 t DM/ha when cut once, with dry matter digestibility being higher for the multiple cuts than for the single cut crops (Pritchard, 1987). In addition, recent controlled studies from Queensland have reported average total yields of forage sorghum being at least 20 t DM/ha and up to 29 t DM/ha in a fully irrigated crop that was grazed 3 or 4 times before finally being cut and harvested for silage

(Benvenutti *et al*., 2018). More recently, the results of trials at Gatton, Queensland, growing the forage sorghum variety, Megasweet and two grain sorghums (Liberty and Sentinel), have demonstrated that sorghum can achieve yields greater than 30 t DM/ha with starch levels around 30% (Byrne, 2021).

Under restricted irrigation conditions, yields of sorghum can be extremely variable and on commercial farms the potential yields described above are rarely achieved. For example, on two commercial farms in northern Victoria the total yield from 5 grazings between late October and early April was 9.9 t DM/ha, while on the other farm dry matter yield over 4 grazings from early January to early March was only 6.4 t DM/ha (Kelly & O'Connor, 2018). Further comparative studies between grain sorghum varieties and maize grown under optimum and deficit irrigations are being conducted in the Murray Dairy region in 2020/21 (Byrne, 2021).

Sowing

Extensive details on the agronomic management of sorghum for grain in northern Australia are provided in the respective copy of GrowNotes, produced by Grains Research and Development Corporation (GRDC, 2017b). This technote highlights the main issues around the agronomy of sorghum, but more detailed information can be sought from the respective GrowNotes.

Sorghum is a summer growing crop and is usually sown in northern Victoria from late November to December with the sorghum being grazed over the summer period and harvested for silage by April. Sorghums are well suited to heavy soils and can be direct drilled or sown into a prepared seedbed. Highest yields are often associated with early sowings but the soil temperature for sowing and successful establishment of sorghum is critical. Sorghum requires a soil temperature of 18°C at a depth of 10cm for 3–4 consecutive days and rising. It should be sown into moisture at a depth of 3–5cm.

Sorghum plant populations for silage production in irrigated crops should be between 10–25kg/hectare, but the seeding rate for sorghum when rain-fed in southeast Queensland could be reduced to only 1–5kg/ha (Callow, 2013), depending upon the type of sorghum. The various commercial seed companies will provide sowing rate recommendations for sorghums under dryland or irrigation systems. The desirable distance between rows is 50 to 75cm, but the sudan grass and sorghum x sudan hybrid forages may be established by broadcasting or drilling the seed, not necessarily in rows.

Water use efficiency and fertiliser requirements

Callow (2013) reported the water requirements for sorghum based upon the sum of evapotranspiration rates, less rainfall in southeast Queensland to be between 1.9 and 2.7 ML/ha. Furthermore, the WUE of forage sorghum was similar to that of maize in the subtropical dairy region in Queensland (Callow & Kenman, 2006). The WUE of forage sorghum grown under irrigation in northern Victoria has yet to be reported. But extrapolation of this data from southeast Queensland to northern Victorian suggest that the WUE for forage sorghum would be similar to that recorded for maize, which was about 30kg DM/ha/mm (range 29–34kg DM/ha/mm) in on-farm studies conducted by Greenwood *et al* (2005).

To achieve the potential yields for sorghum, it has a high requirement for nutrients with high nitrogen applications having a very positive effect on the yield for grazing and silage, as well as boosting the crude protein levels of the plant material. The fertiliser and nutrient requirements of the sorghum crop may be estimated from the quantities of nutrients removed from a paddock when the forage sorghum is harvested. For a 20 t DM/ha sorghum silage crop, this equates to about 340kg N, 360kg K and 45kg P per hectare for the growing season (Callow, 2013).

Harvesting

Grazing

Sorghum offers more flexibility than maize as there are opportunities to graze sorghum at various stages during its growth, prior to harvesting. If the crop is to be grazed, then the timing of grazing should keep stem elongation and flowering to a minimum. For short rotational grazing, the ideal height at grazing is 1 metre or at least 75cm, with 25cm residual when cattle are removed to allow satisfactory regrowth (Callow, 2013).

Silage production

Harvesting at the correct time is critical for quality control of silage production. Whole plant dry matter should be within the dry matter target of 28–35% DM for precision chopped silage and 35–40% DM for wilted bale silage. Harvesting in this window should maximise yield, quality, and stack fermentation. Harvesting a crop too early will result in a yield loss and potentially poor fermentation and losses of valuable sugar fluids. Late harvest may result in a loss of quality as plant stalk increases in fibre and becomes less digestible. Drier crops are also difficult to compact and ferment properly.

Hay production

Palatable hay can be made from forage sorghums. The fine stemmed sudan grass varieties make good quality hay. If sorghum x sudan hybrids or sweet sorghums are cut for hay, a mower conditioner is essential because of the thicker stems. The optimum cutting time is early flowering, striking a balance between forage quality and the likelihood of rain damage.

Composition and nutrient content of forage sorghum

The composition of sorghum that is grazed or harvested as silage is highly variable (Table 4) and is affected by the type and hybrid of sorghum, maturity at grazing and at harvest and subsequent processing. Sorghum silage has a much lower concentration of starch and quite high levels of NDF compared to maize and consequently maize silage is often preferred in high producing cows at critical times during early lactation.

Note that the dry matter content of sorghum silage harvested in southeast Queensland by Callow (2013) was 49.1% which is considerably higher than the more normal levels of dry matter (mean of 36% and range, 25.6–45.3%) reported elsewhere for sorghum silage (Little, 2007).

Table 4. Composition of sorghum harvested as silage or grazed (Callow, 2013)

Nutrient content	Grazed		Silage	
	Average	Range	Average	Range
Dry matter (%)	23.2	12.0–43.5	49.1	25.6–78.6
NDF (% DM)	55.4	34.3–65.8	57.7	38.9–70.0
Crude protein (%)	16.4	8.3–29.0	10.7	4.8–19.7
Starch (% DM)	3.3	0.1–20.5	7.3	0.2–32.3

Table 5. Composition of sorghum harvested as silage or grazed and analysed at DPI Wagga (Richard Meyer, Pers. comm.) and sorghum silage analysed by Forage Labs Australia (Trevor Dorman, Pers. comm.)

Nutrient content	Grazed		Silage		FLA Silage samples	
	Average	Range	Average	Range	Average	CV (%)
NDF (%DM)	58.2	43.1–67.7	46.0	37.0–57.6	36.0	16
Crude protein (% DM)	9.7	0.5–22.9	9.3	3.7–19.4	11.1	38
ME (MJ/kg DM)	8.9	6.5–11.3	9.8	9.0–10.2	9.2	11
Starch (% DM)					7.8	92

The composition of samples analysed by Forage Labs Australia and by NSW DPI laboratories at Wagga for samples collected between 2012 and 2019 are shown in Table 5 and reveal similar considerable variation in composition of sorghum forage and silage samples. Some of this variation in the composition of sorghum silage could be attributed to the variety of sorghum used, as grain sorghums would have a different nutritional profile compared to forage sorghum types because of the greater grain content. For example, Barber (2020) reported that silage produced from 7 grain sorghum varieties that they grew in southeast Queensland contained an average of 10.0% CP, 34.2% NDF and a considerably higher starch content of 27.7%. In view of this large variation in the composition of different samples of sorghum silage, these forages that will be fed to dairy cows should be tested by a feed testing laboratory.

Grazing

The composition of forage sorghum depends to a large extent, when the sorghum crop is grazed. While the yield on two commercial farms in northern Victoria varied between 6.4 t DM/ha and 9.9 t DM/ha, the average nutrient composition of sorghum on the two farms was remarkably similar (Kelly & O'Connor, 2018). The average composition across the two farms was 9.5 MJ ME/kg, 60.7% NDF and 17.4% CP although about 25-30% of the protein may have been in the form of non-protein nitrate form. However, at individual grazings, the ME ranged from 8.3 to 10.7 MJ/kg DM, 57 to 64.4% NDF and between 13.2 and 20.6 % CP (Kelly & O'Connor, 2018).

Silage

The composition of sorghum silage contains more starch and less protein as it is harvested at a later stage of growth than grazed sorghum and is shown in Tables 4 and 5 above.

Animal health

Stock risk prussic acid poisoning if sorghum is grazed at certain stages of growth. Sorghum can contain lethal levels of prussic acid better known as cyanide. As well as cyanide, sorghum can have elevated levels of nitrates. Careful management can greatly lower any potential animal health risk associated with feeding sorghum to livestock, (Dairy Australia, 2019b). To assist in reducing the risk of cyanide and nitrate poisoning, grazing should be avoided if the plants are stressed and when regrowth has begun. Sorghum plants should be more than 45cm high for short varieties and 75cm high for tall varieties to help reduce the risks of cyanide and nitrate poisoning. Ensiling dissipates prussic acid, but it will not destroy nitrate. Farmers can test crops for cyanide and/or nitrate levels before using as fodder if in doubt about its safety. However, plant breeding advances for forage sorghum have reduced the risk of prussic acid poisoning. Sweet sorghum and grain sorghums still tend to have higher levels of prussic acid which can be controlled by good grazing management and ensiling.

Conclusion

The term forage sorghum covers a range of C4 summer forages including sudan grass (sudan X sudan), sorghum x sudan hybrids, sweet sorghums hybrids and sorghums that are bred to express the BMR genes. Varieties have different traits, yields, quality, and growing characteristics and should be chosen to match the nutrient requirements of the livestock and the feed gaps in the individual farm.

Although sorghum does not have the same yield potential as maize, one of the main advantages of sorghum over maize is that sorghum can be direct grazed as well as harvested for silage or even harvested for hay at the end of the season. Sorghum also requires less close agronomic management and tolerates water stress.

The composition of sorghum that is grazed or harvested as silage is highly variable and is affected by the type and hybrid of sorghum, maturity at grazing and at harvest and subsequent processing. Sorghum silage has a much lower level of starch and quite high levels of NDF compared to maize. This inferior nutrient composition of sorghum reduces its flexibility in dairy cow rations and is less suited for high producing dairy cows than maize silage.

MILLET

RELATIVE SCORE	
Yield	✓✓✓
Nutrient content	✓✓✓
Simple management	✓✓✓✓
Water use efficiency	✓✓✓
Versatility	✓✓✓✓
Reliability	✓✓✓

Background

Millet is a summer forage option for dairy farms due to its potential to grow rapidly in the warm conditions experienced during the summer months. Millet is mainly sown in late spring when soil temperatures are high and there has been good summer rainfall or irrigation available. The nutritional composition of millet is inferior to the other summer forage options – maize and sorghum. However, it is the cheapest to sow and is a safe option in terms of animal health risks and if the season gets challenging then there are no restrictions for cutting or feeding to livestock.

While the main millet growing area in Australia has traditionally been in southeast Queensland, often for producing grain, grower's further south are increasingly including millet in their crop rotations to provide fodder in the summer months. Overall, about 30% of Australian dairy farmers have sown millet in the last 5 years. Sowing millet was well above average in Gippsland (45%) whereas in Tasmania, South Australia and Western Australia less than 20% of the farmers have sown millet (Dairy Australia, 2019a).

AT A GLANCE:

- Wide variation in the types of millets that are available in Australia, so select the most appropriate variety for your environment and use.
- Millets are sown earlier than sorghum when soil temperatures exceed 14–16°C.
- Generally, less productive than sorghum and maize. Yields in Murray Dairy region are often only about half that of sorghum.
- WUE is much less than maize or sorghum, but millet can withstand water stress much better than sorghum or maize.
- Millet is less suited to high producing cows.

R&D GAPS AND OPPORTUNITIES:

- Low priority for new R&D to investigate the role of forage millet.

Varieties

Millets that are available in Australia belong to two main genera, Echinochloa and Panicum. In the Panicum genus, the main millet used in Australia is pearl millet or *Pennisetum glaucum*. Millets in the Echinochloa genus have generically often been called Japanese millets in the past and include E. esulenta, E. utilis and E. frumentacea. Forage varieties of the Echinochloa genus that are available from seed companies in Australia include Shirohie, Siberian, White French and Rebound. Each of the varieties available may have a place in forage production in the dairying regions in Australia, but dairy farmers should be guided by their agronomist and seed companies to select the most appropriate variety for their own situation and environment.

Yields

Millets are generally less productive than sorghum. Dry matter yields of millets are only about 50–70% of the yield of forage sorghums in northern subtropical regions (Callow, 2013). In a particularly wet summer, Fisher and Jones (2011) reported yields of 5.3 to 13.3 t DM/ha for millets against forage sorghum yields of 21.4 to 30.1 t DM/ha in crops sown in November at three sites in northern Victoria.

Under dryland conditions, yields of millet can be extremely variable and on commercial farms in southern Victoria, high yields approaching that of forage sorghum and particularly, maize are rarely achieved. For example, the yield of millet (cv. Shirohie) ranged from 8.0–11.5 t DM/ha in dryland conditions near Warrnambool in Victoria, but when irrigated, the average yield harvested from this millet increased to 13.8–14.4 t DM/ha over two years (Jacobs *et al.* 2006). A series of replicated trials conducted later in the 3030 Project in western Victoria revealed that the yields of millet ranged up to about 9 t DM/ha but was heavily dependent upon summer rainfall. In northern Victoria, under irrigation and experimental conditions, yields of between 12–18 t DM/ha have been achieved when millet was sown as the sole crop over 30 years ago (Pritchard, 1987).

Dairy Australia (2018) concluded that for crops grown when they are not unduly limited by water or nutrients, the average yields of millets have been reported to be between 7–14 t DM/ha whereas forage sorghums yield more at between 17-20 t DM/ha.

Sowing

Millets are suited to most soils and are mainly sown in late spring around November when soil temperatures are reasonably high for good germination. The average minimum soil temperature for sowing millet should be at a soil temperature of 14–16°C at the sowing depth of 10cm and rising, although minimum soil temperature again varies with the type of millet, with Pennisetum varieties requiring warmer soil temperatures than the Japanese millets. Because of the lower minimum soil temperatures required by millets, the millets may be sown earlier than sorghum crops, and thus can be a better feed option early in the summer period.

The sowing rate for most millets is about 10–20kg/ha, with higher rates being applied if the crop is to be irrigated. However, sowing requirements depend upon the variety, so local advice from the agronomist or seed company is warranted.

Image supplied by Brian Corr, dairy farmer, Poowong

Water use efficiency and fertiliser requirements

Millet is often a poor summer feed choice relative to other forages as its WUE is often about half of that in forage sorghums and even further less than in maize. Greenwood *et al.* (2005) reported that the WUE for maize was more than 30kg DM/ha/mm for an irrigated maize crop in northern Victoria, which is substantially higher than the range of 7.7–15kg DM/ha/mm reported by Jacobs *et al.* (2006) for a fully irrigated millet crop in Southwest Victoria.

The fertiliser and nutrient requirements of millet depends upon yield. Commercial recommendations for nutrients required for a 10 t DM/ha crop are 120kg N, 120kg K and 30kg P (IHSeeds, 2019).

Harvesting

Grazing

Millet can be grazed between January and March and is often ready for grazing as early as about 6 weeks after emergence. The temperate millets may be grazed at a minimum of about 20–30cm tall and up to 50cm, while the Pennisetum varieties should be grazed higher at a minimum of about 40–60cm (Callow, 2013). Millets do not stand harsh grazing and recovery from grazing is usually slower than that of forage sorghum. Millets should not be grazed below about 20cm but can be grazed for 1-2 weeks at a time every 4 to 6 weeks during summer to prevent the plant from going to head with subsequent reduced feed quality.

Silage and hay production

Millets are suitable for both silage and hay, although millets are mainly grown for direct grazing. Ensiling recommendations should follow those for similar forage crops such as the forage sorghums, which is that the whole plant dry matter should be within the dry matter target of 28–35% DM for precision chopped silage and 35–40% DM for wilted bale silage.

Composition and nutrient content of millet

The composition of millet can be quite variable and will be affected by hybrid, environment, and management factors such as population density, grazing time, maturity at harvest and subsequent processing. The crude protein content of millet ranged from 9.2–21.1% with the higher values associated with grazing during early harvests (Jacobs *et al.*, 2006). Callow (2013) reported that the composition of millet at optimum grazing height was expected to be about 15–17% CP and 9.5 MJ ME/kg DM.

However, once millet has been harvested and ensiled, the composition of millet silage is similar to sorghum silage, although millet usually has a higher crude protein as a proportion of dry matter (Little, 2007). The average composition of forage millet and millet silage, together with the ranges in nutritive value is shown in Tables 6 and 7.

Table 6. Composition of millet silage (Little, 2007)

Nutrient content	Millet silage	
	Average	Range
Dry matter (%)	41	
NDF (%DM)	58	44.0–65.0
ME (MJ/kg DM)	9.7	8.5–11.6
Crude protein (%DM)	14.4	5.9–26.6

Table 7. Composition of samples of millet forage collected during grazing between 2012 and 2019 (Richard Meyer, Pers. comm.)

Nutrient content	Millet silage	
	Average	Range
NDF (%DM)	54.0	13.6–72.9
ME (MJ/kg DM)	9.1	6.7–13.2
Crude protein (%DM)	12.2	5.9–25.1

Conclusion

The millet family covers a wide range of species with many different names. Millets that are available in Australia belong to two main genera, Echinochloa and Panicum. Millets in the Echinochloa genus have generically often been called Japanese millets in the past and include E. esulenta, E. utilis and E. frumentacea. In the Panicum genus, the main millet used in Australia is pearl millet or *Pennisetum glaucum.*

Dairy Australia (2018) concluded that for crops grown when they are not unduly limited by water or nutrients, the average yields of millets have been reported to be between 7–14 t DM/ha, whereas forage sorghums yield more at between 17–20 t DM/ha. Millet is often a poor summer feed choice relative to other forages as its WUE is often about half of that in forage sorghums and even less than in maize. Thus, the combination of yield and WUE, despite often having a higher nutrient content, sees millet as a less preferred option to sorghum for dairy grazing.

The composition of millet can be quite variable and will be affected by hybrid, environmental, and management factors such as population density, grazing time, maturity at harvest and subsequent processing. However, once millet has been harvested and ensiled, the composition of millet silage is similar to sorghum silage. Millet like sorghum has a high fibre content and low ME value and thus has a relatively poor nutritive value as a feed for lactating cows.

Image supplied by Brian Corr, dairy farmer, Poowong

LUCERNE

RELATIVE SCORE	
Yield	✓ ✓ ✓ ✓
Nutrient content	✓ ✓ ✓ ✓ ✓
Simple management	✓ ✓ ✓ ✓ ✓
Water use efficiency	✓ ✓ ✓
Versatility	✓ ✓ ✓ ✓ ✓
Reliability	✓ ✓

Background

Lucerne (*Medicago sativa* L.) is a highly productive deep-rooted perennial legume that is usually sown in late winter and may persist for at least 4-5 years with good management. It has a deep taproot that allows it to extract water from deeper soil layers and has greater tolerance to moisture stress than most pasture species.

Lucerne can be used for grazing as well as conservation as silage or hay. Lucerne may be grazed to fill the summer feed gap and provides a high protein forage during the summer/autumn dietary protein shortage.

However, often lucerne is harvested for hay or silage from regular cuts during the year, the interval between cuts being greater during the slower growing winter periods.

Overall, 28% of farmers have sown lucerne over the past 5 years with over 50% in the Murray Dairy region, followed closely by dairy farmers in the DairySA (44%), Dairy NSW (39%) and Subtropical Dairy (39%) regions (Dairy Australia, 2019a). In addition, the spread of dairy farmers either sowing or conserving lucerne for silage and hay was fairly even across herd size (Dairy Australia, 2019a).

AT A GLANCE:

- Lucerne is a deep-rooted legume that has been traditionally grown in the Murray Dairy region under summer irrigation.
- Lucerne persists for at least 4–5 years and most of the growth occurs over spring and summer.
- Lucerne may be grazed or harvested for silage or hay.
- Yields of lucerne can be up to 15–20 t DM/ha under summer irrigation, but lucerne can still survive if water is limited at various stages.
- High protein forage that complements the lower CP content of cereal forages.

R&D GAPS AND OPPORTUNITIES:

- Low priority for new R&D as sufficient previous research has been undertaken on the growth and yield of lucerne in the irrigation areas.

Varieties

There is a broad range of cultivars of lucerne available, and they are usually categorised according to their level of dormancy during winter. The dormancy rating explains a large part of the genetic variation between cultivars in their seasonal growth pattern. Lucerne cultivars with a high rating (8–11) are highly winter active, while cultivars with a low rating (1–3) are winter dormant. Those with a rating of 4–5 are termed semi-dormant and these have little winter growth but good summer quality for silage/hay or grazing, while winter active varieties have a rating of 6–7 and have good growth year-round provided, they are not limited by water and nutrients.

Highly winter active cultivars are more upright in their growth than winter dormant cultivars and have their crown more exposed above the soil surface. This means that grazing highly winter active cultivars needs greater management so as not to damage the lucerne crowns. Cultivars with a low rating may be more resistant to the grazing and trampling effects of animals. Choosing the appropriate lucerne variety depends upon many factors including:

- The purpose of the lucerne stand (hay/silage types are leafy with fine stems, grazing types have low crowns).
- How long the stand is required (2–4 years for hay/silage, 3–7 years for grazing).
- Resistance to, or tolerance of pests and diseases.
- Whether plant growth is required in winter.
- Whether grazing tolerance is needed.

Dairy farmers should be guided by their agronomist and seed companies to select the most appropriate variety for their own situation and environment.

Yields

In general, expected yields of lucerne range from 5–10 t DM/year under rain-grown conditions and up to about 20 t DM/year with irrigation. About 70% of the growth of lucerne occurs during spring and summer months depending upon the winter activity level, with most of the growth of dormant varieties occurring in spring and summer.

Queensland Department of Agriculture and Fisheries (QDAFF) suggested that yields of irrigated lucerne approach 16–20 t DM/ha in the first year or two and from 10–16 t DM/ha in subsequent years. They also reported an average annual yield of 19 t DM/ha over three years for a highly winter active cultivar grown at their research station at Gatton, Queensland, but only 14 t DM/ha for a dormant cultivar (QDAFF, 2009).

There have been several recent research studies with lucerne conducted by Department of Primary Industries, Victoria. Firstly, in northern Victoria under irrigation, the average amount of forage removed was 17.1 and 19.3 t DM/ha in successive years from a fully irrigated crop of lucerne (Lawson *et al.*, 2009). Later, Rogers *et al.* (2016) found that the annual dry matter production of lucerne stands over the 5 years ranged from 1.4–17.7 t DM/ha, with the highest production occurring in plots that received full or adequate irrigation. For the first 3 years after establishment, the average annual yield for plots that were fully irrigated ranged from 13.4–15.4 t DM/ha (Rogers *et al.*, 2016). Overall, farmers should aim for annual yields of about 15 t DM/ha, at least for the first 3–4 years after establishment of the lucerne stand.

Sowing

Lucerne is particularly suited to deep and light textured soils that are higher than pH 5. The seed should be covered by about 1–2cm of soil and rolled after sowing to ensure good seed/soil contact. The maximum sowing depth should be 5 cm if lucerne is drill sown. The planting rate varies depending upon conditions; between 15 and 25kg/ha is recommended as the sowing rate for lucerne under irrigation, while for dryland sowing the rate varies between about 4 and 15kg/ha with higher seeding rates for the higher rainfall areas. Lucerne is usually sown in late winter/early spring when soil temperatures are rising to ensure good germination and establishment.

Water use efficiency and fertiliser requirements

By applying deficit irrigation treatments to pure stands of lucerne over 4 years, Rogers *et al*. (2016) confirmed that there was a strong linear relationship between total water supply and dry matter production. Callow (2013) reported that lucerne grown in Queensland had a high annual water requirement equivalent of up to 12 ML/ha, which is within the range of 10–15 ML/ha that Rogers *et al.* (2016) reported for total water use by well irrigated lucerne in northern Victoria.

Rogers *et al*. (2016) examined a range of irrigation protocols for lucerne and found that there was little difference in WUE between the treatments that were only partially watered during the year and the fully watered treatments (range 9.1–12.9 kg DM/ha/mm over the first four years after establishment). The WUE for lucerne in the fully irrigated treatment was an average of 10.6kg DM/ha/mm (Rogers *et al*., 2016) leading the researchers to conclude that lucerne dry matter production may be significantly reduced in the irrigation regions of south-eastern Australia in seasons when water is restricted. However, the lucerne stand was able to fully recover once a full irrigation regime is resumed (Rogers *et al*., 2016). This makes lucerne an ideal forage species for situations when water is limited.

The fertiliser and nutrient requirements of lucerne depends upon yield. Callow (2013) calculated the nutrient removal in a 10 t DM/ha of lucerne and reported figures of about 150kg N, 200kg K and 30kg P and 170 Calcium (Ca)kg/ha. Similarly, PGG Wrightsons Seeds (2019) reported that between 200–300kg N, 20–30kg P and 150-200kg K were removed in 10 t DM. Note that about half of the nitrogen required is assumed to come from nitrification with only the remaining half needing to be applied as N fertiliser.

Harvesting

Grazing

In general, the grazing management of lucerne is a compromise between yield, quality, and persistence. Lucerne does not tolerate frequent grazing as the plant needs sufficient time to replenish the nutrient reserves stored in the crown. Lucerne has a high crown and is sensitive to grazing and a residual height of at least 15cm is required to avoid overgrazing. Grazing lucerne should be delayed until the new shoot emerges from the crown.

In Queensland, Ison *et al*. (2020) found that using a grazing strategy that ensures that some lucerne remains ungrazed and the pre-grazing height of lucerne is at 39cm above ground level will maximise pasture intake in sub-tropical dairy systems. A rest period of about 6 weeks, depending upon the time of year, allows for sufficient regrowth for optimum production and persistence. If grazing occurs after only a 3-week rest period, particularly under conditions of restricted water and lower temperatures, the lucerne plant does not have sufficient time to replenish roots and over time, the plant is weakened, production declines and the plant will not persist.

Burnett *et al.* (2018) reported that yield of lucerne at Rutherglen and Hamilton in Victoria decreased by 20–30% when lucerne stands were harvested every 3 weeks compared to 6-week cuts. By grazing, lucerne will often be used more efficiently that when harvested for silage/hay as nutrients from cows' excreta are returned to the soil and there no losses or costs that may be involved in cutting, conditioning, transportation, storage and feeding out after harvesting.

Silage and hay production

For silage and hay production, lucerne may be cut between 6–8 times per year under irrigation to produce about 15–20 t DM/ha. The crop should be cut at early flowering or when new growth buds form from the crown at 3–5cm. A common recommendation for hay production is to harvest when there are 10% of lucerne shoots presenting flowers (Dairy Australia, 2017a). Lucerne is often made into high-protein hay but is increasingly ensiled to produce a protein-rich supplement for dairy cows.

Cutting at the traditional early flowering stage (about 10% of lucerne shoots presenting flowers) is a good compromise for silage and hay between quality, yield and stand persistence. Even though yield may be optimised at this time, quality is already in decline. Cutting at the full-flower stage can reduce quality significantly, as well as negatively impacting subsequent hay yields. Cutting height should be as low as possible without damaging the crowns or new shoots and Lattimore (2008) suggested that the cutting height of 7–10cm is ideal.

Composition and nutrient content of lucerne

The composition of lucerne varies with time of grazing or cutting. Callow (2013) reported that the protein content of lucerne decreases, and the fibre content increases as the crop grows and these changes are reflected in the average composition of lucerne when grazed or harvested for silage or hay (Table 8). Lawson *et al.* (2009) reported similar nutrient levels in lucerne harvested in northern Victoria with an average of 22.8% CP, 10.1 MJ ME/kg and 38.7% NDF.

Table 8. Average nutrient content of lucerne when grazed and harvested for silage and hay (Callow, 2013)

	Grazing	Silage	Hay
Dry matter (%)	25.1	66.3	88.6
NDF (% DM)	31.7	39.8	40.9
CP (% DM)	26.4	23.5	21.4
ME (MJ/kg DM)	10.8	10.1	9.6

However, actual values of legume silage that have recently been presented to feed testing laboratories in Australia reveal lower dry matter and CP levels and higher NDF levels for silage (Table 9). In view of the large variation in the composition of lucerne silage and hay shown in Table 9, samples of lucerne that will be fed to dairy cows should be tested by a feed testing laboratory.

Table 9. The composition of lucerne silage in samples analysed by FeedTest (2020) and DPI Wagga laboratories (Richard Meyer, Pers. comm.) during 2018/19

	FeedTest Samples		DPI Wagga Samples	
Nutrient	**Average**	**Range**	**Average**	**Range**
DM (%)	54.9	27.0–84.9	51.8	16.1–79.8
NDF (% DM)	41.7	24.7–69.1	46.4	41.3–52.8
CP (% DM)	19.3	5.4–27.3	18.6	13.5–21.0
ME (MJ/kg)	10.5	8.1–12.8	9.5	2.8–10.9

Conclusion

Lucerne (*Medicago sativa* L.) is a highly productive deep rooted perennial legume that is usually sown in late winter and may persist for at least 4–5 years with good management. In general, expected yields of lucerne can be up to about 15–20 t DM/year with irrigation, with about 70% of the growth occurring during the spring and summer months. Although lucerne yield may be reduced when water is restricted, the lucerne stand is able to fully recover once a full irrigation regime is resumed. This makes lucerne an ideal forage species for situations when water is limited.

Lucerne provides a high protein forage that can be used for grazing as well as conservation as silage or hay. Lucerne may be grazed to fill the summer feed gap and provides a high protein forage during the summer/autumn dietary protein shortage. Lucerne does not tolerate frequent grazing as the plant needs sufficient time to replenish the nutrient reserves stored in the crown. Often lucerne is strip grazed for only 1–2 weeks followed by a rest period of about 6 weeks, depending upon the time of year. However, increasingly, lucerne is harvested for silage or hay from regular cuts during the year, the interval between cuts being greater during the slower growing winter periods.

The composition of lucerne varies with time of grazing or cutting. The average nutritive content of the lucerne when grazed is 26.4% CP, 32% NDF and 10.8 MJ DE/kg. The protein content of lucerne decreases and fibre content increases as the crop grows, and these changes are reflected in the changes in the average composition of lucerne when harvested for silage or hay. For example, in samples that had been submitted to feed testing laboratories, the average nutrient levels of lucerne silage were 52–55% DM, 18.5–19.5% CP, 42–46% NDF and 9.5–10.5 MJ ME/kg. However, the range in nutrient composition of individual samples was extremely variable. In view of the large variation in the composition of lucerne silage and hay, samples of lucerne that will be fed to dairy cows should be tested by a feed testing laboratory.

WINTER CEREALS

RELATIVE SCORE	
Yield	✓✓✓
Nutrient content	✓✓✓✓
Simple management	✓✓✓✓
Water use efficiency	✓✓✓✓
Versatility	✓✓✓✓
Reliability	✓✓✓✓

Background

The major winter cereals that are grown to provide feed for livestock include wheat, oats, barley, and triticale. Winter cereals are usually sown in early Autumn to fill the early-autumn feed gap that often exists in ryegrass systems and can produce more feed over the winter period than most perennial pastures. Winter cereals also provide the flexibility of grazing during winter and subsequent harvesting at a single cut for silage or hay in the Spring.

Most of the cereals have traditionally been bred for grain. However, over the past 20–30 years in all types of cereals, there has been an increased interest in varieties that may be used for grazing and silage and hay production.

Overall, about 36% of Australian dairy farmers have sown winter cereals in the last 5 years, with over 50% of the farmers in the Murray Dairy and NSW Dairy regions growing various types of winter cereals. In addition, the spread of dairy farmers growing winter cereals is fairly even across herd size. (Dairy Australia, 2019a).

AT A GLANCE:

- Newer varieties of wheat and barley that are suited to the high rainfall zone and are not limited by water or nutrients may yield 30–35 t DM/ha of forage.
- Commercial yields from winter cereals are more likely to be up to 15 t DM/ha.
- Winter cereals can be grazed and can provide high quality forage during key parts of the winter.
- There is little published information on the yield and nutritive value of winter cereals grown in the Murray Dairy region.

R&D GAPS AND OPPORTUNITIES:

- Comparative trials of wheat and barley with other winter forages in northern Victoria when grown under BMP guidelines.
- Evaluate the high yielding winter varieties of wheat and barley in the Murray Dairy region when irrigated or rain-fed.

Varieties

There are many varieties of wheat (*Triticum vulgare*), oats (*Avena sativa*), triticale (*Triticale hexaploide*) and barley (*Hordeum vulgare*) that have been bred for forage production and are suited to higher rainfall areas. Wheat and triticale tend to be more reliable than barley and oats as barley tends to suffer from rust and oats have a higher tendency to lodge in the later stages of growth. The so-called winter wheats are capable of not only producing high grain yields, but the crop canopies have produced significant amounts of forage during the growing season. For example, the results of the GRDC project that has evaluated new wheat and barley germplasm better suited to high rainfall zones indicate that grain yields of an average of 15–17 t/ha in research plots are accompanied by crop canopies that have produced 30–35 t DM/ha of forage (Poole *et al.*, 2019).

Within each species, the various cultivars have different growth characteristics, time of maturity, yield, grain to straw ratio, etc. In addition, forage cereal suitability for high forage production will also vary greatly according to climatic and local district conditions and will require their own agronomic package. Dairy farmers should be guided by their agronomist and seed companies to select the most appropriate variety for their own situation and environment.

Yields

Jacobs *et al.* (2009) conducted extensive studies under dryland conditions in SW Victoria, on the effects of different grazing strategies on yield and nutritive characteristics of a wide type and variety of whole crop cereals. They found that yield was highly dependent upon season, but when climatic conditions were favourable, total DM yield was reasonably consistent across cereal types (Jacobs *et al.*, 2009). The average yield across two seasons, for all cereal types and varieties was about 13.5 t DM/ha, although one of the triticale varieties that was not grazed yielded up to 19.8 t DM/ha in one season (Jacobs *et al.*, 2009). Furthermore, they found that if the crop was to be grazed, then ideally there should be a single grazing around tillering, because cereals that were grazed at tillering and again at stem elongation significantly decreased total dry matter yield. There was little difference in dry matter yield between treatments that were grazed once or were not grazed at all until final harvest in late October/early November.

There is little information on the yield of forage winter cereal crops in more northern regions of Victoria or southern NSW, but the yields observed by Jacobs *et al.* (2009) should be attainable, particularly if irrigation is available in early or late growth. Callow (2013) suggested that forage yields up to 7–10 t DM/ha for oats and 14t DM/ha for barley could be achieved when nutrients and water were not limiting growth. Later, Barber (2020) established demonstration plots of several winter cereals which were sown in May 2019. He found that the single harvest yields of cereal rye, oats, wheat, barley, and triticale ranged from 5.2–7.5 t DM/ha whereas under irrigation, the yields averaged 15.0 t DM/ha with a triticale plot reaching 19.3 t DM/ha at a single harvest.

Sowing

Extensive details on the agronomic management of wheat, barley, and oats for grain in southern Australia are provided in the respective copy of GrowNotes that has been produced by Grains Research and Development Corporation (GRDC, 2016a; GRDC, 2016b; GRDC, 2017c). These technotes highlight the main issues around the agronomy of winter cereals, but more detailed information can be sought from the respective GrowNotes.

Different cereals have different tolerances for soil temperature at sowing and emergence. Most winter cereals prefer soil temperatures between 15°C and 25°C. Poor emergence may occur if soil temperatures are higher than 25°C although some oat varieties are able to be sown at comparatively higher soil temperatures of up to 30°C. The sowing time is usually between April and June, but cereals may be sown earlier if autumn feed is required. Those cereals that are sown in April are a late to very late maturity type because early and mid-season varieties will run up to head too early.

For most farms, a sowing depth of 2.5–5cm is going to be the range of depths that are recommended depending on the soil type, soil moisture and soil temperature. Row spacing is between 15 and 35cm (Callow, 2013). Higher sowing rates are used for cereal crops that are grown for grazing or silage production rather than grain. The recommended sowing rate for a crop that will be grazed should produce about 250 plants/m^2 to try to maximise early growth (Mickan *et al.* 2009). This sowing rate is equivalent to about 60kg/ha with higher sowing rates favoured in high rainfall conditions or under irrigation.

Water use efficiency and fertiliser requirements

Neal *et al.* (2011) demonstrated that the WUE of winter cereals grown at Camden, NSW was between 29.7–42.9kg DM/ha/mm for winter cereals which compares favourably with 13.5–30.1kg DM/ha/mm for annual pastures when crops were grown either under optimum or deficient irrigation regimes. Similarly, expected WUE of winter cereals grown in northern Victoria are likely to approach the high WUE experienced with sorghum and maize. Certainly, in southeast Queensland, Callow and Kenman (2006) estimated that irrigated barley, although yielding at least 50% less, had a very similar total (irrigated and rainfall) water efficiency as forage sorghum and maize, being about 3.8 t DM/ML.

The fertiliser and nutrient requirements of winter cereals depends upon yield. The commercial recommendations for nutrients required for a 10 t DM/ha barley crop are 180kg N, 160kg K and 25kg P (Callow, 2013). Similar nutrient requirements would be required for the other winter cereals. Mickan *et al.* (2009) calculated the nutrient removal in a 10 t DM/ha of winter cereal forage and reported figures of 100–200kg N, 180–310kg K and 18–25kg P which are comparable to Callow (2013).

Harvesting

Grazing

Cereals can be grazed during winter once the plant has reached at least 30cm in height and well anchored if they are grazed to no lower than 10cm. Residual height of the crop post-grazing below 5cm will severely reduce plant regrowth. If the cereal crop is planned for further fodder production, it is important to stop grazing well before stem elongation or when the heads start being pushed up above the ground to ensure total yield is not compromised. If winter cereal crops are sown very early, they may be grazed two, or possibly three times before stem elongation begins. Up to 1–2 t DM/ha may be removed by grazing without significantly affecting yield (Jacobs *et al.*, 2009).

Achieving the highest dry matter yield possible in forage crops is not necessarily the most profitable system. As the winter cereal matures, the nutrient composition changes to lower contents of protein and energy. In many cases, grazing winter cereals may reduce the total yield of the forage crop, but the value of the higher protein and energy forage that can be grazed in the autumn/winter months to contribute to milk production often compensates for the greater yield of the lower quality feed in the spring that needs to be conserved. In addition, conserving feeds has a large cost to it compared to grazing feeds due to harvesting equipment and the risk of significant wastage.

Silage and hay production

For silage production, winter cereals are usually cut at 7–10cm above ground level, with higher cutting height associated with lower yields but better nutrient content. If considering cutting a cereal crop for silage, there are two recommended growth stages. Cereals can be harvested at the flag leaf/boot to early ear emergence stages or at the soft dough stage.

- Flag leaf/boot – early ear emergence, if desiring a higher quality silage. Harvesting the winter cereals at the flag leaf/boot stage will usually be well below 30% DM (often about 18–22% DM). Thus, harvesting at this stage will require the crop to be wilted to reach the preferred DM content of 33–40% DM for pit silage or 38–50% DM for baled silage (Mickan *et al.,* 2009). All cereals can be harvested before or at this stage and should produce higher energy (over 10 MJ ME/kg) and higher protein silage than cutting later.

- Soft dough stage if a higher yield, but not as high protein and energy content, is required. Harvesting at this later soft dough stage results in much higher DM yields but silage of lower energy and much lower crude protein levels than earlier at the vegetative stage. The DM content of most winter cereals harvested at the soft dough stage of growth will likely be within the desired DM range (33–50%) as a standing crop without prior wilting. Winter cereals should be harvested using a precision chopping forage harvester to ensure a short chop length of between 20–50mm to ensure that material can be well compacted minimising nutrient loss and DM. The drier the crop DM content at harvest, the shorter the chop length required.

Composition and nutrient content of winter cereals

The composition of winter cereals varies between the vegetative stages where it may be grazed and when it may be harvested for silage or hay. The nutrient content of the forage grazed early in the growth of winter cereals is normally high and around 12 MJ ME/kg DM and 20% CP or higher. However, the corresponding figure for silage from winter cereals is usually between 8–10 MJ ME/kg DM and 10–17% CP (Dairy Australia, 2017b). The average composition of winter cereal silage samples submitted to the major feed testing laboratories in Australia reveal CP levels at the lower end and ME values at the higher end of these figures. Table 10 shows the average composition of winter cereal silage is quite similar between samples that were analysed either at the DPI Wagga feed laboratory (Richard Meyer, Pers. comm.) or FeedTest laboratories in Melbourne (FeedTest, 2020).

Forage Lab Australia report the cereal silages separately as wheat, barley, and oats silage rather than group them together. They found that dry matter content was less than the figures in Table 10 and the average NDF and CP levels in the respective forage cereal tended to mirror the differences in these cereals as grain samples. The composition of silages arising from different winter cereals is shown in Table 11. The variation within a particular species of cereals is much greater than the differences between cereal silages.

Table 10. Composition of winter cereal silage samples collected in the 2018/19 season and analysed by either FeedTest or DPI Wagga

	Wagga		Feedtest (n=152)	
	Mean	**Range**	**Mean**	**Range**
DM (%)	53.9	25.9–79.9	54.1	21.2–84.3
NDF (% DM)	52.2	41.2–66.4	50.2	34.3–73.1
CP (% DM)	10.6	7.1–14.4	12.2	5.5–23.5
ME (MJ/kg)	10.4	8.9–11.5	10.4	7.9–12.5

Table 11. Composition of wheat, barley, and oat silage samples (Trevor Dorman, Pers. comm.)

	Wheat silage		Barley silage		Oat silage	
No samples	**335**		**158**		**166**	
	Mean	**CV (%)**	**Mean**	**CV (%)**	**Mean**	**CV (%)**
Dry matter (%)	41.4	29	38.7	29	41.7	31
NDF (% DM)	48.8	13	49.2	14.5	52.3	16
CP (% DM)	14.4	26	13.2	36	12.4	38
ME (MJ/kg)	10.0	8	10.0	9	9.8	11

Conclusion

The major winter cereals that are grown to provide feed for livestock include wheat, oats, barley, and triticale. There are many varieties of wheat (*Triticum vulgare*), oats (*Avena sativa*), triticale (*Triticale hexaploide*) and barley (*Hordeum vulgare*) that have been bred for forage production and are suited to higher rainfall areas. Winter cereals are usually sown in early Autumn to fill the early-autumn feed gap that often exists in ryegrass systems and can produce more feed over the winter period than most perennial pastures. Winter cereals also provide the flexibility of grazing during winter and subsequent harvesting at a single cut for silage or hay in the Spring.

Winter cereals can be grazed once or twice during the winter and then will be harvested for silage later in the year. Average yields of forage from winter cereals should approach about 15 t DM/ha including the smaller amounts that may be taken off during grazing periods.

The composition of winter cereals varies between the vegetative stages where it may be grazed and when it may be harvested for silage or hay. The nutrient content of the forage grazed early in the growth of winter cereals is normally high and around 12 MJ ME/kg and 20% CP or higher. The corresponding figures for silage from winter cereals will be lower. Although quite variable, the average composition of samples of cereal silage collected in SE Australia is about 54% DM, 52% NDF, 10.5% CP and 10.4 MJ ME/kg DM.

MULTI-CROP SYSTEMS

AT A GLANCE:

- Two types of cropping systems that offer potential to increase dry matter yield and/or the nutrient content of the harvested forage.
  - Companion cropping where plant species are oversown with another species to produce a mixed sward.
  - Double cropping where two crops are sown in succession, usually a winter crop (winter cereal or annual grass species) followed by a high yielding summer crop to produce greater annual yields.
- Double cropping offers greater potential to produce greater annual yield of forage in the Murray Dairy region.
- The most promising double cropping system for the Murray Dairy region will be winter cereals (wheat, barley, or oats) followed by irrigated maize or sorghum as the summer crop.
- Annual yields of more than 30 t DM/ha have been demonstrated in northern Victoria with double cropping.
- Annual yields of more than 40 t DM/ha have been recorded with triple cropping, but time of sowing and harvesting become very critical in trying to achieve these yields.
- Companion cropping involving oversowing a winter cereal with a legume such as vetch will improve the quality and CP content of the mixed forage.

R&D GAPS AND OPPORTUNITIES:

- Evaluate double cropping systems involving winter cereals and maize or sorghum as the summer crop in the Murray Dairy region under BMP guidelines.
- Investigate companion cropping system by undersowing winter cereals with legumes such as vetch or annual clover species to produce a higher quality winter forage.

Background

There are basically two types of cropping systems that offer potential to increase dry matter yield and/or the nutrient content of the harvested forage. These two strategies, being companion cropping and double cropping were examined in the "3030" Program. The aim of the Dairy Australia program "3030" was to deliver a 30% improvement in return on assets through a 30% increase in the consumption of home-grown forage for non-irrigated dairy farms in southern Australia.

Firstly, in the companion cropping option, other plant species are integrated into a predominant forage species by over-sowing to produce a mixture of species in the one sward.

The potential advantage of this system is that the combined composition of the pasture may better meet the nutrient requirements of the dairy cow.

For example, over-sowing cereal crops in autumn into an existing stand of chicory improved the nutritive characteristics at ensiling in spring without adversely affecting DM yield (Dairy Australia, 2011). Furthermore, the use of over-sowing chicory with cereals resulted in a more continuous supply of DM compared to a double cropping strategy with annual species in winter and summer (Dairy Australia, 2011). Similarly, winter wheat when sown with a range of legumes including peas, vetch, and Persian clover, while it had no positive effect on DM yield had some positive effects on nutritive characteristics (Dairy Australia, 2011).

Double crop systems

Double cropping of cereals with summer crops was also the focus of extensive research within the "3030" Project. Most of the double-cropping options included winter cereals followed by summer crops. The summer crops examined, included millet and brassica crops. Brassica crops were more suitable to be sown after the early harvested cereals whereas millet suited farm systems where the winter cereals were cut later to coincide with the higher soil temperatures required by millet at sowing.

Double cropping, or even triple cropping systems, offers much greater potential to increase DM yield under irrigation in northern Victoria and southern NSW. The definition of double cropping is growing a winter crop and a summer crop following one another. Over the years, there has been research into the potential of double cropping systems in the irrigated areas of both northern Victoria and southern New South Wales.

Double cropping in northern Victoria provides irrigation farmers with an opportunity to capitalise on their investment in irrigation infrastructure and improve their WUE. Many of the barriers to double cropping, identified in early attempts to adopt the system, have since been addressed through plant breeding, innovative technology, and adaptation of sowing equipment. Improved access to fodder markets and better agronomy and irrigation methods to increase WUE, has also made double cropping more viable in recent times. The critical issue with double cropping is the timeliness of sowing. Sowing must be on time to maximise yield potential, and to ensure harvest is complete before the optimal sowing window of the next crop phase. This time of sowing and harvesting is even more critical for triple cropping.

One of the first extensive studies into double cropping in northern Victoria was conducted by Boyd (2009). The winter crops were wheat, barley, oaten hay, faba beans, canola, and Persian clover, while the summer crops in the trial were maize and sorghum (both harvested as silage), and soybeans. The initial aims of this double cropping project were to achieve 20 t DM/ha per year. Boyd (2009) observed total annual yields of more than 30 tonne DM/ha when forage maize and sorghum, sown as the summer crops, were followed the winter crops of Persian clover or oaten hay.

Forage Plus was a R&D program that was developed by the dairy research team at Gatton, Queensland to address the need to increase forage utilisation on northern Australian dairy farms. A combination of a field trial over two years and simulation modelling (APSIM) was used by Callow (2010) to assess the yield and variability of an annual crop sequence of

maize, barley, maize being harvested as silage. From the field studies, total cumulative yield in year 1 was 35.1 t DM/ha with 89% of that harvested as maize silage. In the second year, annual cumulative yield increased to 40.6 t DM/ha with a similar proportion coming from maize. APSIM simulations of crop growth were consistent with these yields, varying from 35–47 t DM/ha/year for this triple cropping system. These results indicated that, while substantial yields may be obtained in the field with triple cropping systems, under ideal management conditions, potential yields may even be higher.

The University of Sydney have undertaken many trials through their Future Dairy program to investigate the double cropping option (or as they have termed it, the complementary forage rotation systems, or CFR) to increase yields and produce more home-grown feed than could be achieved from pasture alone. The CFR system involves growing two or three crops on the same area of land within one year, for example, a triple crop system may involve a summer crop (maize, sorghum), a forage to provide a pest disease break (brassica) and a legume for nitrogen fixation (clover). The different crops are often designed to complement each other.

Triple crop systems

An experiment in the Future Dairy program evaluated the triple crop system of a brassica sown in late February/early March as a break crop, an annual legume (Persian clover) sown in early August followed by maize sown in early October and harvested for silage in February, each year for 3 consecutive years. The crops were irrigated and fertilised as required to maximise yield. The total annual yield varied from 40.8–44.4 t DM/ha over the three years (Garcia, 2011) with maize providing the bulk of the yield and brassica and the legume contributing about 27–10%, respectively. The CFR system compared favourably to a pasture system (kikuyu over-sown with ryegrass) which produced an average of only 17.3 t DM/ha each year. Input and management of both nitrogen and water were crucial to maximise forage yield as the annual yield of the maize/brassica/legume system could be reduced by up to 15 t DM/ha with zero nitrogen fertiliser and by up to another 15 t DM/ha when there was no irrigation.

In a 3-year whole farm system, Future Dairy has also compared a double crop with a triple crop CFR (Garcia, 2011). The double crop was clover for grazing followed by maize for silage while the triple crop system was forage rape followed by clover and then followed by maize for silage. The annual yield of the triple crop was 37 t DM/ha while the double crop produced 28.8 t DM/ha (Garcia, 2011). The forage yield of the double crop CFR was about 80% of the yield of the triple-crop CFR, but the management of the triple crop was much more complex.

Later studies of double cropping with canola, clover, or field peas as the autumn/winter crop and either maize or sorghum as the spring/summer option confirmed the likely yields of 30-38 t DM/ha with maize and 25–30 t DM/ha with sorghum (Garcia, 2011).

The results of this comprehensive program at the University of Sydney found that triple crop CFRs are the better option to achieve a substantial increase in total forage yield as yields of more than 40 t DM/ha are achievable but only with very good management.

Double crop CFRs often yield between 20–30% lower than triple crop CFRs but require lower nitrogen fertiliser input and much simpler management and may be much more attractive to dairy farmers than trying to chase triple cropping systems. An added option for dairy farmers may be to under-sow the winter cereal with a legume such as vetch so that a higher protein silage (6–8 t DM/ha) or hay is produced, followed by maize or sorghum as the summer crop option.

Conclusion

The multi-cropping system for the irrigated Murray Dairy region is most likely to be a double cropping system with maize or sorghum in summer and pasture with annual rye and/or clover that can be grazed or a cereal crop in winter that may be grazed and harvested for silage. If irrigation water is limited in summer, sorghum may be a better option as it tends to do better than maize with limited water. This type of system is much easier to manage than to try to get 3 crops per year. A major concern with triple cropping is with the logistics involved in establishing, growing and harvesting three crops per year, which would require a level of management, technical expertise and financial support often well beyond the current situation on farm (Busby *et al.*, 2009).

HAY AND CONCENTRATES

While the earlier section, 'Forages Grown in the Murray Dairy Region' of the Technical Review concentrated on forage options that would most likely be grown and fed to dairy cows, a summary of the role that hay and concentrates play in the ration of dairy cows has also been included. Hay has high effective fibre values and is included primarily in dairy diets to provide minimum effective fibre levels. Not only being good sources of effective fibre for dairy diets, some hays like lucerne and vetch can also supply appreciable quantities of protein to complement the low protein values in grains and cereal silages. While concentrate supplements can supply additional energy, fat, and protein.

HAY

AT A GLANCE:

- Australia produces, on average, about 6 million tonnes hay each year with pasture hay historically accounting for the largest share of total hay production (43%) with the other major hays being cereal hay, 32% and lucerne hay 20%.
- Both hay and silage have high effective fibre values and are often included in dairy diets to provide minimum effective fibre levels if insufficient fibre is an issue. Some hays like lucerne and vetch can also supply appreciable quantities of protein to complement the low protein values in grains and cereal silages.
- All successful hay making relies on wilting the cut pasture to a moisture or dry matter level where it is dry enough not to ferment but wet enough not to shatter when baled. This is usually at about 12% dry matter.
- If hay is baled with too much moisture it can ferment leading to heat generation, feed quality decline and a potential fire risk.
- The composition of hay varies greatly with plant species, time of harvesting and storage. Because of this variability, hay to be fed to dairy cows should be analysed by commercial feed testing laboratories.

R&D GAPS AND OPPORTUNITIES:

- Improve the consistency and accuracy of measuring the nutrient content of hays by feed testing laboratories.

Background

Australia produces, on average, about 6 million tonnes hay each year with pasture hay historically accounting for the largest share of total hay production (43%) with the other major hays being cereal hay, 32% and lucerne hay 20%. However, these proportions may vary substantially from year to year, depending primarily upon climate (Sexton *et al.*, 2014).

The largest fodder user is the Australia dairy industry which is estimated to use 31% of the hay and 57% of the silage that is used in the domestic market (Sexton *et al.*, 2014).

Up to about 20% of the energy consumed by dairy cows in Victoria is derived from hay and silage with the proportion of hay versus silage varying from year-to-year and from region-to-region (Waterman, 2019). The northern dairy region of Victoria often uses more hay and silage than other regions in southern Victoria (Waterman, 2019).

Dairy diets require between about 30–35% NDF. At least two thirds of this dietary NDF should be effective fibre, which refers to the ability of a feed to stimulate chewing activity and saliva production. Both hay and silage have high effective fibre values and are often included in dairy diets to provide minimum effective fibre levels if insufficient fibre is an issue. Not only being good sources of effective fibre for dairy diets, some hays like lucerne and vetch can also supply appreciable quantities of protein to complement the low protein values in grains and cereal silages.

Varieties

Up until the early 2000's, most hays harvested consisted of pasture or lucerne (Personal Communication, Colin Peace – Australian Fodder Industry Association 2020). More recently vetch, canola and different types of cereal hays have become available to the livestock industries. Oaten hay now makes up to about 15% of the hay produced in Australia, but much of this is exported. However, there are appreciable quantities of other cereal hays, including barley and wheaten hays that may be available to the dairy industry. Canola hay became important during recent droughts where canola crops were cut for fodder rather than going through to grain.

Vetch is a high protein hay and is readily available and sought by the dairy industry as a high protein hay that can provide extra dietary protein when protein is not available from pasture or legumes. As much as 60% of the vetch hay that is produced is used by the dairy industry (GRDC, 2017d). In addition, nearly 30% of the dairy farmers in the Murray Dairy region have sown vetch in the past 5 years, compared to the overall average across Australia of 13% farmers sowing vetch. The agronomic requirements and possible markets of vetch are provided in the respective GrowNotes.

Harvesting and processing

Hay has been the most common fodder conservation practice in Australian livestock industries and most crops and pastures can be made into hay of varying quality. All successful hay making relies on wilting the cut pasture to a moisture or dry matter level where it is dry enough not to ferment but wet enough not to shatter when baled. This is usually at about 12% dry matter. If hay is baled with too much moisture it can ferment leading to heat generation, feed quality decline and a potential fire risk.

Hay can be fed out directly to dairy cows in the paddock or in appropriate feeders. But if the hay is to be used in appreciable amounts in mixed rations it needs to be processed further. Some mixers will not handle long materials such as hay, but most types of mixer wagons that can cut hay, straw and silage can handle long fibrous feeds such as the different types of hay so that they can for be incorporated directly into a mixed dairy diet.

Composition and nutrient content of different hays

The composition of hay varies greatly with plant species, time of harvesting and storage. Actual values of various categories of hay samples that have recently been presented to feed testing laboratories in Australia reveal similar average composition of samples sent to either of these laboratories (Table 12). But in both laboratories, there was huge variation in the nutrient content of individual samples. For example, the range in CP, NDF and ME of vetch samples analysed by the Wagga Wagga laboratory was 8.2% to 22.6%, 35.7% to 58.8% and 6.6 MJ/kg to 11.9 MJ/kg, respectively.

Another measure of the variation in samples is the coefficient of variation (higher CV values are more variable) and the average coefficient of variation for various samples of cereal hay analysed by Forage Lab Australia was 28%, 12% and 33% for CP, NDF and ME respectively (Trevor Dorman, Pers. comm.).

In view of this large variation in the composition of different samples, hay that will be fed to dairy cows should be tested by a feed testing laboratory.

Table 12. The composition of hay samples analysed by FeedTest (2020) and DPI Wagga Wagga laboratories (Richard Meyer, Pers. comm.) during 2018/19 and Forage Lab Australia at Bendigo (Trevor Dorman, Pers. comm.). The average dry matter of all samples was between 89.5 and 92.5%

	NDF (% DM)			CP (%DM)			ME (MJ/kg DM)		
Type of hay	**FeedTest**	**Wagga**	**FLA**	**FeedTest**	**Wagga**	**FLA**	**FeedTest**	**Wagga**	**FLA**
Cereal Hay	53.3	53.9		8.1	10.0		9.6	9.8	
Oaten Hay	51.8	56.6	54.0	8.7	8.5	8.2	10.0	9.3	9.8
Wheaten Hay	51.9	51.9	50.6	10.2	9.9	10.2	9.8	10.0	10.0
Barley Hay			51.2			9.5			10.1
Pasture Hay	57.5	59.3	57.5	11.5	11.0	10.6	9.2	9.2	9.5
Lucerne Hay		47.6			19.1			8.2	
Vetch Hay		46.0			17.2			9.8	
Legume Hay			40.2			19.8			9.4
Canola Hay		48.3			14.0			8.6	

Conclusion

The largest fodder user is the Australia dairy industry which is estimated to use 31% of the hay and 57% of the silage that is used in the domestic market. Furthermore, up to about 20% of the energy consumed by dairy cows in Victoria is derived from hay and silage. Hay has high effective fibre values and is included primarily in dairy diets to provide minimum effective fibre levels. Not only being good sources of effective fibre for dairy diets, some hays like lucerne and vetch can also supply appreciable quantities of protein to complement the low protein values in grains and cereal silages.

Successful hay making relies on wilting the cut pasture to a moisture or dry matter level where it is dry enough not to ferment but wet enough not to shatter when baled. This is usually at about 12% dry matter. Hay can be fed out directly to dairy cows in the paddock or in appropriate feeders. Most types of mixer wagons that can cut hay, straw and silage can handle long fibrous feeds such as the different types of hay so that they can for be incorporated directly into a mixed dairy diet.

The composition of hay varies greatly with plant species, time of harvesting and storage. The average nutrient composition of most hays is relatively constant, but there is huge variation in the nutrient content of individual samples that had been analysed by commercial feed testing laboratories. In view of this large variation in the composition of different samples, hay that will be fed to dairy cows should be tested by a feed testing laboratory.

CONCENTRATE FEEDS

AT A GLANCE:

- Cereal grains provide dairy cows with substantial quantities of starch which is the major source of energy to the cow and is considered the primary driver of microbial protein synthesis in the rumen.
- Cereal grains provide dairy cows with substantial quantities of starch which is the major source of energy to the cow and is considered the primary driver of microbial protein synthesis in the rumen.
- Understanding starch digestion is the key to optimizing protein and energy supply to the cow, and to improving the efficiency and effectiveness of high grain diets.
- Understanding starch digestion is the key to optimising protein and energy supply to the cow, and to improving the efficiency and effectiveness of high grain diets.
- Protein supplements are added to dairy cow diets to compensate for the lower protein levels in cereal grains when cows have limited access to the higher protein levels in pasture.
- The most common protein supplements that are used by the dairy industry in Australia include, canola meal, soyabean meal, cottonseed meal and lupins.
- Inclusion of protein sources such as canola meal not only provide good source of dietary protein but may also have a positive effect on dry matter intake and subsequent milk yield.

Background

The average annual quantity of grains, mixes and concentrates fed to dairy cows in Australian dairy systems is about 1.7 t/cow (Dairy Australia, 2019a) and this amount has remained relatively stable over the past 10-15 years. Although the average annual quantity of concentrates fed to cows in the Murray Dairy region was only 1.6 t/cow, in the larger herds above 500 cows across Australia, the amount used per cow increases up to an annual average of 2.4–2.8 t/cow (Dairy Australia, 2019a).

Cereal grains

When concentrate feeding of dairy cows began to increase over 30–40 years ago, the preferred cereal grains were barley and triticale. Since then, wheat has become more commonly used as the major cereal grain in Australia dairy diets. The production of triticale in Australia has decreased significantly and wheat is now often favoured to barley because of its higher energy and starch content. Other grains fed to dairy cows, particularly in the northern dairying regions of Australia, include maize and sorghum.

Cereal grains are primarily included in dairy diets as an energy source. For forages, the most common measure of energy is the metabolizable energy content, which can vary widely within samples of the same forage. But in cereals, there is little differentiation within grains, and a better measure of the energy value of cereal grains for dairy cows is the starch content. Cereal grains provide dairy cows with substantial quantities of starch which is the major source of energy to the cow and is considered the primary driver of microbial protein synthesis in the rumen. Diets for lactating dairy cows generally contain about 70% carbohydrates, with 20% to 25% of the diet consisting of starch. The cereal grains provide most of this starch, but some cereal silages such as maize silage often contributes to this proportion of the dietary starch.

When comparing the nutritive value of cereal grains, the key measures are starch content, protein content and importantly, the rate of fermentation. While there are often little differences in the protein content of cereal grains, the starch content may vary widely and more importantly, the rate of rumen fermentation varies between cereal grains (Table 13).

Understanding starch digestion is the key to optimising protein and energy supply to the cow, and to improving the efficiency and effectiveness of high grain diets. The two major ways of processing cereal grains are to reduce particle size by rolling or grinding the dried grains or using a combination of moisture and heat. Reducing the particle size increases the surface area for microbial activity in the rumen and enzyme action in the small intestine. Using heat and moisture (steam flaking) results in the gelatinisation of the starch, which increases its rate and extent of digestion.

Herrera-Saldana *et al.* (1990) compared rates of starch digestion of five cereal grains with the *in vitro* and *in situ* methods. The results of the *in vitro* system revealed that the 60-minute starch degradability's were 28, 24, 18, 13 and 9% for oats, wheat, barley, maize, and sorghum, respectively. Fistulated steers were used to determine *in situ* degradability's of starch in the five grains. Grains were incubated in the rumen for 2, 4, 6, 8, 12, 24, and 48 h in dacron bags and the ranking of cereal grains for their starch ruminal availability was the same as in the *in vitro* system; for oats, wheat, barley, maize, and sorghum the starch availability was 98, 95, 90, 62, and 49%, respectively.

The rate of starch digestion in cereal grains can be estimated from the gas production in *in vitro* rumen digestion systems. Gonzalez-Rivas *et al*. (2017) found that, while there was no significant difference in total gas production at 24 hours incubation, gas production was 23% slower for maize than for wheat and maize reached maximum rate of gas production 10% later than in wheat. Slowly fermentable grains such as sorghum and maize contain starch granules that are more resistant to bacterial amylase in the rumen because they contain more amylase and are surrounded by a strong protein matrix (Gonzalez-Rivas *et al*., 2017). In addition, The University of Melbourne also compared soft wheat with hard wheat and found that there was a tendency for the soft wheat to be fermented at a faster rate, thereby increasing the risk of a more unstable rumen and sub-acute rumen acidosis (Freeman *et al*., 2010).

Sorghum has quite poor digestive characteristics for ruminants and is most effective when it is processed by steam flaking. Many dairy farmers struggle to achieve higher production levels due to the poor digestive characteristics associated with feeding sorghum grain. Applying heat to grain sorghum through steam flaking successfully increases starch availability and improves degradation in the rumen to increase the digestion of starch. Steam flaking sorghum is used extensively by the cattle feedlot industry, but it is not economically feasible to produce the smaller amounts that would be used in individual dairies.

On the other hand, the slower digesting source of starch as in maize can be of considerable benefit to the lactating dairy cow.

Maize is an advantageous source of starch for lactating dairy cows because the ruminal digestion of starch in maize is slower than starch digestion in some other cereal grains such as wheat and barley. The slower digestion of starch in maize helps cows maintain a more stable rumen pH and avoid the milk fat depression often seen when diets high in wheat are fed. This slower digestion of starch in maize is often very complementary to winter cereal grain digestion.

Table 13. Approximate nutrient specifications of cereal grains (Dairy Australia, 2010)

Grain type	Energy content (MJ ME/kg DM)	NDF (% DM)	CP (%DM)	Starch (%DM)	Rate of fermentation (x = slow and xxxxx = fast)*
Wheat	13.5	12.3	12.0	62.7	xxxxx
Triticale	13.4	15.0	13.1	60.6	xxx
Barley	12.9	20.0	13.5	54.6	xxx
Oats	12.1	36.0	11.6	44.3	xx
Sorghum	11.5	13.5	10.5	64.5	x
Maize	13.5	11.5	9.5	70.5	x

** Relative rate of rumen fermentation from Little (2015).*

The importance of the slower digestion of starch in maize has been demonstrated by Auldist *et al*. (2013). In one of their early experiments at Ellinbank, they found that isoenergetic diets that contained maize and maize silage were associated with a greater yield of energy corrected milk (ECM) than barley grain, particularly at higher supplement levels. The maintenance of milk fat concentration at the higher supplementation levels contributed to the increased yield.

It has become more common that the grain-based concentrates fed to high producing cows at above 10kg/day may include up to 30% maize in addition to the wheat or barley to take advantage of the benefits of the slower digestion of starch in maize.

Protein supplements

Protein supplements are added to dairy cow diets to compensate for the lower protein levels in cereal grains when cows have limited access to the higher protein levels in pasture. True protein is either broken down in the rumen (rumen-degradable protein or RDP) or bypasses rumen digestion (rumen undegraded protein or RUP) to be digested in the intestine with a small proportion passing undigested out in the manure (ADICP). Metabolizable protein is the protein (microbial protein and RUP) that is absorbed through the intestine and available to the dairy cow.

The most common protein supplements that are used by the dairy industry in Australia include, canola meal, soyabean meal, cottonseed meal and lupins. The average composition of these protein sources is shown in Table 14. The digestion rates of protein in common protein supplements are given in Table 15.

The importance of protein supplements and adequate dietary protein in dairy cow diets has been well demonstrated by the nutrition work at Ellinbank. Auldist *et al*. (2014) conducted a series of experiments that showed that replacing about 20% of the wheat with canola meal in a partial mixed ration (PMR) fed twice daily to grazing cows can increase intake and milk production. The canola meal provided more dietary protein in the isoenergetic PMR. Cows consuming the canola meal diet increased daily intake of both pasture and supplement (Auldist *et al*., 2014). As a result, cows offered the PMR with canola meal produced more energy corrected milk (ECM) (ranging from 1.7-4.0kg ECM/cow/day) than did cows offered the PMR diet without canola meal when the daily level of feeding was at least 12.0kg DM supplement/cow.

Table 14. The protein composition of common protein sources (DairyOne, 2020)

Protein source	DM (%)	CP (% DM)	Soluble protein (%CP)	Degradable protein (%CP)	ADICP (%DM)	NDICP (%DM)	NDF (%DM)
Canola meal	91.9	39.3	31.1	49.6	3.1	7.7	30.5
Cottonseed meal	91.1	43.7	18.1	56.1	2.3	6.9	34.0
Lupins	91.9	33.2	58.8	75.7	1.3	4.9	28.8
Soyabean meal	90.8	50.9	23.0	59.5	2.1	7.5	13.6
Sunflower meal	93.0	32.3	35.7	70.7	1.6	4.0	40.6

Table 15. Protein content and digestion rates of common protein sources (QDAFF, 2013)

Protein source	CP (% DM)	RDP (% CP)	Time in rumen (hrs)
Canola meal	38–44	68–72	2–6
Cottonseed meal	41–47	50–58	6–12
Soyabean meal	47–52	70–74	2–6
Sunflower meal	32–37	70–74	5–10
Wheat	8–15	75–80	2–6

Conclusion

Cereal grains provide dairy cows with substantial quantities of starch which is the major source of energy to the cow and is considered the primary driver of microbial protein synthesis in the rumen. While there are often little differences in the protein content of cereal grains, the starch content may vary widely and more importantly, the rate of rumen fermentation varies between cereal grains. Both wheat and maize have relatively high levels of starch (60–70%), but the rate of fermentation of starch in maize is considerably slower than that in wheat, which helps cows maintain a more stable rumen pH and avoid the milk fat depression often seen when diets high in wheat are fed. It has become more common that the grain-based concentrates fed to high producing cows at above 10kg/day may include up to 30% maize in addition to the wheat or barley to take advantage of the benefits of the slower digestion of starch in maize.

Protein supplements are added to dairy cow diets to compensate for the lower protein levels in cereal grains when cows have limited access to the higher protein levels in pasture. True protein is either broken down in the rumen (rumen-degradable protein or RDP) to be incorporated into microbial protein or bypasses rumen digestion (rumen undegraded protein or RUP) to be digested in the intestine. Metabolizable protein is the protein (microbial protein and RUP) that is absorbed through the intestine and available to the dairy cow. The most common protein supplements that are used by the dairy industry in Australia include canola meal, soyabean meal, cottonseed meal and lupins. Inclusion of protein sources such as canola meal not only provide good source of dietary protein but may also have a positive effect on dry matter intake and subsequent milk yield.

R&D OPPORTUNITIES

The technical review of forages available for the dairy industry revealed little need for the more basic R&D. Much of the agronomy knowledge associated with optimising yields of the various forages is well known and often based upon grain agronomy. In addition, the details of harvesting of these forages for silage or hay have been well established by such programs as TopFodder.

PRIORITY RATING
High Moderate Low

General forage R&D gaps and opportunities

Demonstration of the efficient growth and use of the forages	D	Term: Short	Priority: High
There is a need to establish likely yields of some of these forages in commercial conditions. Certainly, previous Dairy Australia research has shown the potential of forage yields through their Complementary Forage Rotations and Systems program conducted by the University of Sydney and the Queensland Dairy Group. These exceptional yields were achieved because of precise management and agronomy where forages were sown, harvested, irrigated, fertilised to the day under well controlled research conditions. The challenge is to approach this potential on commercial farms. There is a need to demonstrate likely yields and WUE for these forages under best (commercial) practice.			
R&D into the automation and real time forage crop monitoring is worthwhile	**D**	**Term: Medium**	**Priority: Moderate**
There are substantial efficiency gains to be made through more precise sowing, application of irrigation water and fertiliser schedules.			
Potential of double cropping, under-sowing forage crops and even triple cropping	**D**	**Term: Short**	**Priority: Moderate**
Triple cropping may be a stretch that will be beyond many dairy farmers whose primary job is dairying, not cropping. Demonstration sites could be established on commercial farms to examine double cropping systems as well as under-sowing winter cereals with other forages such as vetch to produce silage and hay that may better meet the requirements of the lactating cow. These multi-crop options should be explored to make most efficient use of the resources, including irrigation water, and supply the dairy with high quality fodder.			
Research gaps in the use of these forages in dairy diets	**D**	**Term: Medium**	**Priority: Moderate**
It is hard to identify specific research gaps in the use of these forages in dairy diets as much of this information should be available on the world scene, as the main forages grown are used world-wide. There may be scope to investigate the nutrient content of specific forages that are grown locally. Certainly, as some of the silages derived from maize and grain sorghum varieties in Australia contain appreciable amounts of starch, further evaluation of the content and availability of starch in these forages is well worthwhile. The digestibility and fragility of individual forages and how they fit into the total diet is a key area that will drive productivity gains to account for the higher cost of dry matter relative to pasture forages. Nutrition knowledge, if it is not available in Australia, can be sourced from overseas (USA) where they have had extensive experience in mixed rations for lactating dairy cows and many of the forages that are available in Australia. The Advanced Nutrition course for dairy farmers could be further supported and expanded.			
Development of decision support tools to compare the economics of different forage crops	**D**	**Term: Medium**	**Priority: High**
Although this review has been limited to technical information and there has been no attempt to examine relative costs and returns of the various forage systems, there does seem to be a need to identify the optimum forage crop(s) to be grown, given current forage, water, and other input prices. Similar decision support tools have been developed for grain crops grown under irrigation and it would be worthwhile to develop similar tools that explores how gross margins of the various forage crops varies with input prices and grain yields.			
Capability in forage cropping management	**D**	**Term: Long**	**Priority: Moderate**
There is a need to upskill dairy farmers (or their agronomists/advisors) in forage cropping management.			
Encourage dairy farmers to get their feed tested	**D**	**Term: Short**	**Priority: High**
In view of the huge variation in the fodder and other feedstuffs, encourage dairy farmers to get their feed tested, not only for Dry Matter, Crude Protein, NDF and ME but also starch levels in cereal grains, maize silage and winter cereals that may be ensiled late in their growth period.			

PRIORITY RATING

High Moderate Low

R&D gaps and opportunities for specific forage crops

Sorghum	**D**	**Term: Short**	**Priority: High**
Comparative trials with alternative types of sorghum and against maize in Murray Dairy region when BMP guidelines are followed. Further work on the growth and suitability of grain sorghums as a forage source for dairy cows is required.			
Maize	**D**	**Term: Medium**	**Priority: Low**
Evaluate BMR maize against existing forage varieties of maize if BMR maize is introduced into Australia.			
Maize	**D**	**Term: Short**	**Priority: High**
Comparative trials with other summer forages in northern Victoria.			
Maize	**D**	**Term: Medium**	**Priority: Moderate**
Yield and WUE on dairy farms in the Murray Dairy region when BMP guidelines are strictly followed.			
Maize	**D**	**Term: Medium**	**Priority: Low**
Assess quality of maize silage when BMP guidelines are strictly followed.			
Winter cereals	**D**	**Term: Short**	**Priority: High**
Comparative trials of wheat and barley with other winter forages in northern Victoria when grown under BMP guidelines.			
Winter cereals	**D**	**Term: Long**	**Priority: Moderate**
Evaluate the high yielding winter varieties of wheat and barley in the Murray Dairy region when irrigated or rain-fed.			
Multi-crop	**D**	**Term: Short**	**Priority: High**
Evaluate double cropping systems involving winter cereals and maize or sorghum as the summer crop in the Murray Dairy region under BMP guidelines.			
Multi-crop	**D**	**Term: Medium**	**Priority: Moderate**
Investigate companion cropping system by under-sowing winter cereals with legumes such as vetch or annual clover species to produce higher quality winter forage.			

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02

Technical Review: Infrastructure required for more diverse feeding systems on dairy farms

Steve Little

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CONTENTS

INTRODUCTION

The Australian Dairy Industry over many years has been prepared to explore a variety of innovative solutions enabling an extensive range of supplementary feeds to be incorporated into the herd's diet to support a predominantly grazing industry.

This range of feeding infrastructure has been used in dairying as an important management tool to aid supplementary feeding and to accommodate herds during periods of adverse weather, seasonal variability, and emergency events to minimise production losses, animal health issues, protect paddocks from pugging and damage to laneways.

In most recent years, the dairy industry has seen an increase in cattle shelters. These shelters have been used for extended loafing to combat months of the year, which routinely impact production i.e. wet winters or hot summers. Some farmers are selecting more contained housing options when undertaking complex decision-making to change their farming system away from grazing to intensive zero grazing farm systems. These intensive contained housing options such as freestalls, bedding pack barns and dairy dry lots provide improved management flexibility for livestock and improve opportunities to explore technologies and significantly mitigate farming risks.

Determining the most appropriate feeding infrastructure, from mobile-temporary solutions for infrequent usage for feeding and short-term herd containment to the regularly utilised permanent concreted roofed feedpads or ultimately a zero-grazing system, requires careful consideration, planning, and engagement with professional service providers to ensure farm changes are successfully implemented.

SILAGE STORAGE

Introduction

This technical review of feed storage systems will be confined to providing more recent information on silage storage systems for conserved forages. This is in line with the companion technical review of alternative forages for the dairy industry which was commissioned at the same time as the review of infrastructure associated with storage, mixing, and delivering feed to the dairy industry.

Watts *et al.* (2016) has extensively covered the storage infrastructure required for hay, grain, liquid feedstuffs, protein supplements, by-products, and other bulk commodities, as well as silage facilities. In the publication by Watts *et al.* (2016), there is a comprehensive chapter on the storage facilities required for each of these feeds and these chapters include the design of the relevant storage facility, types of storage available, mandatory requirements and the relevant Australian standards.

The feed storage facilities and infrastructure required for beef feedlots described by Watts *et al*. (2016) would be very similar to what is required for dairy farms that have recently adopted more intensive feeding systems. There is likely to be little further development in feed storage facilities since the publication by Watts *et al.* (2016). Thus, people are directed to the recent review of Watts *et al.* (2016) for information on the storage of these other feed commodities.

Silage storage

Silage is forage cut at high moisture content (typically between 30 and 50% DM) and stored in an anaerobic environment. This anaerobic storage promotes fermentation and the production of lactic acid which causes the pH to fall to a level of about pH 4.0-4.5 that preserves the forage.

Any technical review of the storage options suitable for both chopped and longer fibre silage would rely upon the extensive information provided several years ago in the “Successful Silage” manual (Kaiser *et al.*, 2004) which was produced as the output from the TopFodder Project. This project was a jointly run by NSW DPI and Dairy Australia with contributions from other State Departments of Agriculture or equivalent.

A considerable amount of the excellent information compiled by Kaiser *et al.* (2004) in the “Successful Silage” manual is still accurate and relevant today and has been used extensively since and has been included in more recent publications. For example, Mickan (2008) prepared a technical note on storing forage cereals, and Watts *et al.* (2016) drew heavily upon Kaiser *et al.* (2004) when they prepared their chapter on design and construction of silage infrastructure. In addition, Frank Mickan has produced many reports and technical notes about silage as part of his extensive work with Agriculture Victoria over many years and has made them available to industry through the National Library of Australia Catalogue website **catalogue.nla.gov.au**

There are a wide range of options for storing silage. Essentially there are three silage storage options: stack, bunker and bale (Figure 1).

Figure 1. The three silage storage options (top to bottom) – stack, bunker, bale

Storage options suitable for chopped silage range from relatively inexpensive buns or stacks to concrete bunkers, that require substantial capital investment. In both these types, feed from the face of the stack is removed daily. Baled silage is stored in square or more commonly, individual round bales which are wrapped in plastic and the whole bale is fed directly or may be incorporated into a mixed ration. The cost of plastic and wrapping makes this option of storing conserved forage as one of the more expensive.

Overall, 76% of dairy farmers store silage as baled silage whereas less than 40% of dairy farmers store their silage in stacks of bunkers (Dairy Australia, 2019a). However, over 68% of dairy farmers with herd sizes exceeding 500 cows, store their silage in stacks or bunkers (Dairy Australia, 2019a). The average amount of silage conserved each year on dairy farms was 766 t DM, with the Dairy NSW, Western Dairy and Subtropical Dairy regions conserving the most silage, being 1,688 tonnes, 1,147 t DM and 1,088 t DM, respectively (Dairy Australia, 2019a). In addition, an average of 368 t DM of silage was purchased by dairy farmers each year, with farmers in the Dairy NSW region easily buying the most silage (Dairy Australia, 2019a).

The most appropriate system for storing forage on the farm should consider the storage time, location of storage site relative to harvesting and feeding out, accessibility for harvesting and feed-out equipment and of course, how much it will cost. A comparison of the advantages and disadvantages of the three silage storage options is presented in Table 1.

Table 1. The three silage storage options: advantages and disadvantages

Stack	Bunker	Bale
Advantages	**Advantages**	**Advantages**
• No material construction costs • Easily sealed using a grader blade or front-end loader bucket • Not limited by the amount of silage produced, the size can be adjusted to suit the rate of feeding • More vulnerable to operator error resulting in poor fermentation • Flexibility in location, i.e. near feedout site or in harvested paddock • Are adaptable for self-feeding	• Can be reasonably inexpensive to construct (with earthen floors) – the life of the structure is usually proportional to the construction cost • Lower plastic costs per tonne of silage made compared to stacks • Relatively easy and safer to roll than stacks • A solid base enables all-weather access • Depending on construction can be expanded relatively inexpensively using the common walls on either side	• Smaller storage and handling losses (typically under 10%) • More likely to be well preserved until feed out • Flexible system suitable for small batches • No construction costs for storage • Flexibility in locating storage site • Existing hay-making equipment may be used • Easy to monitor silage stocks • Convenient to handle and feed out • A saleable commodity
Disadvantages	**Disadvantages**	**Disadvantages**
• High surface to volume ratio means, highest plastic costs per tonne of ensiled forage • Insufficient drainage causing pooling (odour, leachate seepage and poor silage quality) • Possible risk of fire by using car tyres on stacks • Any surface wastage represents a large proportion of the silage • Can be dangerous for operators during rolling, limiting the height of the stack	• Concrete floor bunkers are expensive to construct • Possible contamination of silage with gravel and rock base with further possible damage to feed out machinery • More vulnerable to operator error resulting in poor fermentation • Insufficient drainage causing pooling (odour, leachate seepage and poor silage quality) • Earth walls must have stable slopes • Requires regular maintenance • Earthen floors can make wet-weather access difficult, particularly if the design has not allowed sufficient floor slope for drainage	• Not suitable for all crop types • High cost per tonne of silage DM produced • More storage space required • Susceptible to damage if handled after wrapping • Susceptible to bird and vermin damage • Short-term storage (12 months) Note: if bales are to be stored for periods greater than 12 months additional layers of plastic can be applied (i.e. up to 6 layers) • High feed out costs for large quantities • Disposal of wrapping and netting waste

In the case of ensiling forages such as maize, grain or forage sorghum, millet and winter cereals, the preferred method is precision chopping and subsequent storage in stack or bunkers. The short chop length achieved by this method allows better compaction of the silage. Further discussion of forage silage will be restricted to the stack and bunker systems of storage.

Description

Stack silage

Open air stack or bun stored silage is the cheapest and easiest option but may not be a good solution for longer term storage of conserved fodder, as wastage can be high. The forage is dumped onto the ground, regularly rolled, covered with plastic which is then weighed down and edges sealed. Ideally the base is firm to allow traffic and reduce waste in wet weather.

Bunker silage

Low-cost bunkers can be made cheaply from square bales or wooden sleepers onto a compacted surface. However, contamination may occur with stones and soil if the forage is loaded directly on the compacted surface. Bunkers with concrete floors are the ideal option as they minimise wastage and drain well if well designed. These bunkers can be lined up adjacent to one another sharing a common side wall, thereby reducing costs.

If the stack or bunker is being filled over several days, it should be covered overnight with a plastic sheet to minimise plant respiration and heating and each new day's harvested material should cover yesterday's material by at least one metre to prevent respiration of the earlier harvested material. Once harvesting and the final compaction is completed, the stack should be sealed airtight using plastic sheeting specifically manufactured for silage (>150 micron thickness). Then the entire surface of the stack should be weighed down and sealed by burying the edges of covers to ensure an air-tight seal. For an airtight seal use gravel bags, filled with pea gravel or washed sand along bunker walls and stack surface. Even a double row of tyres around the perimeter does not achieve an airtight seal.

The siting of silage (and other storages for grain, protein sources and hay) stacks and bunkers should consider two fundamental aspects of planning. Firstly, linking the development of feed infrastructure with key farm assets such as access to laneways, water supplies and power, access to the dairy shed and effluent systems, etc. Secondly, determining the suitability of the site to ensure infrastructure does not cause risks, particularly environmental risks such as buffer distances, water ways, ground water, noise, dust etc.

The MLA publication prepared by Watts *et al.* (2016) covers a wide range of factors involved in the design and construction of beef feedlots. Much of the information may be directly applied to the dairy industry, particularly those parts of the industry that have more intensive feeding systems.

Watts *et al.* (2016) adequately cover the infrastructure associated with the storage of feed, including whole grains, processed grains, by-products and liquid feeds and hay. In addition, they have a full chapter on silage storage systems that brings together results of the latest work with different forage silage systems but draws heavily upon the earlier work from Kaiser *et al.* (2004).

The chapter in Watts *et al.* (2016) on the infrastructure of silage systems provides extensive information on the design and specifications of silage storage systems, including site, slopes for floors and walls, safety aspects, capacity, sealing and feeding out and should be consulted for further up to date information on silage storage infrastructure.

Costs and lifespan

There has been little published information on either the capital costs or operating costs of different silage systems. One of the earliest analyses of the costs of fodder conservation systems on dairy farms was conducted by the Kondinin Group in 1997 (Meat & Livestock Australia, 1997). They found that the average costs for silage making systems from mowing to feeding out ranged from $52/t DM for direct chopped silage to $138/t DM for wrapped round bales of silage. There was no analysis of the cost of storage in either system and in fact the costs may not be relevant today.

The "Successful Silage" manual also has little information on the capital and operating costs involved in the stack, bunker or the plastic wrapped round bale systems (Kaiser *et al.*, 2004). Furthermore, since then there has been little published information on costs of the silage systems. In the case study conducted by Dairy Australia (2020), the cost of making silage in round bales was $115/t DM but when silage was stored in a stack, the cost reduced to $85/t DM (i.e. a difference of about $40/t DM).

Silage stacks are likely to be the lowest cost system for storing silage as there are no material construction costs. But with a high surface to volume ration, the operating costs may be greater; plastic costs/tonne will be greater than silage stored in bunkers and labour costs involved in building the stacks will also be greater. Silage stacks are often the most efficient short-term option and can have a storage life of up to 2–3 years. Often only 1–2 years of silage inventory may be required on dairy farms, so stacks may be a viable option in these cases.

Bunkers can be a more expensive option than silage stacks but will minimise wastage. Low-cost bunkers can be made very cheaply from square straw bales or wooden sleepers. Concrete side wall and floor bunkers would be the most expensive, but wastage would be kept to a minimum. However, the overall feeding system will need to be designed well and thought through if the dairy farmer installs concrete bunkers to store their silage. Once the concrete is poured for a bunker, it cannot be picked up and moved if your dairy operation changes. Bunkers may also be protected either by a cover or in a shed which will add to the cost but likely to further reduce wastage. Above ground bunkers can store silage for up to 2–3 years.

As discussed above, there is little published information on the capital and operating costs of different silage systems, including the newer bag systems for storing bulk silage. It would be worthwhile to collect information on the costs and expected wastage of various silage storing systems to provide the dairy farmer with quantitative information on the relative merits of the various silage storing systems.

Skill level required

Most dairy farmers would have good knowledge of silage preservation of various crops, particularly pasture, as much of the information in the "Successful Silage" manual produced by Kaiser *et al.* (2004) has been the basis of many TopFodder workshops around the country. In addition, Frank Mickan, Pasture and Fodder Conservation Specialist at the Victorian Department of Agriculture has held many workshops on silage making and produced countless publications suitable for dairy farmers in the dairy extension programs. These resources, together with the more recent publication by Watts *et al.* (2016) provide considerable information on storage systems for silage and ways to reduce wastage.

KEY AREAS TO ADDRESS IN SILAGE STORAGE SYSTEMS:

Irrespective of whether the silage is conserved in a stack or bunker system, critical processes for good quality silage include:

- timing of harvest
- harvesting methods
- filling, packing and sealing of the silage storage system, and
- feedout systems.

Much of the basic information on optimising these processes has been described in the "Successful Silage" manual produced by Kaiser *et al.* (2004). However, there have been more recent developments in some of these areas that have improved the quality of silage and reduced wastage. Modern technologies such as inoculants, preservatives and oxygen impermeable covers can greatly reduce surface losses, irrespective of storage methods. In addition, machinery has been developed to remove silage from the stack or bunker and ensure good face management.

TIMING OF HARVEST:

The optimum dry matter content for ensiling varies for different forages and pastures, either in stack/bunker or bale silage storage. Growth stage at harvest has a major impact on forage quality and yield. Wilt to the target dry matter range as quickly as possible. The forage dry matter and quality losses are minimised if dry matter targets are reached, ideally within 24 hours but certainly 48 hours. Tables 2 and 3 sourced from the TopFodder Silage Note No. 4 describe requirements to ensure quality silage of some common crops (Dairy Australia, 2019b).

Table 2. Yield and quality potential of crops grown for silage production, identifying requirements to ensure quality silage (Dairy Australia 2019b)

Crop	Perennial ryegrass & clover	Forage ryegrass	Other temperate perennial grasses & clover	Pasture legumes & legume dominant pastures[1]	Lucerne	Kikuyu & other tropical grasses	Forage sorghum	Millet (several types)	Cowpea & lablab
Growth stage at harvest	1st head emerge on ryegrass	10-20% head emergence	Stem elongation of grass component	Early to mid flowering	Very early (<10% flower)	25-35 days growth	1m high	Pennisetums: 1m high Japanese: pre boot	Flowering
Potential yield[2] (t DM/ha/cut)	2.5–4	2.5–4.5	2–4	2–3.5[1]	1.5–3.2	2–3.5	2–5	2–5	1.5–6
Potential number of cuts per year[2]	1–2	1–2	1	1–2	4–7	1–3	1–4	1–3	1
Wilting requirement	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Target range DM content(%)									
Chopped	30–40	30–40	30–40	35–40	35–40	35–40	30–40	30–40	35–40
Baled	35–50	35–50	35–50	35–50	35–50	35–50	35–50	35–50	35–50[6]
ME[3] (MJ/kg DM)	9.5–11	9.5–11	9.5–10.5	9.5–11.5	9–10.5	8.5–10	9–9.5	9–10	8.5–10.5
Crude protein[3] (% DM)	12–22	12–20	12–16	14–26	18–24	12–18	7–17	10–18	14–18
Ensilabilily[4]	**	**	**	*	*	*	**	**	*
Suitable for chopped bulk silage	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Suitable for baled silage	Yes	Yes	Yes	Yes	Yes	Yes	Yes[5]	Yes[5]	Yes[6]

Notes:

1 High-density legumes have potential to produce higher yields (3.5-7.0 t/ha) than pasture legumes sown at the usual rates. Management requirements for silage production and potential forage quality are as for pasture legumes.

2 Yields and potential number of cuts are for crops cut at the optimum growth stage. Yields at the higher end of the range can be obtained with irrigated crops or crops grown under ideal growing conditions.

3 The ME(metabolisable energy) and crude protein values shown are in the range that is achievable with good management.

4 Ensilability: likelihood of achieving a good silage fermentation without wilting or additives. (* Low** Medium *** High)

5 Baling is not recommended for tall, rank crops unless the baler is fitted with knives.

6 Although cowpeas and lablab may be made into baled silage, it is not the preferred option.

Table 3. Yield and quality potential of crops grown for silage production, identifying requirements to ensure quality silage (Dairy Australia 2019b)

Crop characteristics	Maize	Whole crop winter cereal		Whole crop winter cereal /legumes mixtures	Grain sorghum	Sweet sorghum	Soybeans
		Oats	Wheat & barley				
Growth stage at harvest	milk line score 2–3	boot to flowering	boot or mid-dough	boot to dough of cereal component	milky dough (middle of head)	head emergence to dough	65% pod fill
Potential yield[1] (t DM/ha/cut)	12–25	5–15		5–15	4–10	10–25	4–10
Potential number of cuts per year	1	1		1	1	1	1
Wilting requirement	no	boot yes/dough no		yes	no	no	yes
Target range DM content(%)							
Chopped	33–38	35–40		35–40	30–35	25–35	35–40
Baled	NR	35–50		35–50	NR	NR	35–50[4]
ME[2] (MJ/kg DM)	10–11	9–10.5		9.5–11	9.5–10.5	9–10	8–9.5
Crude protein[2] (% DM)	4.5–8.5	6–16		8–18	6–9.5	4–8	15–20
Ensilabilily[3]	***	boot **/dough ***		**	***	***	*
Suitable for chopped bulk silage	yes	yes		yes	yes	yes	yes
Suitable for baled silage	no	yes		yes	no	no	yes[4]

Notes:

1 Yields at the higher end of the range can be obtained with irrigated crops or crops grown under ideal growing conditions.

2 These ME (metabolisable energy) and crude protein levels are achievable with good management.

3 Ensilability is the likelihood of achieving a good silage fermentation without wilting or a silage additive. (* Low,** Medium or *** High).

4 Baled silage is not the preferred option for soybeans.

5 NR not recommended.

Harvesting methods

The critical areas are around grain conditioning, chop length and inoculants. There has been significant R&D to develop silage inoculants since the publication by Kaiser *et al.* (2004). Silage inoculants work by shifting silage fermentation to better preserve the forage. There are two main types of silage inoculants: the traditional homofermentative types, such as Lactobacillus plantarum, the Pediococcus species, and Enterococcus faecium; and the more recently used heterofermentative bacteria, Lactobacillus buchneri. A third group, combining homofermenters with L. buchneri, is also being marketed.

There may be an R&D opportunity to evaluate the use of inoculants and their application rates to improve quality and reduce wastage of silages, but much of this comparative work is already conducted by commercial companies, albeit not totally independent.

Plastic cover on a silage stack

A clean silage pit face

Filling, packing and sealing of the silage storage system

Kaiser *et al.* (2004) provided extensive information in this area. But there have been developments since then, particularly in the materials that have been developed for sealing bulk silage and wrapping silage bales.

The technology for better sealing of silage stacks has involved the development of oxygen impermeable covers in recent years. Several commercial companies offer covers for silage stacks and bunkers that allow for complete fermentation and preservation of the forage with a high level of ultraviolet (UV) light protection, which is particularly important for the high UV light conditions in Australia. Often the covers contain up to 3 layers including a black inner layer that provides 100% sunlight protection to give a uniform level of feed quality and reduced protein breakdown, while a white outside layer helps to keep stored silages cooler by deflecting the heat of the sun. This effectively reduces bunker heating and DM losses. These types of covers should last for at least 2–3 years in the hot and high UV light conditions in Australia.

Combination covers, such as Silostop™, which is an oxygen-impermeable film protected by heavy duty UV-resistant shade cloth or plastic, are ideal for sealing silage and preventing oxygen transfer during ensiling and feed out (Watts *et al.*, 2016). These types of covers can certainly reduce feed wastage near the surface of the stack. Mickan (2020) reported less than 10% loss in the top one metre of the stack with oxygen impermeable covers compared to a 20% loss with traditional white/black sheets or over 50% with no cover. Again, dairy farmers should consult their advisor about the most appropriate and cost-effective material for sealing and covering their silage.

Feed-out systems

Silage requires at least 4 to 6 weeks for the whole stack to ferment if compacted tightly and sealed airtight within hours after the harvest has been completed (Mickan, 2020). After this fermentation has been completed the silage is ready for feeding out. The key when feeding out silage is to minimise the disturbance of the silage face to reduce air penetration and aerobic deterioration. Ideally, a depth of about 15–25cm of the stack face is removed at a time. Furthermore, the face after removal of silage should be smooth shaven to minimise the surface area exposed to the air.

When it comes to feeding out bunker and stack silage it is important to use the correct equipment for the job. Careful use of front-end loaders or purpose-built silage grab equipment with the right attachment for the job can be used to knock down short chop silage, starting from the top and going down the face before being transferred to the feed mixer.

Further developments in feed-out machinery have led to equipment such as face shavers or block cutters becoming available in Australia. This type of equipment can be an additional cost in silage infrastructure but should improve face management thereby minimising silage deterioration. The main objective when feeding out silage is to ensure that the stack face is left clean. Proper stack face management helps to prevent further losses from secondary fermentation and spoilage.

FEED MIXING

As feeding systems become more complex on dairy farms, ingredients are mixed before presenting the feed to dairy cows. To mix and deliver feed to dairy cows, there are two main systems that may be used, the silage cart which was not designed for mixing rations, or the mixer wagon.

Silage carts

Description and characteristics

Silage carts are designed to deliver chopped silage. They have moving floors and shift forage to one end where the silage can then be fed out in a windrow or into a trough through a side delivery chute. Although they have not been specifically designed for feeding mixed rations, many dairy farmers use the cart for more simple mixed rations by layering various feed ingredients in the cart.

Most silage carts range from 10 to 30 cubic metre capacity and can deliver feed from the centre, or more commonly, where feed is delivered in troughs or under a wire, the side feed model would be preferred.

Costs and lifespan

New high-capacity silage carts may cost over $100,000 but good quality silage carts may be purchased second hand for about $20,000 to $60,000 for carts with capacity of between 10 and 30 cubic metres or about $1,000–$2,000 per cubic metre). Silage carts are quite robust, have minimal moving parts and with standard maintenance should last for at least 10 years.

Benefits

A simple and relatively cheap feed out system if one or only a few feed ingredients make up the ration to be fed out. In addition, the power requirements for operating a silage cart are quite low and it does not require a tractor with as much horsepower as that needed for a mixer wagon. Many farmers who have used chopped silage for several years will already have a silage cart. This cart may be used to deliver rations containing up to about 3 ingredients, but thorough mixing is often inadequate which could lead increased risk of acidosis if a starch source such as maize silage or grain are included in the silage cart mix.

Skill level required

Basic skill required as mixing involves layering of up to three ingredients in the silage cart so that at feed out there is some minimal uniformity with the mix.

Issues/limitations

- Need to match the capacity of the silage cart to amount of feed to be delivered. For example, a 10 cubic metre cart may contain 4 t DM silage which would be sufficient to provide 6kg DM silage/day to about 700 cows once a day
- Load cells need to be fitted to the cart to weigh the feed ingredients.
- Silage carts are not designed to mix ingredients and there may be uneven mix and feed out. This may result in uneven feed and nutrient intakes and affect subsequent performance among individual cows.
- Long materials separate and tend to be wasted. In addition, cows may select out certain ingredients such as maize silage in preference to other feeds on offer, thereby consuming an unbalanced ration.
- Silage carts can have a high wastage if the cart has a wide feed out and the ingredients are not well mixed.
- Small inclusion levels of feed ingredients such as minerals and feed additives, and even crushed grain, are not able to be satisfactorily mixed and should not be included in a silage cart for feeding out.
- A maximum of three ingredients, may be included in a ration that is fed out with a silage cart. If more than two or three ingredients are included in the ration, a mixer wagon is the preferred method of mixing a dairy ration.

Mixer wagons

Description and characteristics

Feed mixer wagons are purpose built for mixing a greater range of ingredients in mixed forage-based rations. They should be used if more than two or three ingredients are included in the ration and can handle a wide range of ingredients that can vary from 90% dry matter for crushed grain through to liquids such as water and molasses.

Mixer wagons offer a great opportunity to reduce feed wastage, particularly hay and silage wastage, and a feedpad is essential and required to get the best outcomes from a feed mixer wagon.

There are about 15 brands of feed mixer wagons available to the dairy industry in Australia, and these are essentially of three types of design: paddle mixers, horizontal mixers, and vertical mixers.

The paddle mixers have horizontal paddles that mix the ration and blades that will cut hay, straw, and silage. They are very good at mixing, are relatively simple with no gear boxes and lower power requirements and fuel usage. As a rule, these horizontal mixers should only be filled up to about 75% of capacity to reduce the risk of some of the ration being thrown over the top.

The other two types of mixers rely upon centrally located augers that rotate and mix the feed. The horizontal mixer is usually V-shaped and has several augers running the length of the body in banks or one or two. The horizontal mixer works well with grain mixes and some brands can also process hay. The vertical mixer is usually conical shaped with one or two central augers. Both these mixers have a higher power requirement and fuel usage than the paddle mixers. While it is true that horizontal mixers will often operate with a lower horsepower requirement than vertical mixers, it is made possible by a greater gear reduction that moves the feed slower and thus could require a longer mixing time to achieve a comparable amount of mixing action. Vertical mixers are designed for rapid mixing and a uniform mix can be achieved in as little as three minutes following the addition of the last ingredient.

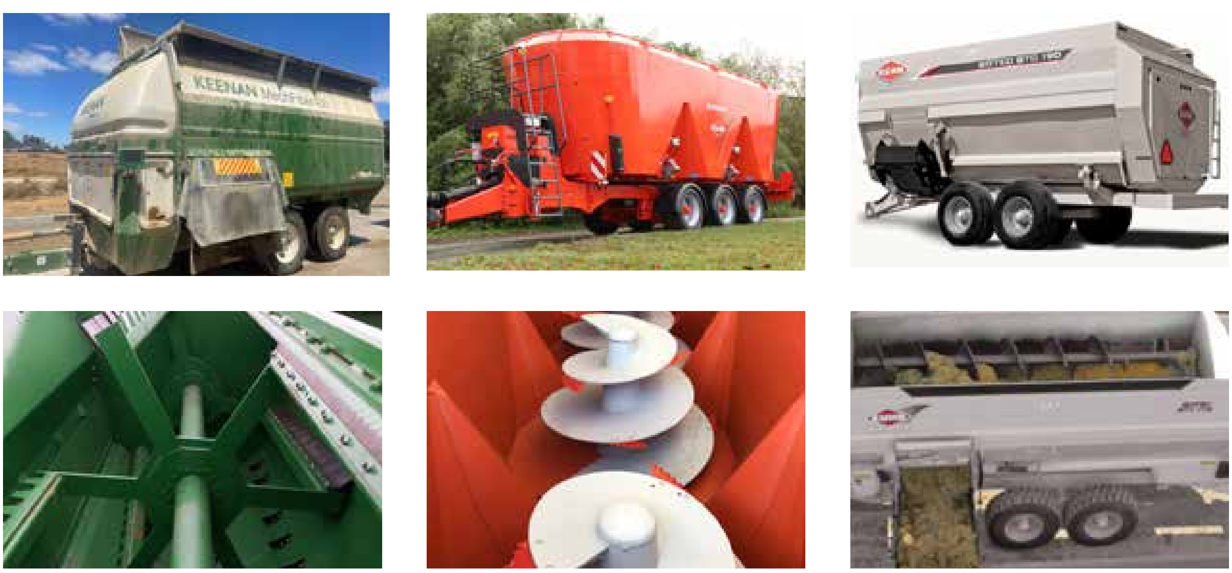
Mixer wagons vary in capacity from about 10 cubic metres and up to about 50 cubic metres and can be mounted on either a truck or, more commonly for the dairy industry, a tractor-drawn trailer.

These capacities are equivalent to between about 4 and 20 tonnes of feed. The mixer wagons contain augers for mixing and often a series of blades that can chop baled silage and hay thereby reducing particle size, enabling hay to be incorporated into the ration.

For these mixer wagons, additional facilities are required to deliver a range of feed ingredients to the feed mixer. These facilities include a front-end loader, forklift, or silage grabber to transfer hay/silage and other bulk ingredients into the mixer, augers on grain silos to deliver crushed grain to the mixer, as well as facilities to provide water and other liquids such as molasses, vegetable oils and syrups to the mix. In addition, silos and a feed shed, or bays are required for storing bulk quantities of ingredients. A comparison of the three types of mixer wagons available to the dairy industry in Australia has been provided by Dairy Australia (2007) in a Fact Sheet and the relevant table has been edited and is now presented in Table 4.

Table 4. Three types of mixer wagons – advantages and disadvantages

Paddle mixer	Vertical mixer	Horizontal mixer
• Simple drive, typically with no gear boxes • Higher loading height required • No dead spots (if used correctly) and watertight (when new) • Lower horsepower needed and fuel usage, although longer mix time required • Hard to over-process feed • Volume will depend on feed bulk density but can only fill to about 70% capacity • Relatively heavy • Slow moving • Cuts feed for processing: hay, straw, and silage	• Single, twin, or triple cone • Lower loading height required • May not be watertight • High horsepower needed • Good for delivering feed on feed-out facilities • Mix uniformly but depends upon operator • Take care not to over-process • More usable capacity • Need to prepare mix to machine's size or run at higher speed • Mixes by lifting feed and allowing it to fall back down the walls	• Single, twin or more augers • Lower loading height required • Some designs have dead spots • High horsepower needed and fuel usage • Some work well in the paddock, as well as on feedout facilities • Works well with grain mixes • Can compact feed • Will process dry hay but some do not take whole bales



Three types of mixer wagons (left to right) – paddle, vertical and horizontal

Costs and lifespan

Mixer wagons can cost well over $350,000 but it depends upon capacity and whether it is selfpropelled, on the back of a truck or as a trailer behind a tractor. Truck mounted wagons are quite common in feedlots in Australia, but most mixer wagons used in the Australian dairy industry are a tractor-drawn trailer. The cost of new mixer wagons will vary according to capacity but $100,000+ could be an expected price for a 20 cubic metre mixer. Second-hand mixer wagons that can be purchased at a much-discounted price may also be an option for the dairy farmer. Hiring or leasing the mixer wagon may also be an attractive option for those farmers that are unable to make the large capital investment upfront. In addition to the capital cost of the mixer wagon, there will be maintenance costs (maybe an extra $10,000/year; Dairy Australia, 2020) as well as labour costs associated with mixing and feeding out.

If farmers are looking to purchase a new or used mixer wagon, there are many questions to ask before committing to the cost. For example:

- Is the mixer's capacity big enough for my expected use pattern?
- Is my tractor big enough to operate the mixer wagon efficiently or do I need to buy a bigger tractor?
- Do I need the mixer to break open and cut up whole bales of hay and straw?
- The wagon may have been designed for European or North American conditions. Is the suspension and tyres of sufficient heavy duty to withstand travelling on often rough farm laneways to and from feedpad?
- What is the nature of the feedstuffs likely to be used, and is the wagon suitable regarding particle size, pH, liquids, etc?
- Are the walls and floors thick enough to withstand the frequent beating and mixing in the tub?

Working on average costs of $60–80/hour for labour and running costs of the mixer and the frontend loader used to fill the mixer, a very efficient system where the mixer is loaded, mixed, and delivered to the feedpad within 15 minutes of finishing loading the mixer wagon will cost about $28/outload or add about $5–6/t DM to the cost of the ration. However, most systems may take about an hour for this process and an additional $25/t DM could be added to the cost of the ration in time and labour costs (H Archibald, Pers. comm.).

The lifespan of a mixer wagon can vary, but farmers should aim to keep their mixer wagon for at least 5 years or until they need to purchase a bigger capacity mixer as the number of cows given a mixed ration, increases.

The lifespan of a mixer wagon on US dairy farms is often determined by the number of tonnes mixed and a target of at least 60,000 tonnes feed mixed is set before the mixer is traded in (H Archibald, Pers. comm.).

Benefits

- The major benefit of using a mixer wagon is that it can provide a better-balanced ration that promotes greater DM intake and subsequent milk yield. For example, Dairy Australia (2020) reported that milk yield increased by 3.6kg/day or 0.37kg milk solids/day after a mixer wagon replaced hay feeders in the paddock at a case study farm in northern Victoria. The extra revenue more than covered the cost of running costs, including interest and depreciation on the mixer wagon and increased net income by nearly $2.00/cow/day (Dairy Australia, 2020).
- More grain may be included in the ration with confidence as there is reduced risk of metabolic diseases such as acidosis.
- Uniform mix of ration that leads to reduced wastage as cows have much less chance to pick out and reject certain ingredients. The ration is well mixed so that each mouthful the cow takes is balanced and consumption of individual feed ingredients is eliminated.
- The mixer wagon provides the ability to source a wider range of feed ingredients that may be considered in the ration to reduce cost.

Skill level required

The use of a mixer wagon requires greater technical skill in cow nutrition and developing and implementing mixing protocols to prepare good quality rations. The formulation of the mix may be done by the nutrition consultant or is a skill that must be learnt by the dairy farmer, but the ability to uniformly mix dairy rations is an important skill that the dairy farmer must acquire.

Key areas to address in feed mixing systems

Variation in ration mixes

There are many factors in the loading and mixing of ingredients in a mixer wagon that can contribute to the variation in the final mix that is consumed by dairy cows. Oelberg and Stone (2014) identified at least ten key factors that may cause variation in the composition of the final ration and will affect the consistency of mixes. These include:

- Worn mixer augers, kicker plates and knives
- Auger timing
- Level mixer box
- Mix time after the last added ingredient
- Loading position on the mixer box
- Load size
- Hay quality and processing
- Ingredient loading sequence
- Liquid distribution
- Auger speed
- Forage restrictor settings.

Order of ingredients

A general rule of thumb for loading order is to go long and dry first and short and wet at the end. The high and long fibre materials such as hay can go first so that the blades can shred and cut the plant stems. Depending upon the brand and type of the mixer wagon, the manufacturer will recommend the most desirable order of ingredients in the mixed ration.

Low density ingredients with long particle length such as hay should be added first so that the knives on the mixer can reduce the length of the plant stems. The hay can be followed by grain, protein concentrates and premixes, followed then by chopped silages and finally water or molasses can be added to make the mix more adhesive and try to achieve for a dry matter content of about 50% +/- 5% as at these levels, palatability and feed intake are optimised (H Archibald, Pers. comm.). Adding water to a dry mixed ration promotes ration adhesiveness and decreases feed sorting, but there is a limit to the amount of water that can be added. Molasses tends to bind smaller particles to larger particles, thereby decreasing sorting, as well as providing "sweetness" to the ration. DeVries and Gill (2011) reported that adding 4% of a molasses-based liquid feed to a ration decreased feed sorting, increased intake, and improved milk yield.

Feed troughs being filled from a paddle mixer

The mixing order of ingredients may affect the consistency of the mixed ration and the variation within each mix. With experience of trial and error together with support from the manufacturer, mixing order may be adjusted with certain ingredients to reduce the variation and improve the consistency of the final mixed ration.

Hygiene

The mixer wagon should only be used for mixing feeds and not for mixing other materials that may contaminate subsequent dairy rations. It is important to regularly clean out mixer wagons to ensure mould and other contaminants do not build up in the machine.

Mixing time

The is an optimal time for the correct processing of forage material and mixing other ingredients into the ration to ensure that mixer wagon does not over-process or under-process the ration. Once all the ingredients have been added to the operating mixer, the final mixing time may only be a several minutes before the mix is fed out. It is important to follow the manufacturer's guidelines and adjust these if necessary, depending upon the ingredients used.

Capacity

It is much more cost effective to mix one large load each day rather than 1½ smaller loads. One mistake often made by farmers is that they do not buy a mixer wagon big enough, so that they have to make multiple trips to feed out. Vertical mixers may be filled up to 90% of the volume of the mixer, whereas horizontal mixers may be filled to about 75% and paddle mixers filled to 70% capacity because of the increased risk of the ration being pushed out of the side of the mixer wagon.

The capacity of a wagon depends upon the bulk density of the individual ingredients. If there is a substantial amount of hay in the ration, the bulk density will be lower and less weight of feed can fit a small amount of hay may have an as fed bulk density of about 400kg/m^3. Thus a 20 cubic metre mixer may be able to hold up to about 8 tonnes of that ration, on an as fed basis. The bulk density of various feed ingredients that may be used in dairy rations is shown by DairyNZ (2020b), but as bulk density varies widely within feed ingredients, it may be prudent to collect some wet density data for your own ingredients.

Match the tractor to the mixer wagon (power, capacity) and ensure that the tractor is large enough to tow a fully laden wagon on slippery and sloping surfaces. In addition, ensure that the laneways can withstand the load and there is sufficient space so that the mixer wagon can safely travel around the feedpad.

Luck and Kammel (2014) conducted a survey of US mixer wagon manufacturers to assess the minimum power requirements of mixers based upon mixing capacity. They found a linear relationship between capacity and minimum HP requirements, the respective equations being:

Capacity (m^3) = 0.181 HP – 2.2 (r^2 = 0.89, n=68),
or alternatively: HP = 5.52 Capacity (m^3) + 12.03

These equations can be useful when pairing a mixer wagon to an existing tractor. For example, if you have an 8 cubic metre mixer wagon, you will need a tractor of about 120 HP.

Technical support

Because mixer wagons are used daily it is critical that they are adequately maintained and if they breakdown, that they can be quickly repaired and back in operation for the next feed out. Mixer wagons are available from a large range of manufacturers and the ability of their retailers and distributors in Australia may vary in terms of their capacity to supply parts, perform repairs, and help maintain wagons.

Location

The mixer wagon will be most efficient if the central mixing area, feed storage and feed out areas are close by, to reduce the time collecting ingredients and travelling to the feedpad and back again.

Grain being augured into a twin tub vertical mixer

Three things to get right when mixing rations for dairy cows (keys to success)

1. Choose the capacity of the mixing equipment carefully.

Preferably you would travel from the feed mixing area to the feedpad the minimum number of times each day to reduce time and labour costs. Often farmers choose a smaller wagon or cart because they are cheaper, but if they must double the trips to and from the feedpad, this will add considerably to the cost of the finished ration, in terms of labour and operating costs. So, if possible, err on the larger size.

Furthermore, the size and capacity of the mixer wagon should be matched to the size or horsepower of the tractor that is to be used, otherwise a larger tractor may be required, particularly for the vertical and horizontal mixers.

2. Develop protocols for mixing that ensure that the mixed ration is consistent from day to day, as well as from cow to cow.

The ration formulation will contain specific amounts of the various ingredients that should meet the nutrient requirements of the cows that will be fed. However, there will be variations in a few parts of the mixing process that may lead to an inconsistent ration for the cows. These include errors include weighing the ingredients, processing some of the higher fibre forages, as well as the actual mixing and feed out process.

A check on the consistency of the ration consumed by the cows would allow the development of protocols for specific types of rations to ensure that the ration that is formulated on paper is the same ration that is offered to each cow. This could involve collecting 6–10 samples of the ration from one mixed batch during feed out, analysing for a marker nutrient and calculating the coefficient of variation (CV).

3. Arrange the efficient location of the storage, mixing and feed out facilities.

Infrastructure will develop as feeding cows becomes more intensive. It is important to consider at an early stage where to locate silos, silage stack, bunkers with respect to the feed out area and the mixing area, so that time and effort in collecting ingredients, mixing them delivering the finished ration to the cows is minimal. In addition, a surface of concrete in the feed storage and mixing area would facilitate easier and quicker collection and delivery of feed.

FEED DELIVERY INFRASTRUCTURE – GENERAL INFORMATION

A diverse range of alternative feed delivery methods and feeding/housing infrastructure are used on Australian dairy farms. Dairy Australia's Feed and Animal Nutrition Survey Report (2019a) of a phone survey of 503 dairy farmers across Australia, found that:

- Nationally, 69% of farms fed out in the paddock, 10% used a gravel feedpad, 14% used a concrete feedpad and 7% used other infrastructure (which presumably includes dairy dry lots, freestalls and compost bedded pack barns.
- Use of permanent feeding infrastructure increased with herd size and was highest in the Western Dairy region (54% of farms) and the Murray Dairy region (41%).
- About half of farms in the Murray Dairy region with permanent feeding infrastructure (20%) had a constructed concrete feedpad.
- More farms in the Murray Dairy region have invested in cooling infrastructure such as sprinklers and fans in the dairy holding yards, and shade structures, particularly over the feedpad, than in most other regions.
- Respondents who said they fed a TMR used many types of feeding infrastructure: feedpads, dairy dry lots, freestalls, compost bedded pack barns.
- 19% of Murray Dairy farms surveyed said that they planned to change their feeding system in the next 5 years. A further 6% were unsure. Nationally, those most likely to plan to change were herds between 501–700 cows.
- Interest in changing to a fully housed system (i.e. a barn) in the next 5 years was greatest in Dairy NSW and the Murray Dairy region.

There is no best (or worst) way to feed cows. Dairy farms are complex, and there are many ways to make a profit (or a loss).

The type of feed delivery infrastructure used on a particular farm, and the way in which it is used, is a personal choice that farmers should not need to justify or defend to others. Many factors influence their choice, including:

- Farm's natural resources: land area, infrastructure, herd (i.e. cow type, breed, size), soil type and fertility, climate, irrigation water, etc.
- Stocking rate
- Personal preferences: focus on growing pasture versus feeding cows, lifestyle/profit, equity levels and comfort with debt, preferences for technology and machinery, etc.
- Degree of between year variability and extremes in climate
- Milk supply company and pricing system
- Labour constraints and employment preferences, and
- Life stage and/or business cycle stage.

The feed delivery infrastructure chosen impacts on:

- Total daily feed intake (and therefore milk yield) a cow is capable of and the efficiency with which she converts feed to milk (FCE)
- How important it is to nutritionally balance the diet
- Level of complexity involved in managing the farm's feeding system, the set of farmer competencies required, risks to be managed, and farmers' needs for training and advisory support (feed purchasing, diet formulation etc.)
- Capacity of farms to manage the risk of ruminal acidosis, mix and deliver more 'complex' diets to cows, and to do so without excessive feed wastage, and
- Capital investment required and cost structure of the farm business.

Main types of feed delivery infrastructure and rationale

Dairy businesses may choose to invest in one of five main types of feed delivery infrastructure:

1. Temporary feed-out area
2. Basic feed-out area
3. Formed earthen feedpad
4. Concrete feedpad
5. Integrated facility for feeding and housing cows, such as a freestall, compost bedded pack barn or dairy dry lot

The rationale for the classification system described in this review is as follows:

- A classification system should be based on a facility's design and its pattern of use. It is de-coupled from the type of ration fed.
- A classification system is best limited to 5 main types of feed delivery infrastructure as more would be difficult for farmers and advisers to grasp.

Table 5 describes the five types of feed delivery infrastructure in detail.

Table 5. Five main types of feed delivery infrastructure

Type	Description	Concerns	Typical patterns of use
Temporary feed-out area	• Area located in a pastured paddock, sacrifice paddock or along a laneway • No prepared surface • Feed on ground, in hay rings or tractor tyres • Can be readily relocated to other sites on the farm • Very basic feed storage facilities and machinery • Use front-end loader (FEL) or silage cart • Capital cost for feed-out facility: <$100/cow	• Risk of herd health problems (mastitis, lameness) if wet conditions and poor drainage • Risk of heat stress if shade not available • Difficulty accessing area with tractor if wet conditions and poor drainage • Pugging • Very high feed wastage • Manure build-up if over-used • Nutrient runoff • Odour, flies	• Feed out hay/silage before/after milkings to sustain cows' daily feed intakes during periods when is limited standing pasture • Hold, feed, and water cows between am and pm milkings on very hot days if tree shade is plentiful • Hold, feed, and water cows during emergency event such as bushfire or flood • *If use for 3-4 hours/day: require >3.5 m^2/cow* • *If use for 8-12 hours/day: require >6 m^2/cow* • *If use for 24 hours/day: require >10 m^2/cow*
Basic feed-out area	• Contains an area with a compacted surface shared by cows and vehicles which may be able to be scraped • Can be relocated to another site on the farm (with effort) if necessary • Low-cost modular concrete troughs or conveyor belting under cable or hot wire +/- loafing areas • Very basic feed storage +/- mixing facilities and machinery, effluent system • Use silage cart or mixer wagon • Capital cost for feed-out facility: $200–300/cow	• Risk of herd health problems (mastitis, lameness) if wet conditions and poor drainage • Risk of heat stress if shade not available • Pugging of loafing area • High feed wastage • Manure build-up/stockpiles contaminated with rubble, making it difficult to spread on paddocks • Nutrient runoff • Odour, flies	• Feed out hay/silage before/after milkings to sustain cows' daily feed intakes during periods when is limited standing pasture • Hold, feed, and water cows between am and pm milkings on very hot days if tree shade is plentiful • Hold, feed, and water cows during emergency event such as bushfire or flood • *If use for 3-4 hours/day: require >3.5 m^2/cow* • *If use for 8-12 hours/day: require >6 m^2/cow* • *If use for 24 hours/day: require >10 m^2/cow*
Formed earthen feedpad	• Formed earthen pad with a compacted surface shared by cows and vehicles and regularly scraped. Fixed structures including purpose-built concrete troughs or nib wall under cable or hot wire +/- narrow cement strip for cows to stand on while eating +/- loafing areas, shade structures • Basic to more developed feed storage and mixing facilities and machinery, effluent system • Use mixer wagon • Capital cost for feed-out facility: $300–500/cow	• Risk of herd health problems (mastitis, lameness) if wet conditions and poor drainage • Risk of heat stress if shade not available • Pugging of loafing area • Moderate feed wastage • Manure build-up/stockpiles contaminated with rubble, making it difficult to spread on paddocks	• Feed out hay/silage before/after milkings to sustain cows' daily feed intakes during periods when is limited standing pasture • Practice 'on-off grazing' of day paddock to protect pastures from pugging damage during prolonged wet weather • Hold, feed, and water cows between am and pm milkings on very hot days • Cool cows on hot days if feedpad is fitted with shade structures and/or sprinklers over feeding table fitted with concrete apron • *If use for 3-4 hours/day: require >3.5 m^2/cow* • *If use for 8-12 hours/day: require >6 m^2/cow* • *If use for 24 hours/day: require >10 m^2/cow*

Type	Description	Concerns	Typical patterns of use
Concrete feedpad (includes dairy dry lots)	• Concrete areas for cows and feed (usually separated) which can be scraped, or flood washed • +/− loafing areas, shade structures, sprinklers and fans for cow cooling • Well-developed feed storage and mixing facilities and machinery, effluent system • Usually use mixer wagon • Capital cost for feed-out facility: $1,000–2,500/cow • When combined with shade structures over large loafing areas, may use facility to hold, feed and water cows for extended periods when there is no standing pasture e.g. summer	• Risk of herd health problems (mastitis, lameness) if wet conditions and poor drainage • Risk of heat stress if shade +/− evaporative cooling not available • Pugging of loafing area • Low-moderate feed wastage • Manure build-up/stockpiles contaminated with rubble, making it difficult to spread on paddocks	• Feed out hay/silage before/after milkings to sustain cows' daily feed intakes during periods when is limited standing pasture • Practice 'on-off grazing' of day paddock to protect pastures from pugging damage during prolonged wet weather • Hold, feed, and water cows between am and pm milkings on very hot days • Cool cows on hot days if feedpad is fitted with shade structures and/or sprinklers over feeding table fitted with concrete apron • *If use for 3-4 hours/day: require >3.5 m^2/cow* • *If use for 8-12 hours/day: require >6 m^2/cow* • *If use for 24 hours/day: require >10 m^2/cow*
Integrated facility for feeding and housing cows **a) Freestall** **b) Compost-bedded pack barn** **c) Dairy dry lot**	• Many fixed structures including shade structures • Well-developed feed storage and mixing facilities and machinery, effluent system +/− sprinklers and fans for cow cooling • Use mixer wagon • Capital cost for feed-out facility: - Freestall: >$4,000/cow - Compost bedded pack barn: $2,500–3,000/cow - Dairy dry lot: $1,000–2,500/cow	**Freestall:** • Cow comfort • Risk of heat stress if ventilation and cooling systems not adequate • Ability of cows to move around barn and access feed and water **Compost bedded pack barn:** • Cow comfort • Risk of heat stress if ventilation and cooling systems not adequate • Ability of cows to move around barn and access feed and water **Dairy dry lot:** • Cow comfort • Risk of heat stress if shade or cooling systems are not adequate • Weather variability and wet conditions	**Freestall or compost-bedded pack barn or dairy dry lots:** • Hold, feed, and water cows permanently with zero grazing

MOVING FROM ONE TYPE OF FEED DELIVERY INFRASTRUCTURE TO THE NEXT

It is common for a farm to set up a basic feed-out area or formed earthen feedpad, and then, over many years, develop it into a fully concreted permanent feedpad (or possibly even into an integrated facility for feeding and housing cows). This is only feasible if the factors in Table 6 are well considered at the outset. Otherwise, down the track, a new permanent feedpad may need to be constructed at another site on the farm (with many costs being incurred again) and another use found for the old feedpad (e.g. as a calving pad).

Table 6. Factors to consider when moving from one type of feed delivery infrastructure to the next

Factor	
Area	Will the feedpad be large enough to cater for increased cow numbers and how long you intend cows to stay on the feedpad per day?
Site on farm	Consider weather and wind, proximity to the dairy, feed storage and mixing facilities, water points, drains, effluent ponds. Think about vehicle access, distance from boundaries and easements etc.
Orientation	Is it possible that the feedpad may evolve into a permanent, concrete-surfaced feedpad with a roof? If so, consider an east-west orientation.
Topography, soil type and slope	Consider the natural slope and drainage of the proposed site. What will happen to storm water? Will you need to undertake earthworks? Soil investigations and permeability tests establish load tolerance and likelihood of pad surface cracks, nutrient leaching, and seepage into effluent storage.
Impact on ground and surface water	Consider how siting and effluent runoff management will impact ground and surface water. Remember, runoff containing effluent must not leave the boundary of your property.
Odour, dust, noise	Cow numbers, climate, type of feed and feedpad management all affect feedpad odour. What buffer distance is planned? Fine particle dust can be managed by good laneway design and regular management. Buffer zones help reduce noise too – very important if you have neighbours close by.
Vehicle access to feedpad	Vehicles require a minimum of 3.7m for easy access – 4m for all weather access. Have you allocated enough room for the distribution of feed as well as access for cleaning? Large trucks need high clearance.
Cow access to dairy, loafing pad, feed areas	Routes for laneways should permit easy cow flow and allow for herd expansion.
Stock water	Stock need access to water close to where they will be feeding. You may need water for cleaning the feedpad. How will water be delivered to the site? If collecting off roofs, how will rainwater be diverted and stored?
Drainage	Effective drainage is important for all weather access. Can your proposed feedpad handle a flood or one-in-20-year-24-hour storm event? You may need diversion banks and catch drains to carry storm runoff and effluent.
Power	Will you need access to power at the feedpad site – now and in the future?

How one farm's feedpad evolved through 3 stages of development over 15 years

Feed delivery infrastructure for basic feed-out areas, formed earthen feedpads, concrete feedpads and integrated facilities for feeding and housing cows all enable mixed ration feeding systems to be used. These have advantages and disadvantages (Table 7).

Table 7. Mixed ration feeding systems – advantages and disadvantages

Advantages	• More resilient in the face of drier, hotter weather conditions and extreme weather events, greater fluctuations in home-grown forage availability and quality due to greater climate variability, and greater volatility in milk, water, grain and fodder markets • Can further intensify their operation to increase productivity and remain profitable (increasing stocking rate and feeding more supplementary feeds per cow) • Increase flexibility, to access cost-effective by-products and cope with increased climate and market volatility • Can feed cows higher levels of grain/concentrates with less ruminal acidosis and better feed efficiency than possible using bail feeding in the milking shed • Can better control diets and reduce feed wastage associated with feeding out hay, silage and other supplements • Can better control monthly milk flows to suit their processor's requirements and payment scheme (particularly if supplying the domestic liquid milk market)
Disadvantages	• Increase complexity – diets, pasture and feeding management • More time pressures on staff and cows • Increase business overheads - finance and capital costs for new facilities and equipment • An increase in the cost structure of the farm business which necessitates achievement of higher levels of feed efficiency to remain viable • Fixed structures which cannot be moved or sold • Increased risk of cow health problems such as lameness and mastitis if not managed well • A need to manage manure and effluent well and avoid image and odour problems • Changes required in thinking re. feeding cows and in daily work routines

Before committing to a specific type of feed delivery infrastructure, you need to consider these farm management questions:

- How will pasture management be adjusted to maximise efficiency?
- How will a feedpad impact the farm's profitability?
- What will the feedpad be used for?
- How will animal health and welfare on the feedpad be managed?
- How will the proposed system be operated long term, for example feed management?
- Will a change in system align with goals for the farm?
- Will the farm change to a higher input feeding system?
- Does the farm have sufficient staff to run a supplementary feed system?
- How will the increased effluent and stormwater generated from the pad be managed?

A feeding facility which enables mixed rations to be fed and perhaps also enables cows to be sheltered or housed for varying periods of time (from a few hours a day to a few days at a time to permanently) invariably involves:

- Increased capital
- A changed operating environment with increased operating costs
- Increased complexity, with impacts on labour and time management, and skills required, and
- A change in risk profile for the farm business

Future designs of permanent infrastructure for feeding and housing cows

The main factors shaping future designs for feeding and housing cows are:

- Animal welfare issues, especially less lameness and fewer hock lesions, and more natural behaviour
- Less emissions of ammonia and greenhouse gases
- Reuse of waste products
- Climate control
- Aesthetics of the building in the landscape
- Increased capital efficiency, and
- Increased manure quality.

(Galama et al.*, 2020)*

Additional factors shaping future design to consider include:

- Farm production, larger higher production animals – US freestall designs and cubicle spacing is increasing
- Increased technologies (e.g. cattle monitoring, manure systems with advanced solid separation and anaerobic digestion), and
- Incorporation of robotic milking systems into housed complexes.

(Scott McDonald, Pers. Comm.)

FEED DELIVERY INFRASTRUCTURE – BENEFITS

THROUGH USE OF FEED DELIVERY INFRASTRUCTURE, IT IS POSSIBLE TO ACHIEVE:

- More milk/cow/day from:
  a) increased rumen stability and daily feed intake
  b) reduced walking distance per day, and
  c) Reduced heat stress
- Higher feed efficiency and reduced feed costs from:
  a) reduced feed wastage, and
  b) reduced pugging damage to soil in wet weather

More milk/cow/day from:

a) Increased rumen stability and feed intake

Milk yield increases seen from progressing from a system where grain and concentrates are fed in the bail and conserved forage in the paddock to a PMR system where all the forage and concentrates are included in the one ration and delivered on a feedpad are at least 3.5kg/day. Milk yield increases by progressing from a feedpad to a TMR housed system with no access to pasture may be in excess of an additional 6.0kg/day. These increases are achieved due to improved rumen stability, higher daily feed intakes and improved feed conversion efficiency.

Kolver and Muller (1998) were one of the first to quantify the difference in production of dairy cows fed either only high-quality pasture or a nutritionally balanced TMR. The increase in milk yield from 29.6–44.1kg/day was due largely to the increase in DMI from 19.0–23.4kg/day.

Bargo *et al.* (2002) demonstrated that feeding a TMR maximised DMI and milk production. They found that the dry matter intake of cows receiving pasture and up to 10kg/day concentrate in the bail consumed 21.6kg/day comprising 12.9kg DM pasture and 8.7kg DM concentrate, while TMR cows consumed 26.7kg DM/day. Cows on an intermediate treatment of grazing during the day, and then housed and fed a mixed ration overnight consumed a total of 25.2kg/day comprising 2.2kg DM concentrate, 7.5kg DM pasture and 15.5kg DM/day of the mixed ration. The respective milk yields were 28.5kg/day for pasture plus concentrate in the bail, 38.1kg/day for the TMR cows and 32.0kg/day for the intermediate system.

The research group at Ellinbank confirmed greater dry matter intakes were associated with a mixed ration being offered to dairy cows, in addition to grazing on pasture. At the higher daily supplement intakes of about 15.0kg DM total supplement, cows that were provided with their nutrients in a mixed ration form produced about 2.0kg ECM/day more than cows feed the same concentrate in the bail and silage in the paddock (Auldist *et al.*, 2013). In addition, the replacement of part of the wheat with canola meal in the mixed ration improved pasture intake and consequently, ECM milk yield by up to 5kg/day.

The results of a case study of dairy farmers progressing from a system that involved grazed pasture, conserved forage fed with a mixer wagon under a hot wire and grain mix in the dairy, to grazed pasture and forage and grain mix from the mixer wagon fed to cows on a feedpad, have been described by Dairy Australia (2020). In this case study, milk yield increased by 3.5kg/day, which is similar to that observed by Bargo *et al.* (2002).

b) Reduced walking distance per day

Feed delivery infrastructure may also increase milk yield by reducing the amount of energy expended in activity if it enables cows' walking distances to be reduced. On relatively flat terrain as in the Murray Dairy region, each kilometre walked requires a conservative 2 MJ metabolisable energy (ME). Given that each litre of milk produced requires about 5.0 MJ ME, the milk yield loss for every km walked is approximately 0.4 litres.

Janna Heard used the equations from the Standing Committee on Agriculture (1991) to calculate the energy cost of walking from the paddock to the dairy (Heard *et al.*, 2004). Using the Standing Committee on Agriculture equations, Heard and co-workers calculated that the energy used in walking 1 km along the horizontal was 2.6 MJ/kg bodyweight, which is about 1.6 MJ for a 600kg cow. Assuming the efficiency of converting energy from feed into milk is 75% another 2.1 MJ ME is required for every km walked. Assuming 5.0 MJ ME required per litre of milk (Moe & Tyrell, 1975), this equates to 0.42kg milk/km walked on predominantly flat terrain.

Moran (2005) estimated that on flat terrain an additional 1 MJ ME will be required to provide the energy to walk to and from the dairy for every km covered. In hilly country this energy requirement increases up to 5 MJ ME/km. Assuming about 4.5 MJ ME are required to produce a litre of milk (Moran, 2005), the estimated loss in milk yield/km walked would be about 0.22kg/km on relatively flat terrain, but over 1kg/km travelled in hilly terrain. Later, Islam *et al.* (2015) provided an intermediate value when they estimated that milk yield decreased by 0.61kg for every 1 km increase in total walking distance between the dairy and paddock.

c) Reduced heat stress

> Modifications to the infrastructure involved in housing cows, even for relatively short periods of time during summer, can have a marked effect on cow comfort and productivity. Physical modification has been the primary way of reducing these adverse effects of hot weather conditions. The use of shade and various forms of cooling that may include sprinklers, fans and ventilated buildings can been used to reduce heat stress exposure.

When cows are suffering heat stress, their maintenance energy requirement increases 20–30% due to efforts to defend their core body temperature to ensure it stays within the optimal range through panting. In addition, during hot weather, dry matter intake decreases. NRC (1981) estimated that dry matter intake can drop by about 8% as temperature increases from the thermoneutral level of about 20-35°C. Thus, the energy status of the cow receives a double hit, greater energy costs trying to maintain a stable internal body temperature as well as the lower energy intake. It is not surprising that milk production decreases. Again, NRC (1981) estimated that milk yield drops by over 30% when the temperature increases from 20–35°C. At these higher temperatures, dairy cows may also be more prone to ruminal acidosis and less able to digest and absorb nutrients.

The susceptibility of cows to heat stress is dependent on farm location, breed, the herd's age profile and level of milk production.

The best single descriptor of heat stress is the Temperature Humidity Index (THI), because this combines temperature and relative humidity into a single comfort index. The higher the index, the greater the discomfort, and this occurs at lower temperatures for higher humidity's. Many of the experiments that have examined the effect of heat stress have used maximum daily THI as the key measure of heat stress.

Although feed management may help in controlling the adverse effects of heat stress on intake and milk yield, physical modification of the environment has been the primary way of reducing these adverse effects of hot weather conditions. Shade and various forms of cooling that may include sprinklers, fans and ventilated buildings can be used to reduce heat stress exposure. Use of sprinklers and fans helps cows offload heat through evaporative cooling. These measures will decrease respiration rate and subsequently increase dry matter intake and milk yield. Provision of shade can lessen the intensity of the heat load of cows each day.

There has been little quantitative information on the impact of heat stress on dairy herd milk production in Australia. In their study of effectiveness of adaptations to heat stress to maintain dairy productivity in the Murray Dairy region Nidumolu *et al.* (2010) calculated estimates using conversion factors based on literature and expert knowledge for cows with different susceptibility to heat stress. They examined low susceptibility cows (i.e. a Brown Swiss Jersey producing less than 5,500 litres or milk per year), moderately susceptible cows (i.e. other European breeds or cross breeds producing 5,500–8,000 litres of milk per year) and highly susceptible cows (i.e. Large Holstein-Friesian producing more than 8,000 litres of milk per year) (Little & Campbell, 2008). In all three cases milk production losses were assumed to occur when daily THI values exceeded 75. When THI exceeded this threshold the amount of milk lost in litres per cow per day was calculated by subtracting 75 from the daily THI value and multiplying this difference by a scaling factor.

For the cows with low susceptibility to heat stress a scaling factor of 0.6 was used. For moderately susceptible cows a scaling factor of 0.8 was used and for highly susceptible cows a scaling factor of 1 was used. Maps of the Murray Dairy region were generated to show the impact of THI on milk production (litres/cow/year) using climate data for 1971–2000 as base years (Figure 2). Additional impacts of THI on milk production over and above those for the base years due to climate change by 2025 and 2050 were also projected using a climate model with 3 alterative emission scenarios. Figures 3a and 3b show impacts based on the most pessimistic emission scenario 'A1F1', which is how actual emissions are tracking.

Figure 2. Impact of THI on milk production for 'low susceptibility', 'moderate susceptibility' and 'high susceptibility herds in Murray region, based on climate data for 1971–2000

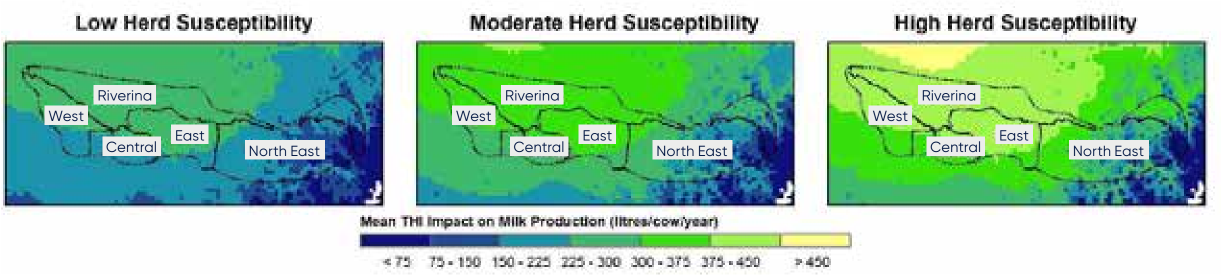


Figure 3a. Further changes in milk production for 'low susceptibility', 'moderate susceptibility' and 'high susceptibility herds for 2025 (based on A1FI emission scenario)

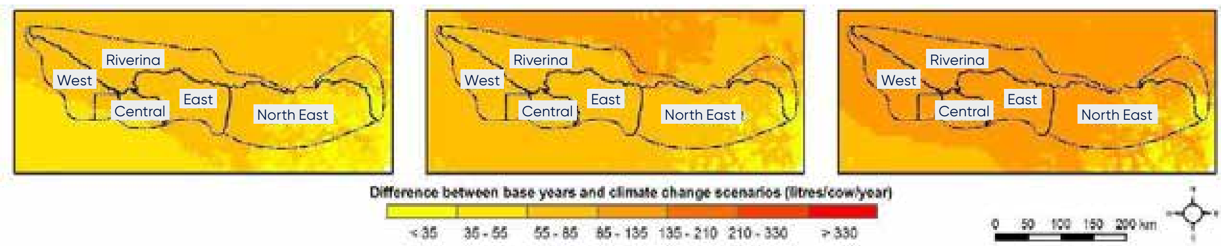
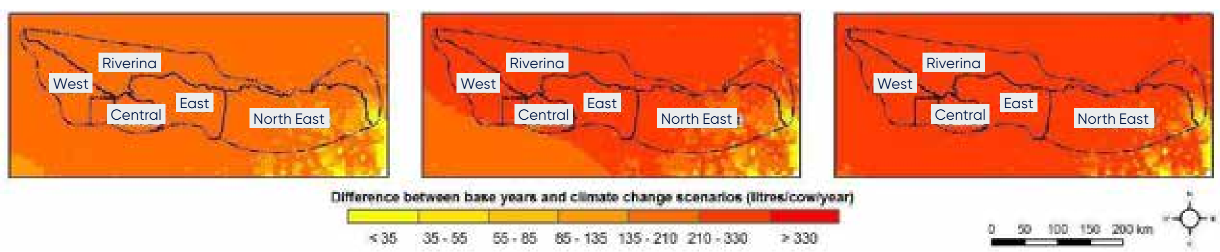


Figure 3b. Further changes in milk production for 'low susceptibility', 'moderate susceptibility' and 'high susceptibility herds for 2050 (based on A1FI emission scenario)



Providing shade and cooling to dairy cows limits their accumulation of heat load during long periods of hot days and warm nights and during heat wave events, thereby avoiding dramatic falls in daily feed intake, milk yield, protein test and cow health problems. There has also been little quantitative information on what are the benefits of providing shade and cooling to dairy cows that has been published in Australia. A few studies conducted in Australia confirm the beneficial effects of shade and cooling.

For example:

- The results of trials in Queensland have shown that 30 minutes of wetting cows with sprinklers at the dairy can produce an extra 1 litre of milk/cow/day, while 60 minutes has produced an extra 1.5 litres of milk/cow/day in hot weather (QDAF, 2013).
- Shade can reduce a cow's heat load from the environment by up to 50% (QDAF, 2013).
- Wildridge *et al.* (2017) found that providing shade in the yard for the short period before milking during summer in a pasture-based system can alleviate heat stress by decreasing respiration rate and improving milk yield by 0.5kg/day. Obviously providing shade for longer times in the more intensively housed dairy systems will have an even more beneficial effect on cow comfort and productivity.

Cost:benefit estimations provided towards the end of this section, assume that the provision of cooling infrastructure in paddocks and laneways, and on dairy holding yards and feedpads will reduce losses in milk production per year due to heat stress by differing percentages, as proposed in Table 8 (Pers. comm. S. Little). Note that the percent reduction in milk production losses per year due to heat stress in Table 8 are additive. For example, if a herd's annual milk yield drops by 350kg/cow due to heat stress, the addition of sprinklers and fans used with a shade structure over a feedpad to ensure good evaporative cooling, even on days with little/no wind, will reduce this annual milk yield loss by 50% to only 175kg/cow, or an improvement of 175kg milk/cow.

Table 8. Estimated reductions in milk production losses per year due to cooling infrastructure

Cooling infrastructure item	Estimated percent reduction in milk production losses per year due to heat stress
Trees provide every cow with 4m² shade at midday in paddocks on all warm/hot days.	45%
Additional water troughs enable cows to access cool drinking water in all paddocks and main laneways.	5%
Sprinklers in dairy holding yard used effectively on all cows before morning and afternoon milkings on all warm/hot days.	15%
Structure over dairy holding yard provides cows shade while waiting to be milked.	10%
Structure over dairy holding yard provides cows shade for longer periods before afternoon milking on warm/hot days	15-20%
Fans used with sprinklers in holding yard to ensure good evaporative cooling, even on days with little/no wind.	5%
Trees in a sacrifice paddock provide cows 4m² shade each at midday on all warm/hot days	30%
Structure over feedpad (shade cloth or solid roof) provides cows 4m² shade each at midday on all warm/hot days	35-45%
Sprinklers and fans used with shade structure over feedpad to ensure good evaporative cooling, even on days with little/no wind.	10–15%
Additional water troughs enable cows to access cool drinking water within 15m of feed while on feedpad	5%

There have been many studies in the US that have studied the effects of environmental mitigation strategies on the physiology and productivity of dairy cows. For example, results of these types of studies have provided good quantitative information on the effects of sprinkler attributes such as flow rate, frequency of spray application and amount of water delivered on productivity and cow comfort.

In addition, there have been several extensive reviews on environmental strategies for alleviating heat stress of dairy cows. For example, Fournel *et al.* (2017) recently reviewed the effects of cooling in humid climates through shade, fans, and sprinklers on thermal stress and consequently on cow health and productivity.

Much of this information is transferable to Australian dairy farms, and good practical information and tools for managing heat stress in dairy cows have been provided by Dairy Australia (2019b) in their Cool Cows publication and website.

Higher feed efficiency and reduced feed costs from:

a) Reduced feed wastage

Feed wastage during feed-out can be significant and will vary depending upon the type of feed delivery infrastructure that is in place. Based upon feed wastage values measured on commercial dairy farms, reliable values for feed wastage are ascribed for each of the 5 feed delivery infrastructure systems that may be used on Australian dairy farms.

Feed wastage is reduced as one progresses to more developed feed delivery infrastructure. Although feed wastage can be significant and in some cases approach well over 20%, the amount of feed losses during feed-out has not been well documented. About 10 years ago the amount of feed wastage was measured in a range of different feed-out methods on Australian dairy farms from feeding on pastures in the paddock through to a TMR type system (Dairy Australia, 2009). Six feed-out methods were assessed, and the average estimated feed wastage ranged from 8.8% (range 0.9–22.3%) for a temporary feed-out area to 1.8% (range 0–5.6%) in a permanent and well developed feedpad (Dairy Australia, 2009).

Based upon these observed feed wastage values measured in commercial dairy farms, the following values for feed wastage may be reliably used when comparing different feed delivery systems (Table 9). Applying these feed wastage values effectively reduces the cost per tonne of feeds fed out.

Table 9. Feed wastage rates for different feed delivery systems (dry conditions)

Feed delivery infrastructure	Feed wastage
Temporary feed-out area	Range: 5-35% Typical: 25%
Basic feed-out area	Range: 5-20% Typical: 10%
Formed earthen feedpad	Range: 2-10% Typical: 5%
Concrete feedpad	Range: 0-5% Typical: 3%
Integrated facility for feeding and housing cows	Range: 0-5% Typical: 3%

A key finding of the feed wastage study (Dairy Australia, 2009) was that there was substantial variation in the amount of feed refusal and wastage between and within feed-out methods on Australian dairy farms. With all feed-out methods, some farmers achieved very low wastage. These variations may reflect variations in farm management with a particular feed-out method e.g. feed-out procedure, feed bunk management, forage quality, operator skill etc. There was no significant association between the amount of feed offered per cow and amount of feed wastage per cow across all feed-out methods.

Unlike temporary and basic feed-out infrastructure, formed earthen feedpads, concrete feedpads and integrated facilities for feeding and housing cows enable feed not consumed by cows after a certain period following feed-out (termed 'refusals') to be collected before it is contaminated and spoiled. It can then be fed to other cattle on the farm such as dry cows.

Three critical factors help to minimise waste during feed-out on feedpads and therefore help to optimise the return on investment in the feedpad. These include:

a. feedpad design and construction

b. feed ingredients/rations offered, and

c. feeding management.

These are discussed later in this review, in the section 'Keys to Success'.

There are emerging discussions from farms transitioning to permanent feeding infrastructure that supplementary feed wastage is significantly declining. However, on the other hand, pasture-grazing wastage is increasing with herds returning to paddocks already full of the feed.

b) Reduced pugging damage

> Poorly drained soils are prone to treading or "pugging" damage and may occur on grazed pastures during the wetter months of the year. The results of research studies conducted in Australia and New Zealand have shown that if pugging in winter is significant, pasture yield in the following spring and pasture utilisation may be reduced by about 40%. One simple method of reducing pugging is removing the cows from pasture and housing them for various lengths of time on a feedpad. A feedpad with a large loafing area enables 'on-off' grazing management to be used, which reduces pasture wastage by cows and enhances re-growth. Under extremely wet conditions, a feedpad with an adequate area and surface may enable cows to be held on it continuously for several consecutive days.

Pugging is a form of compaction and is the term used for when cows damage both the soil structure and the pasture. Pugging seals the soil surface and exacerbates waterlogging of the topsoil by impeding infiltration and providing surface indentations for water storage, thereby reducing the efficiency of surface drainage from the paddock to many soil types in wet weather.

As pasture is the cheapest source of feed for most farmers it is important to minimise the damage that cows can do to pastures through pugging up the paddocks. A grazing trial conducted in south-western Victoria found that medium to heavy pugging in winter reduced pasture yield in the following spring by 40–42%, pasture utilisation by 34–40% and perennial ryegrass tiller density by 39–54% (Nie *et al.*, 2000). DairyNZ research has shown similar results in that pasture seriously pugged in Spring will likely produce about 40% less DM than undamaged pasture through the following season, although pasture yield reductions of up to 80% have been recorded (DairyNZ, 2020a).

Cost:benefit calculations provided towards the end of this section, assume that pugging causes a 30% reduction in pasture utilisation rate. One simple method of reducing pugging is removing the cows from pasture and housing them for various lengths of time on a feedpad. A feedpad with a large loafing area enables 'on-off' grazing management to be used, which reduces pasture wastage by cows and enhances re-growth.

Cost: benefit estimations (typical examples)

More milk/cow/day from:

a) Increased rumen stability and feed intake

If use of a feedpad enabled an increase in feed intake of 3kg DM/day at a cost of $350/t DM, and this resulted in an increase in milk yield of 3.5kg/day at a milk price of $0.40/kg, this would give a milk income minus feed cost (MOFC) of $0.35/cow/day. For a herd of 300 cows, this equates to $105 extra MOFC per day or nearly $40,000 extra MOFC per year.

b) Reduced walking distance

If a typical 300 cow farm in the Murray Dairy region was to reduce the walking distance of each cow by 4 kilometres per day using a permanent feedpad near the dairy which meant that cows only had to walk to/from a paddock to graze once a day (instead of twice), this would equate to 1,200 km saved per day for the herd. Assuming, on an energy basis, 0.5 litres milk per km walked on flat terrain, this would equate to 600 litres extra milk per day.

At a milk price of $0.40/litre, this would equate to extra income per day of $240. If this pattern of use continued for 60 days over summer, when pasture was limited, this would equate to extra income of $14,400 during this period.

c) Reduced heat stress

The inherent level of susceptibility to heat stress of a herd of 300 moderate sized Holstein-Friesian cows on a farm at Tatura in the Murray dairy region producing 6,500kg milk/year is moderate. Nidumolu *et al.* (2010) estimated that this herd would incur an average annual milk production loss due to heat stress of 355kg/cow based on expected climatic conditions. At an average milk price of $0.40/kg, this would equate to a cost of approx. $142/cow/year or $42,600 for the herd per year.

If an investment of $70,000 was made in a shade cloth structure over an existing feedpad and installation of sprinklers, and this feeding and cooling facility was used effectively, this would reduce this annual milk production loss by 45% (35% for shade cloth structure plus 10% for sprinklers, as per Table 8) i.e. 160kg/cow, to 195kg/cow.

At an average milk price of $0.40/kg, this would equate to an annual benefit of approx. $19,200 per year due to a reduction in lost milk production. The represents a return on investment of 27% per annum, and a payback period of less than four years.

Note:

- Losses in milk income due to effect of heat stress on milk yield can often be doubled when you also account for losses from low milk protein and fat tests, reduced in-calf rates, more clinical mastitis cases and other cow health problems.
- Payback period assumes no debt funding. If debt funding is required, payback period will be longer.

Higher feed efficiency and reduced feed costs from:

a) Reduced feed wastage

If a typical 300 cow farm was feeding out 1,500kg DM of hay/silage per cow per year valued at $300/t DM in hay rings and wasting 20% using this method, this equates to a loss of $90/cow/year or $27,000 for the herd per year. If use of a well designed and constructed permanent feedpad enabled feed wastage to be reduced by 15% to 5%, this would represent a saving of $68/cow/year or $20,250 for the herd per year.

b) Reduced pugging damage to soils

If a paddock from which 9 t DM/ha/year would have been utilised was subjected to very wet weather, and a 30% reduction in utilisation rate was prevented through practising 'on-off grazing' using a feedpad, this would equate to a saving of 2,700kg DM/ha. Assuming a pasture growing cost of $0.15/kg DM, this would equate to a saving of $405/ha/year.

Additional benefits captured by industry:

The benefits outlined earlier focus on cow production, feed, and pastures. As farms transition to TMR feeding and housed systems farmers are experiencing additional productivity gains. While the gains may be small in isolation, the cumulative effect may be greater than the sum of the parts. These include:

- Increased labour efficiencies
- Potentially greater ability to retain labour as some staff favour indoor environment compared to working outdoors in variable weather
- Optimal milking plant performance
- Improved conception and animal health detection with closer monitoring
- TMR/PMR systems help create an environment for high genetic cows the reach their genetic potential
- Improved farm WUE on higher yielding fodder crops under cut and carry as opposed to pasture-based systems
- Reduced laneway maintenance costs, particularly with a winter stand-off
- Decreased costs to renovate and recover pastures, pugging and compaction
- Reduced fertiliser costs associated with improved effluent and manure distribution
- Improved machinery efficiencies
- Opportunity to attract premium milk pricing
- New income opportunity to sell solids, bedding compost and energy anaerobic digestion, and
- Improved fodder production with less compaction.

The dairy transition economic and risk project being conducted by Agriculture Victoria, DPI NSW and Dairy Australia will attempt to identify and where possible estimate, the productivity gains farmers are experiencing from their change to a TMR feeding system. While the gains may be small in isolation, the cumulative effect may be greater than the sum of the parts.

THE FIVE TYPES OF FEED DELIVERY INFRASTRUCTURE

1. TEMPORARY FEED-OUT AREA

Description

Area located in a pastured or bare cropping paddock, a designated sacrifice paddock or along a laneway without a prepared surface where feed is delivered to cows either on the ground, in hay rings or in tractor tyres. Can be readily relocated to other sites on the farm.

Generic types

Grazing or cropping paddock, sacrifice paddock, laneway

Suitable for use with

Low bail feeding system	Moderate-high bail feeding system	PMR feeding system	Hybrid feeding system (if large loafing areas)	TMR feeding system

Purposes

- Fill seasonal pasture gaps
- Increase herd feed intake and milk production without increasing farm size
- Better manage pasture residual mass on each rotation (prevent over-grazing)

Characteristics

Frequency of use	Before/after milkings to sustain cows' daily feed intakes during periods which pasture is limited or during an emergency event (i.e. fire/flood)
Typical hours per day	3-4 hours per day
Surface	Pasture, bare earth, or roadway
Feeding table	On the ground, in hay rings or tractor tyres
Loafing areas	Nil
Shade/cooling	Nearby trees if available
Effluent management	Dry scraping manure and stockpiling
Feed prep. and delivery	Front-end loader, side winder round bale feeder, silage cart or mixer wagon
Feed storage	Silage pits/bunkers and hay sheds +/- commodity bunkers if using mixer wagon to prepare PMR

	Very low	Low	Moderate	High	Very high
Time and effort to set up	✓				
Weather durability		✓			
Permanency		✓			
Capital cost	✓				
Feed wastage					✓
Potential production benefits	✓				
Improved farm efficiencies		✓			

Costs

Capital cost: <$100/cow (not including silage cart, mixer wagon and feed storage and mixing facilities)

Operating costs: Very low

Lifespan

Depends on how firm the area's surface is and how quickly it deteriorates with use by cow and vehicles in dry and particularly wet conditions.

Examples of temporary feed-out areas

Hay/silage fed out under wire along a laneway and along an irrigation check bank

Hay fed out in rings in sacrifice paddock. Note high level of wastage

Old tractor tyres cut in half and used as feeders on a sacrifice paddock

Hay fed out in a line on a grazing paddock

Skill level/training required to operate

- Low if feeding out forage mixes with a silage cart
- Need to ensure silage or hay is placed correctly on the feed-out area and not wasted
- Moderate if preparing and feeding out a mixed ration

Wastage after feeding out lucerne and cereal hay on this grazing paddock was measured at 18%

Possible benefits

Benefit	Comment
More milk/cow/day through: • Improved rumen stability • Higher feed intake • +/- less walking • +/- reduced heat stress	• Temporary feed-out area may be used to deliver hay, silage or a mixed ration to cows. • It may increase milk production by increasing total daily feed intake. • If the area is located near the dairy and is large enough to be used to feed cows and enable them to rest between milking instead of a day or night paddock, it may help to reduce energy spent walking. • If cows are fed a high level of concentrates in the bail at milking, using the feed-out area immediately before or after milking it may help to maintain a more stable rumen. • If herd is highly susceptible to heat stress due to farm location, breed, the herd's age profile and level of milk production, and the feed-out area provides plentiful tree shade, then its use may help to reduce heat stress on cows in hot weather, resulting in more milk.
Higher feed efficiency and reduced feed costs through: • reduced feed wastage • reduced pugging damage	• A sacrifice paddock may be used to some extent to reduce pugging damage in grazing paddocks in wet conditions. However, feed wastage will be high, and the area may become unusable in a short period of time, requiring another site on the farm to be set up as a temporary feed-out area.

Limitations/concerns

Limitation	Comment
Maintenance	• Very difficult to maintain feed-out area as it does not have a prepared, well drained surface and effluent cannot be captured. It will therefore need relocating regularly to maintain an adequate level of hygiene for cows.
Feed wastage	• Feed wastage is high (5–25% on a grazing paddock under dry conditions, 5–35% in a sacrifice paddock, fed on bare ground, in ring feeders, or under a fence line). • Feed refusals cannot be collected and fed to other cattle. They are wasted. • Feed wastage can be very high in wet conditions.
Cow health risks	• Environmental mastitis and lameness if feed-out area deteriorates. • Increased spread of disease if cows spend time in a confined area.
Environment issues	• Runoff of effluent must be managed to ensure no nutrients are reaching waterways. • Odour can be an issue particularly when there is non-agricultural land use close by. • Dust can be an issue to workers and neighbours and poses a respiratory or allergy risk. • Noise can potentially cause nuisance to neighbours with regular use of trucks, tractors, and machinery.
Safety	• A feed-out area in which cows and vehicles share the same area is never ideal. • In wet weather, the area may become slippery for cows and vehicles.

2. BASIC FEED-OUT AREA

Description

Contains an area with a permanent compacted earthen feeding infrastructure shared by cows and vehicles which may be able to be dry scraped. Can be relocated to another site on the farm (with effort) if necessary.

Generic types

Compacted earthen feed-out area +/- loafing areas

Suitable for use with

Low bail feeding system	**Moderate-high bail feeding system**	**PMR feeding system**	**Hybrid feeding system** (if large loafing areas)	TMR feeding system

Purposes

- Fill seasonal pasture gaps
- Increase herd feed intake and milk production without increasing farm size
- Better manage climate and market volatility
- Better manage pasture residual mass on each rotation (prevent over-grazing)
- Help protect pastures from pugging in wet weather

Characteristics

Frequency of use	Before/after milkings to sustain cows' daily feed intakes during periods which pasture is limited or during an emergency event (i.e. fire/flood)
Typical hours per day	3-4 hours per day
Surface	Compacted earth, sand/clay mix, crushed/decomposed rock, or natural gravel, with or without geosynthetic sheets
Feeding table	Low-cost, modular concrete troughs or conveyor belting under cable or hot wire
Loafing areas	Size will depend on time intend to keep cows off pasture
Shade/cooling	Nearby trees if available
Effluent management	Dry scraping off feedpad regularly, may require site drainage to control nutrient runoff
Feed prep. and delivery	Front-end loader, side winder round bale feeder, silage cart or mixer wagon
Feed storage	Silage pits/bunkers and hay sheds +/- commodity bunkers if using mixer wagon to prepare PMR

	Very low	Low	Moderate	High	Very high
Time and effort to set up		✓			
Weather durability			✓		
Permanency			✓		
Capital cost		✓			
Feed wastage				✓	
Potential production benefits		✓			
Improved farm efficiencies		✓			

Examples of basic feed-out areas


Large square hay bales fed out with front-end loader into low-cost troughs with steel frame and conveyor belting


Silage fed out with silage cart into low-cost troughs ('Waste-Not Fair Go Dairy Feedpad' panels)


PMR fed out with mixer wagon into very low-cost troughs made of conveyer belting with/without timber sides


PMR fed out with mixer wagon into 2 types of modular concrete troughs (3-sided profile and 'J' profile). On trough with J profile, note strip of timber added to low side

Costs

Capital cost: $200–300/cow (not including silage cart, mixer wagon and feed storage and mixing facilities)

Operating costs: Low (may be increased if manure needs to be stockpiled and spread)

Lifespan

Depends on how well the area's compacted surface (rock or clay) stands up to use. Surfaces of suitable rock base material or clay compacted with a heavy roller and water may last up to 20 years. Poorly prepared areas may only last a few years before requiring re-surfacing. Lifespan depends on:

- How well the area was formed with drainage and the surface compacted when first set up, and
- How intensely the area is used by cows (number x time) and vehicles in dry and particularly wet conditions.

Skill level/training required to operate

- Low if feeding out forage mixes with a silage cart
- Need to ensure silage or hay is placed correctly on the feed-out area and not wasted
- Moderate if preparing and feeding out a mixed ration

Possible benefits

Benefit	Comment
More milk/cow/day through: • Improved rumen stability • Higher feed intake • +/- less walking • +/- reduced heat stress	• Basic feed-out area may be used to deliver hay, silage, or a mixed ration to cows. • It may increase milk production by increasing total daily feed intake. • If the area is located near the dairy and is large enough to be used to feed cows and enable them to rest between milkings instead of a day or night paddock, it may help to reduce energy spent walking. • If cows are fed a high level of concentrates in the bail at milking, using the feed-out area immediately before or after milking it may help to maintain a more stable rumen. • If herd is highly susceptible to heat stress due to farm location, breed, the herd's age profile and level of milk production, and the feed-out area provides plentiful tree shade, then its use may help to reduce heat stress on cows in hot weather, resulting in more milk.
Higher feed efficiency and reduced feed costs through: • reduced feed wastage • reduced pugging damage	• Feed wastage at feed-out may be reduced by up to 15% when conserved forages and mixed rations are fed out on a basic feed-out area rather than in a sacrifice paddock, on bare ground, in hay rings or under a fence line. This effectively reduces the cost per tonne of feeds fed out by up to 15%. • A basic feed-out area may be used to some extent to reduce pugging damage in grazing paddocks in wet conditions if it provides sufficient space to enable 'on-off' grazing management to be used.

Limitations/concerns

Limitation	Comment
Maintenance	• Repairs may be required if surface or feeding table is damaged by cows or vehicles. • Feed-out area's surface may be difficult to regularly dry scrape. • Feed troughs are generally difficult to clean. Spoiled feed may accumulate in bottom of trough, causing odour, reduced feed palatability. Troughs may hold water during rain events.
Feed wastage	• Feed wastage is moderate to high (5–20% under dry conditions). • Feed refusals cannot be collected and fed to other cattle. They are wasted. • Feed wastage can be very high in wet conditions. • Wastage will be increased if troughs used and their height and width are not compatible with front end loader, feed cart or mixer wagon used.
Cow health risks	• Environmental mastitis and lameness if feed-out area deteriorates because it is not well prepared and/or regularly scraped. • Increased spread of disease as cows spend time in a confined area. • Cows may fall into troughs and injure themselves. • Poor trough hygiene may increase mycotoxin risk.
Environment issues	• If gravel is scraped up with manure, it is unsuitable for spreading on pastures, leading to manure build-up/stockpiles. • Runoff of effluent must be managed to ensure no nutrients are reaching waterways. • Odour can be an issue particularly when there is non-agricultural land use close by. • Dust can be an issue to workers and neighbours and poses a respiratory or allergy risk. • Noise can potentially cause nuisance to neighbours with regular use of trucks, tractors, and machinery.
Safety	• A feedpad in which cows and vehicles share the same area is never ideal. • In wet weather, feedpad surface may become slippery for cows and vehicles.

3. FORMED EARTHEN FEEDPAD

Description

Formed earthen pad with a compacted surface shared by cows and vehicles and regularly scraped. Fixed structures including purpose-built concrete troughs or nib wall under cable or hot wire +/- narrow cement strip for cows to stand on while eating +/- loafing areas, shade structures.

Generic types

Compacted earthen feedpad +/- loafing areas +/- shade structures

Suitable for use with

Low bail feeding system	**Moderate-high bail feeding system**	**PMR feeding system**	**Hybrid feeding system** (if large loafing areas)	TMR feeding system

Purposes

- Fill seasonal pasture gaps
- Increase herd feed intake and milk production without increasing farm size
- Better manage climate and market volatility
- Better manage pasture residual mass on each rotation (prevent over-grazing)
- Help protect pastures from pugging in wet weather

Characteristics

Frequency of use	Feed out hay/silage before/after milkings to sustain cows' daily feed intakes during periods which pasture is limited. Practice 'on-off grazing' of day paddocks to protect pastures from pugging damage during prolonged wet weather. Cool cows on hot days if feedpad fitted with shade structures and/or sprinklers
Typical hours per day	3-4 hours per day
Surface	Compacted earth, sand/clay mix, crushed/decomposed rock, or natural gravel, with or without geosynthetic sheets
Feeding table	Purpose-built concrete troughs or nib wall. Feed barrier usually hot wire or cables, but may be post and rail +/- narrow cement strip for cows to stand on while eating
Loafing areas	Size will depend on time intend to keep cows off pasture
Shade/cooling	Shade cloth or solid roofed structures possible over feeding table and/or loafing areas
Effluent management	Dry scraping off feedpad regularly. Basic to well-developed effluent system
Feed prep. and delivery	Usually a mixer wagon, but may be a side winder round bale feeder or silage cart
Feed storage	Basic to well-developed storage and mixing facilities including silage pits/bunkers, hay sheds +/- commodity bunkers if using mixer wagon to prepare PMR

	Very low	Low	Moderate	High	Very high
Time and effort to set up			✓		
Weather durability			✓	✓	
Permanency				✓	
Capital cost			✓		
Feed wastage			✓		
Potential production benefits			✓		
Improved farm efficiencies			✓		

Costs

Capital cost: $300-500/cow (not including silage cart, mixer wagon and feed storage and mixing facilities)

Operating costs: Low-moderate (may be increased if manure needs to be stockpiled and spread)

Lifespan

Depends on how well the feedpad's compacted surface (rock or clay) and fixed structures stand up to use. Surfaces of suitable rock base material or clay compacted with a heavy roller and water may last up to 20 years. Poorly prepared areas may only last a few years before requiring re-surfacing. Lifespan depends on:

- How well the area was formed with drainage and the surface compacted when first set up, and
- How intensely the area is used by cows (number x time) and vehicles in dry and particularly wet conditions.

Examples of formed earthen feedpad

PMR fed out in two reversed J troughs on an earthen feedpad

Narrow square-profiled trough being overfilled by mixer wagon, resulting in excess

Wider square-profiled trough on earthen pad under solid roof

PMR fed out in one trough on earthen pad. Note vertical bars defining each cow space and frame for shade cloth yet to be installed above feeding table

Skill level/training required to operate

- Moderate if preparing and feeding out a mixed ration
- Low if feeding out forage mixes
- Need to ensure PMR, silage or hay is placed correctly on the feedpad and not wasted

Possible benefits

Benefit	Comment
More milk/cow/day through: • Improved rumen stability • Higher feed intake • +/- less walking • +/- reduced heat stress	• Permanent feedpad may be used to deliver hay, silage, or a mixed ration to cows. • It may increase milk production by increasing total daily feed intake. • If the area is located near the dairy and is large enough to be used to feed cows and enable them to rest between milkings instead of a day or night paddock, it may help to reduce energy spent walking. • If cows are fed a high level of concentrates in the bail at milking, using the feedpad immediately before or after milking it may help to maintain a more stable rumen. • If herd is highly susceptible to heat stress due to farm location, breed, the herd's age profile and level of milk production, installation of solid-roofed or shade cloth shade structures over feeding table and/or loafing areas may result in a saving of 2+ litres milk/day in hot weather.
Higher feed efficiency and reduced feed costs through: • reduced feed wastage • reduced pugging damage	• Feed wastage at feed-out should be reduced to 2-10% when conserved forages and mixed rations are fed out. This compares to wastage of 5-25% on a grazing paddock under dry conditions, 5-35% in a sacrifice paddock, fed on bare ground, in ring feeders, or under a fence line. This effectively reduces the cost per tonne of feeds fed out by up to about 30%. • A feedpad may be used to reduce pugging damage in grazing paddocks in wet conditions if it provides sufficient space to enable 'on-off' grazing management to be used.

Limitations/concerns

Limitation	Comment
Maintenance	• Feedpad surface needs to be regularly dry scraped. • Feed troughs may be difficult to clean. If so, spoiled feed may accumulate in bottom of trough, causing odour, reduced feed palatability. Troughs may hold water during rain events.
Feed wastage	• Feed wastage is moderate (2–10% under dry conditions. Higher under wet conditions). • Feed refusals should be able to be collected and fed to other cattle. • Wastage will be increased if trough height and width is not compatible with FEL, feed cart or mixer wagon used. Other factors related to feedpad design and construction, feed ingredients/rations offered and feeding management may influence % feed wasted.
Cow health risks	• Environmental mastitis and lameness if feedpad is not well designed, constructed and regularly scraped. • Increased spread of disease as cows spend time in a confined area. • Cows may fall into troughs and injure themselves. • Poor trough hygiene may increase mycotoxin risk.
Environment issues	• If gravel is scraped up with manure, it is unsuitable for spreading on pastures. • Runoff of effluent must be managed to ensure no nutrients are reaching waterways. • Odour can be an issue particularly when there is non-agricultural land use close by. • Dust can be an issue to workers and neighbours and poses a respiratory or allergy risk. • Noise can potentially cause nuisance to neighbours with regular use of trucks, tractors, and machinery.
Safety	• A feedpad in which cows and vehicles share the same area is never ideal. • In wet weather, feedpad surface may become slippery for cows and vehicles.

4. CONCRETE FEEDPAD

Description

Concrete areas for cows and feed (usually separated) which can be scraped, or flood washed +/- earthen surfaced loafing areas, shade structures, sprinklers, and fans for cow cooling.

Generic types

Concrete feedpad +/- earthen surfaced loafing areas +/- shade structures

Suitable for use with

Low bail feeding system	**Moderate-high bail feeding system**	**PMR feeding system**	**Hybrid feeding system** (if large loafing areas)	TMR feeding system

Purposes

- Fill seasonal pasture gaps
- Increase herd feed intake and milk production without increasing farm size
- Better manage climate and market volatility
- Better manage pasture residual mass on each rotation (prevent over-grazing)
- Help protect pastures from pugging in wet weather

Characteristics

Frequency of use	Feed out hay/silage before/after milkings to sustain cows' daily feed intakes during periods which pasture is limited. Practice 'on-off grazing' of day paddocks to protect pastures from pugging damage during prolonged wet weather. Cool cows on hot days if feedpad fitted with shade structures and/or sprinklers
Typical hours per day	3-4 hours per day
Surface	Concrete for cows and vehicles. Compacted earth, sand/clay mix, crushed/decomposed rock, or natural gravel for loafing areas
Feeding table	Purpose-built concrete troughs or nib wall. Feed barrier may be cables, post and rail or headlocks
Loafing areas	Size will depend on time intend to keep cows off pasture
Shade/cooling	Shade cloth or solid roofed structures possible over feeding table and/or loafing areas +/- sprinklers and fans
Effluent management	Dry scraping off feedpad regularly, may require site drainage to control nutrient runoff
Feed prep. and delivery	Usually a mixer wagon
Feed storage	Well-developed storage and mixing facilities including silage pits/bunkers, hay sheds and commodity bunkers if using mixer wagon to prepare PMR

	Very low	Low	Moderate	High	Very high
Time and effort to set up				✓	
Weather durability				✓	
Permanency				✓	
Capital cost				✓	
Feed wastage		✓			
Potential production benefits				✓	
Improved farm efficiencies				✓	

Costs

Capital cost: $1,000–2,500/cow (not including silage cart, mixer wagon and feed storage and mixing facilities)

Operating costs: Moderate (may be increased if manure needs to be stockpiled and spread)

Lifespan

If fully concreted, more than 30 years. Depends on how well the facility was designed and constructed.

Skill level/training required to operate

- Moderate if preparing and feeding out a mixed ration
- Need to ensure PMR, silage or hay is placed correctly on the feedpad and not wasted
- Need to push feed up regularly if nib wall

Examples of concrete feedpad

PMR fed out on fully concreted feedpad with nib wall, central feed alley

Cows beginning to push PMR out of reach

Concrete bunkers for storing by-products

Fully concreted feedpad with nib wall, central feed alley, solid roof and flood wash system

Alternative feed barriers: Cables, post and rail, headlocks

Possible benefits

Benefit	Comment
More milk/cow/day through: • Improved rumen stability • Higher feed intake • +/- less walking • +/- reduced heat stress	• Permanent feedpad may be used to deliver hay, silage, or a mixed ration to cows. • It may increase milk production by increasing total daily feed intake. • If the area is located near the dairy and is large enough to be used to feed cows and enable them to rest between milkings instead of a day or night paddock, it may help to reduce energy spent walking. • If cows are fed a high level of concentrates in the bail at milking, using the feedpad immediately before or after milking it may help to maintain a more stable rumen. • If herd is highly susceptible to heat stress due to farm location, breed, the herd's age profile and level of milk production, installation of solid-roofed or shade cloth shade structures over feeding table and/or loafing areas may result in a saving of 2+ L milk/day in hot weather.
Higher feed efficiency and reduced feed costs through: • reduced feed wastage • reduced pugging damage	• Feed wastage at feed-out should be reduced to 0-5% when conserved forages and mixed rations are fed out. This compares to wastage of 5-25% on a grazing paddock under dry conditions, 5-35% in a sacrifice paddock, fed on bare ground, in ring feeders, or under a fence line. This effectively reduces the cost per tonne of feeds fed out by up to about 30%. • A feedpad may be used to reduce pugging damage in grazing paddocks in wet conditions if it provides sufficient space to enable 'on-off' grazing management to be used.

Limitations/concerns

Limitation	Comment
Maintenance	• Feedpad surface needs to be regularly dry scraped or flood washed. • Some feed troughs may be difficult to clean. If so, spoiled feed may accumulate in bottom of trough, causing odour, reduced feed palatability. Troughs may hold water during rain events.
Feed wastage	• Feed wastage is low (0-5% under dry conditions. Higher under wet conditions). • Feed refusals should be able to be collected and fed to other cattle. • Wastage will be increased if a trough with height and width is not compatible with mixer wagon used. Other factors related to feedpad design and construction, feed ingredients/rations offered and feeding management may influence % feed wasted.
Cow health risks	• Environmental mastitis and lameness if feedpad is not well designed, constructed and regularly scraped or flood washed. • Increased spread of disease as cows spend time in a confined area. • Cows may fall into troughs and injure themselves. • Poor trough hygiene may increase mycotoxin risk.
Environment issues	• Runoff of effluent must be managed to ensure no nutrients are reaching waterways. • Odour can be an issue particularly when there is non-agricultural land use close by. • Dust can be an issue to workers and neighbours and poses a respiratory or allergy risk. • Noise can potentially cause nuisance to neighbours with regular use of trucks, tractors, and machinery.
Safety	• A feedpad in which cows and vehicles share the same area is never ideal. • In wet weather, feedpad surface may become slippery for cows and vehicles.

5. INTEGRATED FACILITY FOR FEEDING AND HOUSING COWS: A) FREESTALL

Description

A large, permanent, engineered structure in which cows are fed and housed 24/7. They may be open or partially or fully enclosed. The term 'freestall' refers to the bedding area (or cubicles) where cows lie down and rest. Additional loafing areas may also be provided. Cows are kept in pen groups and access a TMR at a feed bunk via alleyways. Cows leave the barn 2-3 times each day to be milked in an adjacent milking parlour. Alternatively, if it is a robotic freestall, milking stations are located within the barn. Ventilation in barn may be natural, crossflow or tunnel.

Generic types

Freestall with alternative layouts: 3-row, 4-row (head-to-head or tail-to-tail), 6-row, 6-row with perimeter feeding, 8-row wide-body, low profile, cross-ventilated barn (head-to-head or tail-to-tail)

Suitable for use with

Low bail feeding system	Moderate-high bail feeding system	PMR feeding system	Hybrid feeding system (if large loafing areas)	**TMR feeding system**

Purposes

- Have maximum control over feeding, with minimal wastage
- Achieve optimal feed intakes, feed conversion efficiency and milk yields/cow
- Have maximum control over climatic variability and extreme weather events
- Provide maximum cow comfort and minimize heat stress and cold stress
- Control nutrient run-off

Characteristics

Frequency of use	Hold, feed and water cows permanently – zero grazing
Typical hours per day	24 hour per day
Surface	Concrete or rubber
Feeding table	Concrete nib wall. Cow barrier either post and rail or head locks
Loafing areas	Cubicles with bedding +/- additional loafing areas adjacent to barn
Shade/cooling	Solid roof over entire barn
Effluent management	Dry scraping or flood washing flushing of alleyways at regular intervals to remove manure to a professionally designed effluent system
Feed prep. and delivery	Mixer wagon
Feed storage	Silage pits/bunkers, hay sheds, commodity bunkers, tanks for liquids

	Very low	Low	Moderate	High	Very high
Time and effort to set up					✓
Weather durability					✓
Permanency					✓
Capital cost					✓
Feed wastage	✓				
Potential production benefits					✓
Improved farm efficiencies					✓

Costs

Capital cost: >$4,000/cow (not including mixer wagon, feed storage and mixing facilities or milking facilities)

Operating costs: Moderate-high depending on whether bedding in cubicles is sand or mattresses

Lifespan

More than 30 years. Depends on how well the facility was designed and constructed.

Examples of freestalls

Sand bedded cubicles. Flood-washed cow alley

Feed push-up using tractor

Sand replenishment

Alternative cubicle bedding: Sand, mattresses top-dressed with wood shavings or bentonite

Skill level/training required to operate

High

Possible benefits

Benefit	Comment
More milk/cow/day through: • Improved rumen stability • Higher feed intake • Less walking • Reduced heat stress	• TMR enables cows' daily feed inputs to be more closely controlled. • Feeding cows a TMR 2+ times per day is optimal in terms of rumen stability and function. • Presenting the milker diet as a TMR has been shown to optimise daily feed intake. • Cows in freestall expend minimal energy walking. • Under hot weather conditions, a well ventilated freestall with effective cooling systems may result in a saving of up to 5 L milk/day.
Higher feed efficiency and reduced feed costs through: • reduced feed wastage	• Studies indicate that feed wastage at feed-out may be reduced to 1-2% when presented as a TMR and fed out at a feed bunk. • Annual average feed conversion efficiency of 1.6 L/kg DM (ECM) is achievable in a freestall.
Improved cow comfort and welfare	If well designed and managed, a freestall provides cows with: • unlimited access to feed and drinking water • freedom to lie down and rest, eat and move around and socialise each day • close monitoring and assessment for production and health • opportunity to calve in a special maternity barn under supervision • no need to walk long distances or wait in a dairy holding yard to be milked in the hot sun • shade and evaporative cooling, so they are well protected from heat stress • protection from adverse weather events, muddy walking tracks and paddocks etc.
Specialisation of labour and management	• If enterprise is large enough, can train and manage specialised operational teams for fodder growing and harvesting, feed mixing and delivery to cow, herd management, milk harvesting, and young stock management.

Limitations/concerns

Limitation	Comment
High capital cost	• Engineered structures with steel and concrete fixtures. • Addition costs are required for barn ventilation and cooling systems, and effluent system
High operating costs	• TMR needs to be delivered to cows at each feed bunk at least once per day. • TMR needs to be pushed up regularly to maximise intake and reduce wastage. • Cubicles need to be regularly groomed and bedding topped up • Effluent management • Sand (if used) needs to be recovered from effluent system
Planning process	• A planning permit for intensive animal husbandry is required, under the state and local planning policy frameworks. There are several additional state legislations and policies that may impose additional requirements on the development and operation of a freestall. Objections to a planning permit application may be received from neighbours and other members of the local community (noise, odour etc.)
Economies of scale with herd size	• The two major costs of barn systems (besides the cost of capital) are feed costs and labour costs. While major savings in labour and other overhead costs can be achieved with increased herd size, feed costs tend to be similar across herd size. Maximising utilisation of dairy parlour requires a larger herd size.
High skill/training level and standard of management required	• If management of feed purchasing, storage, mixing and delivery to barns, herd numbers and composition (age, stage of lactation, milk yield), and cow comfort are sub-optimal, milk production and milk income less feed costs will be sub-optimal.

5. INTEGRATED FACILITY FOR FEEDING AND HOUSING COWS: B) COMPOST BEDDED PACK (CBP) BARN

Description

A large, permanent, engineered roofed structure in which cows are fed and housed 24/7. They comprise a large, open resting area, bedded with sawdust or wood shavings, adjacent to a concrete feed alley and feed bunk. The bedding is composted in situ and mechanically tilled at least twice each day. As a loose housing system, a CBP barn does not include the stalls and partitions found in a freestall, and the cows' resting, and exercise areas are combined. Ventilation is natural or mechanically assisted.

Generic types

Composted bedded pack barn with either pitched roof with centre ridge, or a hooped structure

Suitable for use with

Low bail feeding system	Moderate-high bail feeding system	PMR feeding system	Hybrid feeding system (if large loafing areas)	**TMR feeding system**

Purposes

- Have maximum control over feeding, with minimal wastage
- Achieve optimal feed intakes, feed conversion efficiency and milk yields/cow
- Have maximum control over climatic variability and extreme weather events
- Provide maximum cow comfort and minimize heat stress and cold stress
- Control nutrient run-off

Characteristics

Frequency of use	Hold, feed and water cows permanently – zero grazing
Typical hours per day	24 hour per day
Surface	Composted bedding material
Feeding table	Concrete nib wall. Cow barrier either post and rail or head locks
Loafing areas	Large resting area without partitions with composted bedding surface
Shade structures	Solid roof over entire barn
Effluent management	Dry scraping or flood washing of feed alleyways at regular intervals Removal of composted bedding material at regular intervals
Feed prep. and delivery	Mixer wagon
Feed storage	Silage pits/bunkers, hay sheds, commodity bunkers, tanks for liquids

	Very low	Low	Moderate	High	Very high
Time and effort to set up				✓	
Weather durability					✓
Permanency					✓
Capital cost					✓
Feed wastage	✓				
Potential production benefits					✓
Improved farm efficiencies					✓

Costs

Capital cost: $2,500–$3,000/cow (not including mixer wagon, feed storage and mixing facilities or milking facilities). Per cow construction costs are generally lower than for a freestall, despite more area being required per cow, as less concrete is used and there is no investment in freestall partitions and bases.

Operating costs: Higher than a freestall due to extra labour, machinery, and material costs to till bedding material and top up regularly.

Lifespan

More than 30 years. Depends on how well the facility was designed and constructed.

Examples of compost bedded pack barns

Cows resting comfortably on compost bedded pack

Cows in feed alley and on pack

Tilling the pack with harrows to help aeration and break up clumps while cows are being milked

Skill level/training required to operate

High

Possible benefits

Benefit	Comment
More milk/cow/day through: • Improved rumen stability • Higher feed intake • Less walking • Reduced heat stress	• TMR enables cows' daily feed inputs to be more closely controlled. • Feeding cows a TMR 2+ times per day is optimal in terms of rumen stability and function. • Presenting the milker diet as a TMR has been shown to optimise daily feed intake. • Cows in CBP barns expend minimal energy walking. • Under hot weather conditions, a well ventilated freestall with effective cooling systems may result in a saving of up to 5 L milk/day.
Higher feed efficiency and reduced feed costs through: • reduced feed wastage	• Studies indicate that feed wastage at feed-out may be reduced to 1-2% when presented as a TMR and fed out at a feed bunk. • Annual average feed conversion efficiency of 1.6 L /kg DM (ECM) is achievable in a CBP barn.
Improved cow comfort and welfare	If well designed and managed, a CBP barn provides cows with: • unlimited access to feed and drinking water • freedom to lie down and rest, eat and move around and socialise each day • close monitoring and assessment for production and health • opportunity to calve in a special maternity barn under supervision • no need to walk long distances or wait in a dairy holding yard to be milked in the hot sun • shade and evaporative cooling, so they are well protected from heat stress • protection from adverse weather events, muddy walking tracks and paddocks etc.
Public acceptance	• CBP barns are generally viewed by the public as better in terms of cow welfare than a freestall, and are likely to have less odours and flies if well managed
Specialisation of labour and management	• If enterprise is large enough, can train and manage specialised operational teams for fodder growing and harvesting, feed mixing and delivery to cow, herd management, milk harvesting, and young stock management.

Limitations/concerns

Limitation	Comment
High capital cost	• Engineered structures with steel and concrete fixtures. • Addition costs are required for barn ventilation and cooling systems, and effluent system
High operating costs	• TMR needs to be delivered to cows at each feed bunk at least once per day. • TMR needs to be pushed up regularly to maximise intake and reduce wastage. • Pack needs to be tillered at least twice per day and bedding regularly topped up.
Availability of bedding material and pack maintenance to control mastitis	• Bedding material may be costly or in limited supply in local area. • If the pack is not managed well, the higher risk of exposure to environmental mastitis pathogens can add to costs. Temperatures reached in the compost bedded pack may not be high enough to eliminate mastitis-causing bacteria
Planning process	• A planning permit for intensive animal husbandry is required, under the state and local planning policy frameworks. There are several additional state legislations and policies that may impose additional requirements on the development and operation of a CBP barn. Objections to a planning permit application may be received from neighbours and other members of the local community (noise, odour etc.)
Economies of scale with herd size	• The two major costs of barn systems (besides the cost of capital) are feed costs and labour costs. While major savings in labour and other overhead costs can be achieved with increased herd size, feed costs tend to be similar across herd size. Maximising utilisation of dairy parlour requires a larger herd size.
High skill/training level and standard of management required	• If management of feed purchasing, storage, mixing and delivery to barns, herd numbers and composition (age, stage of lactation, milk yield), and cow comfort are sub-optimal, milk production and milk income less feed costs will be sub-optimal.

5. INTEGRATED FACILITY FOR FEEDING AND HOUSING COWS: C) DAIRY DRY LOT

Description

These systems typically have centralised roofed shelters over composted bedding packs, located in earthen pens that are adequately sloped for drainage to a centralised manure collection system. The dairy herd is grouped depending on production and stage of lactation and various management groups. Typically, feed troughs and water supply are located away from the shelters to improve cattle movement and reduce congestion. Alternatively, a centralised concreted feedpad (either sloped and flushed or flat and dry scraped) provides effective infrastructure for feeding. Manure from the pens is regularly dry scraped and stockpiled in a designated area for composting and reused as bedding or re-applied to land supporting fodder production. These systems are most suited in hot, arid climates with suitable soils that facilitate drainage.

Generic types

Concrete feedpad +/- earthen surfaced loafing areas +/- shade structures

Suitable for use with

Low bail feeding system	Moderate-high bail feeding system	PMR feeding system	Hybrid feeding system (if large loafing areas)	**TMR feeding system**

Purposes

- Compacted and sloped earthen pens and cattle loafing areas support supplementary feeding with a PMR or TMR
- Increase feed intakes, feed conversion efficiency and milk yields/cow
- Provide cow comfort and minimize heat stress
- Control nutrient run-off

Characteristics

Frequency of use	Hold, feed and water cows permanently
Typical hours per day	System dependent, multiple hours up to 24 hours per day at times of the year
Surface	Earthen sloped pad
Feeding table	Concrete nib wall. Cow barrier either post and rail or head locks. If sprinklers are fitted at feeding table, it is important that the concrete cow feeding platform be constructed with a nib wall against the dry lot to prevent the runoff from the sprinklers reaching the earthen surface of the pen
Loafing areas	Large earthen sloped loafing areas to facilitate drainage
Shade structures	Shade structures constructed with a north-south orientation parallel to the feeding infrastructure. This allows the shade to move throughout the day, resulting in cows resting on different sections of the dry lot surface. Shade shelters are fitted with gutters removing rainfall away from the pen to allow the dry lot earthen surface to dry faster during wet weather and eliminating pugging around the shelters
Effluent management	Dry scraping or flood washing of cow alleys at regular intervals throughout the day Manure from the pens regularly dry scraped and stockpiled for composting and applied to land to support fodder production
Feed prep. and delivery	Mixer wagon
Feed storage	Silage pits/bunkers, hay sheds, commodity bunkers, tanks for liquids

	Very low	Low	Moderate	High	Very high
Time and effort to set up				✓	
Weather durability			✓		
Permanency				✓	
Capital cost			✓		
Feed wastage	✓				
Potential production benefits					✓
Improved farm efficiencies					✓

Costs

Capital cost: $1,000–$2,500/cow (not including mixer wagon, feed storage and mixing facilities or milking facilities). The advantage of dairy dry lot facilities lies in the lower capital investment per cow compared to CBP barns or freestalls.

Operating costs: Higher than a permanent feedpad due to extra labour, machinery, and material costs to till bedding material under skillion shelters and dry scrape manure from earthen pens for composting, handling, transport and application.

Lifespan

More than 5–10 years. Depends on how well the facility was designed and constructed and maintained with regional climate. Extended wet periods can cause pugging so developing systems with adequate slope to accommodate drainage, so water drains off pens is critical. The slope of pens will have a dramatic impact on how fast the earthen surface will dry.

Examples of dairy dry lots

Shade shelters at a dairy dry lot with a north-south orientation

Cows resting comfortably on compost bedded pack aerated daily

Cows feeding at concrete central feedpad

Concrete cow feeding alley ways constructed with a nib wall against the dry lot to prevent the runoff reaching the earthen surface of the pen

Cows resting on sloped earthen pen of dairy dry lot

Flood washing of concrete cow feeding alleyways

Water trough with concrete drinking apron to prevent runoff onto earthen pen and pugging damage around the trough

Skill level/training required to operate

High

Possible benefits

Benefit	Comment
More milk/cow/day through: • Improved rumen stability • Higher feed intake • Less walking • Reduced heat stress	• TMR enables cows' daily feed inputs to be more closely controlled. • Feeding cows a TMR 2+ times per day is optimal in terms of rumen stability and function. • Presenting the milker diet as a TMR has been shown to optimise daily feed intake. • Cows on dairy dry lots expend minimal energy walking. • Under hot weather conditions, a dairy dry lot with effective cooling systems such as sprinklers placed at cow feeding alleyways and adequate shade may result in a saving of up to 5L milk/day.
Higher feed efficiency and reduced feed costs through: • reduced feed wastage	• Studies indicate that feed wastage at feed-out may be reduced to 1–2% when presented as a TMR and fed out at a feed bunk. • Annual average feed conversion efficiency of 1.5L/kg DM (ECM) is achievable in a dairy dry lot (Don Stewart, Pers. comm)
Improved cow comfort and welfare	If well designed and managed, a dairy dry lot provides cows with: • unlimited access to feed and drinking water • freedom to lie down and rest, eat and move around and socialise each day • close monitoring and assessment for production and health • opportunity to calve in a special maternity barn under supervision • no need to walk long distances or wait in a dairy holding yard to be milked in the hot sun • shade and evaporative cooling, so they are well protected from heat stress.
Public acceptance	• Dairy dry lots are relatively new to the Australian dairy landscape – if designed and managed well they will improve cow comfort and may be viewed as an alternative to freestall or CBP barns
Specialisation of labour and management	• If enterprise is large enough, can train and manage specialised operational teams for earthen pen management (scraping and tilling of bedding), fodder growing and harvesting, feed mixing and delivery to cow, herd management, milk harvesting, young stock management and improved monitoring during joining
Improved feed utilisation	• Shifting feedbase to forages which are mechanically harvested eases pugging and compaction which may occur during grazing in miserable weather

Limitations/concerns

Limitation	Comment
Climatic	• Careful choice of location is required (including rainfall and heat considerations) and design for satisfactory year-round dairy health. A dairy dry lot may work in a semi-arid environment. While earthen pens are sloped extensive rainfall events can challenge dairy dry lots – particularly if they are overstocked. • During severe windy, wet conditions skillion shelters provide little protection from wind-chill.
High operating costs	Requires more specialised skills in staff management, animal management, ration balancing and environmental management: • TMR needs to be delivered to cows at each feed bunk at least once per day. • TMR needs to be pushed up regularly to maximise intake and reduce wastage. • Pack needs to be tillered at least twice per day and bedding regularly topped up.
Availability of bedding material and pack maintenance to control mastitis	• If the pack under the skillion shelters is not managed well, there is a higher risk of exposure to environmental mastitis pathogens which can add to costs. • Temperatures reached in the compost bedded pack may not be high enough to eliminate mastitis-causing bacteria.
Planning process	• Dairy dry lots are classed as an integrated facility for feeding and housing cows system and hence trigger a change in land use requiring a planning permit. Obtaining necessary approvals and permits across a range of government departments can be very slow and involved.
Economies of scale with herd size	• The two major costs of barn systems (besides the cost of capital) are feed costs and labour costs. While major savings in labour and other overhead costs can be achieved with increased herd size, feed costs tend to be similar across herd size. Maximising utilisation of dairy parlour requires a larger herd size.
High skill/training level and standard of management required	• Attention to detail and management skill can be critical in the management of a dairy dry lot system to detect and mitigate issues early. Different management skills are required as labour units are increased – including delegating responsibility, providing access to training etc. Regular and open communication is essential. Workplace health and safety needs to be addressed.
More complex labour requirements	• As the size of the enterprise increases, several labour units – with specialised skills and different areas of expertise and responsibility – tend to be required in a large dairy dry lot.
Environmental pressures	• Under dry lot conditions – especially close to urban and non-farming areas – infrastructure and management needs to be sufficient to prevent odours, dust and increased fly population that are likely to attract negative attention. Nutrient movement needs to be controlled, captured, and re-applied within the farm boundary.

FEED DELIVERY INFRASTRUCTURE – KEYS TO SUCCESSFUL DESIGN, CONSTRUCTION AND USE

Each type of feed delivery infrastructure has several characteristics related to its design and construction, and how it is used day to day, that contribute substantially to its success.

Keys to success – overview*

<table>
<tr><th rowspan="2">KEYS TO SUCCESS:</th><th rowspan="2">Temporary feed-out area</th><th rowspan="2">Basic feed-out area</th><th rowspan="2">Formed earthen feedpad</th><th rowspan="2">Concrete feedpad</th><th colspan="3">Integrated facility for feeding and housing cows</th></tr>
<tr><th>a. Freestall</th><th>b. Compost bedded pack barn</th><th>c. Dairy dry lot</th></tr>
<tr><td>Provide cows with a comfortable, clean, low stress environment</td><td>pp111</td><td colspan="3">pp112</td><td>pp115</td><td>pp120</td><td>pp124</td></tr>
<tr><td>Maximise cows' daily feed intakes and minimise waste</td><td>pp127</td><td colspan="3">pp127</td><td colspan="2">pp131</td><td>pp131</td></tr>
<tr><td>Construct earthen feedpad with a durable, long-lasting surface</td><td></td><td colspan="2">pp135</td><td colspan="4"></td></tr>
<tr><td>Layout the farm's 'kitchen' well</td><td></td><td></td><td colspan="5">pp137</td></tr>
<tr><td>Manage feed purchasing well and design well balanced diets</td><td colspan="7">pp139</td></tr>
<tr><td>Ensure feedpad can be further developed in future if desired</td><td></td><td colspan="2">pp145</td><td colspan="4"></td></tr>
</table>

* Note: the colours and page numbers in this table will help you to navigate in the following pages to an expanded description of the "Keys to Success" for each type of delivery infrastructure. Key to success: Provide cows with a comfortable, clean, low stress environment

KEY TO SUCCESS: PROVIDE COWS WITH A COMFORTABLE, CLEAN, LOW STRESS ENVIRONMENT

1. TEMPORARY FEED-OUT AREA

A temporary feed-out area can be set up in several ways:

- Running an electric wire along a laneway or along an irrigation check-bank
- Placing hay rings or old tractor tyres in a designated sacrifice paddock
- Simply running hay/silage mixed ration along the ground in a grazing paddock or a bare cropping paddock

The following factors are important for ensuring that cows are comfortable and low stress while using the temporary feed-out area:

Site selection and set-up

- If setting up a sacrifice paddock, select a paddock which needs to be renovated anyway, has good drainage, and provides tree shade.
- Avoid a paddock near a roadway or waterway.
- If using a grazed paddock, select one that has good pasture cover and is not wet.
- Provide ready access to water troughs.

Adequate area per cow on feed-out area for resting if cows held on it for > 4 hours/day

- As a general guideline, if cows are only on the feed-out area for a few hours per day (i.e. < 4 hours), an area of 3.5m^2/cow is adequate.
- However, if the desired pattern of use of the feed-out area involves cows resting on it for up to 12 hours (i.e. the entire period between consecutive milkings), then at least 6m^2/cow is required.
- If cows are to remain on the feedpad constantly for several consecutive days (e.g. when paddocks are very wet or during hot weather), an area of 10–12m^2/cow is required.

Dry, comfortable surface for cows to rest on

- Avoid using the temporary feed-out area for too long, especially in wet conditions.
- Relocate to another site on the farm as soon as necessary.

Minimal aggressive interactions between cows while eating

- If feeding on the ground, spread hay/silage/PMR over a long distance (at least 1m/cow).
- If using hay rings or tractor tyres, ensure sufficient rings/tyres so that each one caters for only 20 cows and space the feeders well apart.

2. BASIC FEED-OUT AREA

3. FORMED EARTHEN FEEDPAD

4. CONCRETE FEEDPAD

There are several tasks that a cow must perform each 24-hour day:

- Eating and drinking
- Standing and walking around
- Social interactions with other cows
- Being milked
- Ruminating, and
- Resting

Cows are light-active animals. Foraging and social behaviour therefore occur mainly during daytime while they show less activity during the dark hours. However, cows also rest during the daytime. Typically, their activities alternate between eating and lying with shorter periods of search for the most attractive food and resting areas as well as social behaviour in between periods of eating and lying.

Resting provides a cow with several benefits, including:

- Potentially greater milk synthesis due to greater blood flow through the udder
- Greater blood flow to the gravid uterus during late lactation
- Increased rumination effectiveness
- Less stress on her hooves and therefore less lameness
- Less fatigue stress, and
- Greater feed intake.

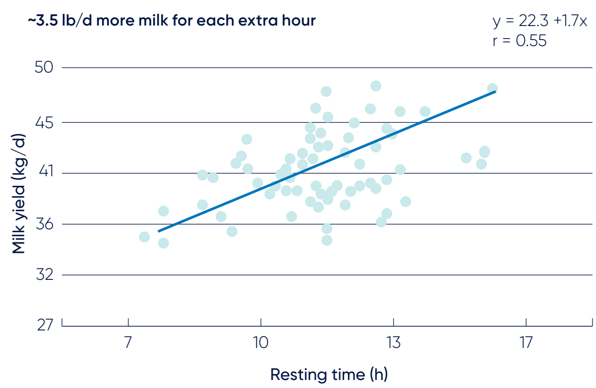
The cow's motivation to lie down and rest is high:

- Studies have shown that cows rate rest as highly as food.
- Decreased lying time reduces the possibility for cows to rest and sleep. Cows sleep for about 4 hours per day, mainly during the night-time.
- Reducing the amount of rest obtained each day by about 50% adversely affects the cow's metabolism and health, altering hormonal function, increasing energy cost, and impairing immune function.
- Cows motivation to rest increases as the length of deprivation becomes greater. Cows will compensate for reduced access to resting by spending less time eating to free up time for making up lost resting activity.

Cows need to lie down and rest for 10–12 hours per day (i.e. almost half their 'daily time budget'). An environment that allows natural resting and feeding behaviour underpins cows wellbeing and productivity. Grant (2004) proposed that each additional hour of resting time translates into 0.9–1.5 litres more milk per cow per day (Figure 4). However, other researchers have not been able to demonstrate such a relationship between resting time and milk yield.

With further genetic increases in milk yield, cows will have higher nutrient requirements so will need more time to eat. However, their need for resting time will probably not alter.

Figure 4. Relationship between resting time and milk yield in cows



Source: Grant, 2004

These factors are important for ensuring that cows are comfortable and low stress while using the feed-out area or feedpad:

Adequate area per cow on feedpad for resting if cows held on it for > 4 hours/day

As a general guideline, if cows are only on the feedpad for a few hours per day (i.e. < 4 hours), an area of $3.5m^2$/cow is adequate. However, if the desired pattern of use of the feedpad involves cows resting on it for up to 12 hours (i.e. the entire period between consecutive milkings), then at least $6m^2$/cow is required. If cows are to remain on the feedpad constantly for several consecutive days (e.g. when paddocks are very wet or during hot weather) 10–$12m^2$/cow is required.

Dry, comfortable, clean surfaces for cows to stand and rest on

Key factors:

- Feedpad location
- Feedpad surface type used (options include woodchips, sand, gravel, straw, compost)
- Drainage/effluent collection

For cleaning feedpads which are not concrete, mechanical scraping with a blade is the only option.

Pros:

- Low capital cost, as can use an existing front-end loader
- Smaller quantities of dry manure to handle

Cons:

- High labour and machinery costs
- More concentrated effluent to handle
- In wet conditions, manure on feedpad surface becomes sloppy and difficult to scrape
- Task tends not to be done frequently enough

Skid-steer and front-end loaders with purpose-built attachments can be used to scrape feedpads. A three-metre-wide scraper blade can be quick and effective. The blade should be fitted with a sacrificial 'edge' to reduce wear on the pad surface. Scraping 3–4 times per week is recommended.

Adequate slope will assist in draining feedpads during the wetter months, and therefore make scraping easier (Moran & McDonald, 2010)

For cleaning concrete feedpads, mechanical scraping and flood washing may be used. Flood washing requires a sufficient volume of freshwater and/or recycled effluent to supply the flood wash system.

Pros:

- Lower labour cost

Cons:

- Higher capital cost
- High water discharge rates with large discharge pipes needed

The volume and subsequent flow rate required to effectively wash an alley is influenced by: alley slope, width, length and surface texture; and the type, consistency and amount of manure that needs to be washed from the surface.

The design principles for cleaning a feedpad by flood washing are similar to those used for cleaning a dairy yard. Most flood washing systems comprise large holding tanks at the highest end of the alley, from which water is released through large diameter pipes (e.g. 300mm) into the alley at high discharge rates (e.g. 12–15m^3/min). Wide channels of manure accumulations may lead to meandering of flush water down alley. To prevent, divide wide channel into multiple narrow channels.

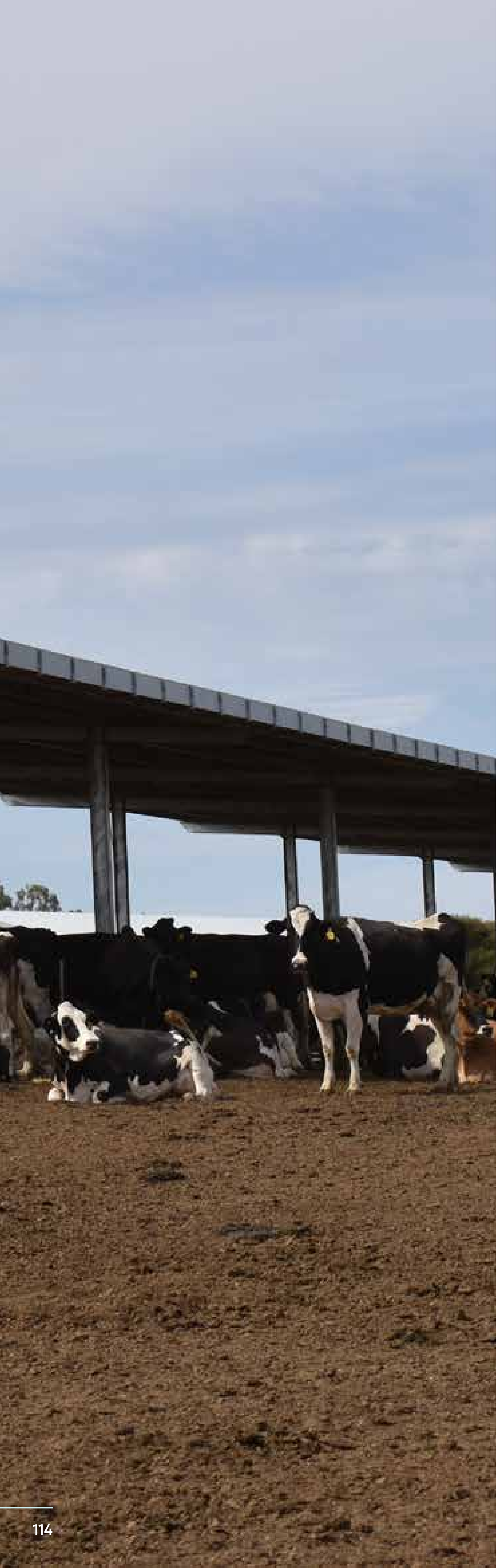
NZ research studies on woodchip based, uncovered stand-off pads indicates when the moisture content of the bedding exceeded 75%, cows' daily lying times were less than the recommended 8 hours/day. However, for bedding regularly refreshed with woodchips, the moisture content remained less than 65% (DairyNZ, 2018).

Minimal aggressive interactions between cows while eating

If there is insufficient linear space at the feed bunk for all animals to feed together then cows must compete for feed. Dominant cows spend more total time eating than cows of lower social rank (Olofsson, 1999). Overstocking the feed bunk increases aggressive interactions between cows and forces cows to change their feeding behaviour. They have reduced feeding time, eat more quickly, and consume fewer, larger, and longer meals each day. Greater feed bunk competition may also be associated with reduced rumination activity (Huzzey *et al.*, 2006; Crossley *et al.*, 2017).

Recent studies have shown that altered feeding behaviour in cows competing for feed bunk space elicits a stress response, especially in first-calvers and subordinate cows (Huzzey *et al.*, 2012), and may also impact on cow reproductive function and performance (Schefers *et al.*, 2010).

In a feeding study conducted on a feedpad at DPI Ellinbank, Victoria (Hetti Arachchige *et al.*, 2014), it was found that when each cow's feeding space was increased from 0.65m to 0.75m to 1.0m there were fewer aggressive interactions between cows. Cows were more likely to gain equal access to feed, with subordinate cows significantly increasing their feeding time. The use of feed barriers separating cows further reduced competition at the feed trough in a PMR feeding system. This is the first time a study has provided information about the potential for influencing feeding and social behaviours in PMR-fed dairy cows on a feedpad by changing the feeding space over the recommended range.



Shade and evaporative cooling

The first step is always to provide shade (i.e. protect cows from direct exposure to radiant heat). Having provided shade, the next most important thing to consider is evaporative cooling, as evaporative heat loss is the most efficient way for cows to off-load heat. Cows can off-load three times as much heat through evaporation when the air is moving at 1 metre/second as when it is still. Sprinkling or soaking cows to the skin and then evaporating water off with supplemental airflow (fans) is therefore the most efficient method to remove heat from cows.

Using sprinkling in combination with supplemental airflow (fans) is superior to either a fan or sprinkling alone. Increasing airflow and wetting frequency has a dramatic effect on the evaporative heat loss from the skin of dairy cows. Both low-pressure and high-pressure systems that soak the skin are more effective than high-pressure systems that only reduce air temperature.

On feedpads with concrete feed alleys, a sprinkler line can also be installed along the top rail at the feed bunk, to wet the cow's shoulders and back while eating, providing cooling over and above the evaporative system.

While efforts to minimise heat stress tend to be focused on lactating cows, it is important to realise that if dry cows are heat stressed, this may negatively impact:

- Mammary gland development before calving, resulting in fewer functional mammary cells at the onset of lactation, thereby compromising subsequent lactation performance (Tao *et al.*, 2013)
- Immune and metabolic function, and may also affect subsequent reproductive performance
- Foetal development in the uterus due to its effect on placental tissue, leading to a decrease in calf birth weight
- Passive immunity and cell-mediated immune function in newborn calves.

Dry cows therefore also require adequate shade.

5. INTEGRATED FACILITY FOR FEEDING AND HOUSING COWS: FREESTALL

Cows housed in a freestall on concrete floors require at least 12 hours lying time per day in a dry, comfortable cubicle (Cook, 2009). The reminder of their daily time budget is taken up with these activities: eating (3–5 hours), drinking (0.5 hours), socialising, walking, grooming, estrous activity (2–3 hours) and being milked (2.5–3.5 hours).

Factors which impact on cows lying time and general level of comfort are:

- Access to cubicles
- Cubicle design and dimensions
- Bedding
- Walking and standing surfaces
- Hoof care
- Shade and evaporative cooling
- Flies

Access to cubicles

In a freestall, cubicle (freestall) stocking density (number of cows per cubicle, often expressed as a percentage) is important as it impacts on cow's time budgets, health and milk yields. It also impacts on utilisation of the facility and financial returns. Most studies have found that in a freestall, cows' lying times (ideally 12 hours/day) are not reduced unless the cubicle stocking rate exceeds 120%. However, for transition cows and early-lactation cows, one usable cubicle should be provided for every animal (i.e. 100% cubicle stocking rate). While some freestalls run cubicle stocking rates above 120% (up to 150%), they are not recommended as they mean that cows must compete for a free cubicle and may need to stand for longer each day, leading to increased foot problems and lameness.

Even when barns are stocked at 100%, cow comfort can still be affected by the general layout of the barn, particularly the number of rows per feed bunk and the number of cubicles between cross-overs (von Keyserlingk *et al.* 2012). Research has shown that most cows prefer cubicles which are in the row closest to the feed bunk and within the centre of the row. These cubicles are occupied for a much greater percentage of the day than other cubicles, which require them to walk further to the feed bunk, and possibly deal with narrower alleyways and dominant cows. Barns with 2 or 3 rows per feed bunk are therefore more comfortable for cows than those with 4 or 6 rows per feed bunk. Even within a given section of cubicles in a barn, some cubicles will be more popular than others.

Cubicle design and dimensions

The purpose of a cubicle is to provide a cow with a clean, dry, comfortable place to rest. A well-designed cubicle should enable the cow to stand, lie down and change position without pushing, banging, or bumping against the neck rail or other stall

Figure 5 Space requirements for resting and rising of a typical stall (DPIV, 2010)

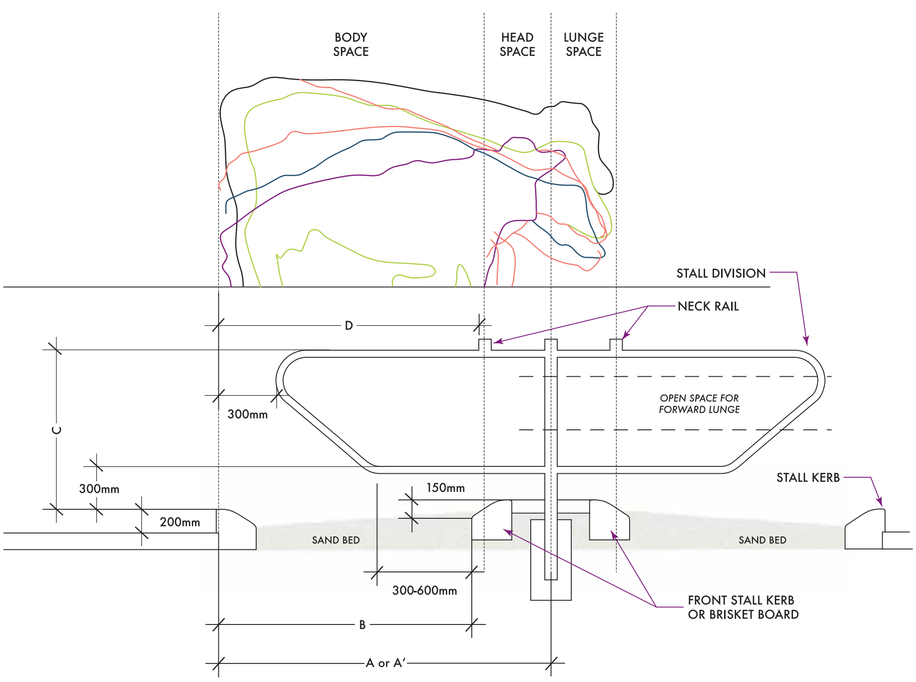


Table 10. Suggested dimensions for open and closed-fronted cubicles for mature dairy cows

Animal weight (lbs)	Total stall length Closed front (LSC) (in)	Total stall length Open front (LSO) (in)	Length to brisket tube or >board (LB) (in)	Length to neck rail (LN) (in)	Stall width centre to centre (WS) (in)	Height to top of partition (HP) (in)	Height to neck rail (HN) (in)	Brisket board or tube height (HB) (in)
900–1100	90–96	78–82	64–66	62–64	41–43	42–44	42–44	4–6
1100–1300	96–102	80–86	66–68	64–66	43–45	44–46	44–46	4–6
1300–1500	102–108	90–96	68–70	66–68	45–48	46–48	46–48	4–6
1500–1700	108–114	96–102	70–72	68–70	48–52	48–52	48–52	4–6

(Penn State Cooperative Extension, 2016)

components, stretch her front feet forward, lie on her side with plenty of room, rest with their legs, udder and tail in the free stall. The cubicle should provide her with adequate lunge space to extend her body as she reclines and rises (Figure 5).

Cubicles may be closed at the front by a barrier or open. Open-fronted cubicles are preferable as they permit a cow to extend her head and neck forward into a facing stall, alley or outside the building as she reclines or rises, and the cubicle does not need to be as long. Facing or head-to-head cubicles may be arranged head-to-head, permitting cows to share lunge space.

Key dimensions for a cubicle are:

- Width
- Length (including lunge space)
- Slope
- Side partition height and length
- Neck rail height and position
- Brisker locator height and position
- Rear curb height

One size does not fit all. The cubicle should be proportional to cow size. It is better to be too big than too small. Recommendations for cubicle dimensions vary. Those provided in Table 10 are useful as they are across a range in cow bodyweight (Penn State Cooperative Extension, 2016).

Bedding

Providing a comfortable, soft surface cushion for cows to lie on is probably the most important factor affecting cubicle usage and lying time. An ideal cubicle bed conforms to:

- the cow's shape
- provides cushioning while the cow is getting up and lying down
- maintains effective traction to minimize slipping, and
- remains dry to minimize bacterial growth and promote optimal udder health.

Bedding material should ideally be economical and readily available, easy to handle and keep dry, carry a low bacterial load and be compatible with the barn's manure handling system.

Inorganic and organic bedding materials may be used.

Inorganic materials include:

- Sand (raked and topped up 1 to 3 times per week)
- Lime
- Gravel
- Waterbeds

Organic materials include:

- Sawdust or shavings
- Peanut hulls
- Straw
- Bark
- Cotton gin trash
- Manure solids

Inorganic materials have lower water holding capacity and do not support as many bacteria as organic materials. Organic bedding materials must be kept as dry as possible and cleaned daily.

Sand is considered the gold standard for bedding for many reasons:

- Provides a comfortable resting surface, improving cow comfort
- Limits bacterial growth
- Has a low initial moisture content, reducing moisture build-up
- Remains cool and reduces heat stress through lower lying temperature than other bedding materials
- Reduces slipping through improved traction, and
- Can be recycled (Buli *et al.*, 2010).

Cows housed in sand cubicles have been found to have higher hygiene scores than cows housed on mattresses or waterbeds (Fulwider *et al.*, 2007). However, sand may not be a practical option for a farm, as large quantities are required per cow per day. Sand also presents challenges such as increased wear on equipment and difficulty in effluent management (Figure 6).

Figure 6. Comfortable cow in open-fronted with good sand depth

Figure 7. Water-filled mattress with wood cubicle shavings on top

Mattresses are the next best option (Figure 7). Soft mattresses are preferable to harder mattresses. If material compresses over time, it will become less comfortable over time. Trials with various mattress systems available show a wide range in cow occupancy rates (Sonck *et al.*, 1999). Mattresses need to pass the "knee test". They should therefore be as thick as possible – at least 3 inches, preferably 5 inches. Research shows that well-constructed mattresses used with a generous topping of bedding material may perform almost as well as sand. If mattresses are to be used, a premium quality model should be selected.

Dry, comfortable, clean surfaces for walking and standing

While well designed freestalls provide cows with facilities for easy access to feed and water, a comfortable place to lie down and rest, shelter, and protection from wind in cold weather, and cooling measures in hot weather, they do require cows to stand and walk for 10–12 hours per day.

Hard flooring surfaces such as concrete may promote claw overgrowth, resulting in unbalanced weight-bearing within and between the claws of the foot, leading to lameness which can have substantial impacts on milk production and reproductive performance. If the concrete is abrasive, excessive wear of the claw also occurs, leading to thin soles and lesions in the toe (Bray, 1998). New concrete (which has sharp edges and exposed aggregate) is more abrasive than old concrete, and wet concrete is much more abrasive than dry concrete. On the other hand, smooth concrete reduces wear and may contribute to claw horn overgrowth, and may be slippery, increasing risk of injury.

Groove patterns are cut into poured concrete floors in freestalls either while the concrete is still curing or after it has fully hardened to provide cows with a slip-resistant surface. There are varying opinions on dimensions, orientation, and configuration of grooves and patterns that should be used. Parallel grooves in one direction or in two directions in a diamond pattern may be used (Figure 8). A diamond pattern is preferred, especially for high traffic areas such as cross-overs. Grooving costs approx. $5–8 per metre.

Figure 8. Diamond grooved concrete in a cross-over

Possible alternative methods to provide cows with a slip-resistant surface include hexagonal patterned grooving, application an anti-slip aggregate over concrete while curing, and application of an epoxy floor coating.

Figure 9. Cows showing a strong preference rubber versus concrete surface

Figure 10. Robotic freestall (NZ) with rubber flooring on all alleyways for maximum cow comfort

Given a choice, most cows prefer to walk and stand on soft rubber (Figure 9) rather than on concrete flooring (Telezhenko *et al.*, 2007). Recent studies indicate that the benefits of providing rubber flooring surfaces extend beyond just reduction of hoof problems and lameness. Cows housed in freestalls with rubber floors in alleyways have also been shown to have higher milk yields and lower levels of chronic inflammation than cows housed on concrete floors (Eicher *et al.*, 2013).

Cheap second-hand conveyor belting may be used, or purpose-made rubber matting, which tends to be softer and less slippery but is much more expensive. Many new freestall systems are therefore now being built with more extensive use of rubber flooring, despite its substantial cost, to maximise cow comfort (Figure 10).

For cleaning concrete feedpads, mechanical scraping and flood washing may be used. Flood washing requires a sufficient volume of freshwater and/or recycled effluent to supply the flood wash system.

Mechanical scraping has some advantages: low capital cost, as can use an existing front-end loader, and smaller quantities of dry manure to handle. However, its disadvantages are:

- High labour and machinery costs
- More concentrated effluent to handle
- In wet conditions, manure on feedpad surface becomes sloppy and difficult to scrape, and
- Task tends not to be done frequently enough.

Skid-steer and front-end loaders with purpose-built attachments can be used to scrape cow alleyways. A three-metre-wide scraper blade can be quick and effective. The blade should be fitted with a sacrificial 'edge' to reduce wear on the pad surface. Alternatively, a cable-driven blade system can be installed in each cow alley when the barn is constructed. Scraping 3-4 times per week is recommended.

Flood washing has lower labour cost. However, it has a higher capital cost, and requires high water discharge rates with large discharge pipes. The volume and subsequent flow rate required to effectively wash an alley is influenced by alley slope, width, length and surface texture; and the type, consistency and amount of manure that needs to be washed from the surface.

Most flood washing systems comprise large holding tanks at the highest end of the alleys, from which water is released through large diameter pipes (e.g. 300mm) into the alley at high discharge rates (e.g. 12-15 m^3/min). Wide channels of manure accumulations may lead to meandering of flush water down alley. To prevent, divide wide channel into multiple narrow channels.

Hoof care

Cows require a sole thickness of 7mm to withstand the mechanical pressures imposed by hard surfaces such as concrete. When excessive wear occurs, as it tends to do in freestall housing systems, the toe becomes shorter and the sole of the toe thinner.

Regular hoof trimming is therefore essential in freestall systems to restore equal distribution of weight bearing between the claws and correct any claw lesions before they cause major problems. Cows are usually hoof trimmed at dry off. An additional trim may be done again during lactation. Some 'high risk' individual animals such as high producers, older cows and cows with a low foot angle, may need regular checks.

Zinpro Corporation, which markets mineral feed supplements, has some excellent information resources and tools to assist with control and prevention of lameness problems, including:

- Zinpro Corporation's Illustrated handbook on cattle lameness (Greenough *et al.*, 2009)
- Locomotion scoring handout and CD
- Hoof check tool
- Dairy claw lesion identification chart
- Footbath options handout, and
- FirstStep™ software program.

Shade and evaporative cooling

The first step is always to provide shade i.e. protect cows from direct exposure to radiant heat. Having provided shade, the next most important thing to consider is evaporative cooling, as evaporative heat loss is the most efficient way for cows to off-load heat. Cows can off-load three times as much heat through evaporation when the air is moving at 1 metre/second as when it is still. Sprinkling or soaking cows to the skin and then evaporating water off with supplemental airflow (fans) is therefore the most efficient method to remove heat from cows.

Using sprinkling in combination with supplemental airflow (fans) is superior to either a fan or sprinkling alone. Increasing airflow and wetting frequency has a dramatic effect on the evaporative heat loss from the skin of dairy cows. Both low-pressure and high-pressure systems that soak the skin are more effective than high-pressure systems that only reduce air temperature.

On feedpads and in barns with concrete feed alleys, a sprinkler line can also be installed along the top rail at the feed bunk, to wet the cows' shoulders and back while eating, providing cooling over and above the evaporative system.

Conductive cooling of bedding in cubicles in freestalls is a relatively new technology. Research showed that conductive cooling placed under the cow's bedding material reduced the core body temperature, skin temperature and breathing rates of lactating cows. It also increased feed intake and milk yield (Ortiz *et al.*, 2015). While conductive cooling may offer an additional means to minimise heat stress in freestall systems, it is limited by the fact that cows only occupy cubicles for a proportion of the day and when lying down have only 20% of their surface area available to exchange heat via conduction (Fournel *et al.*, 2017). GEA has supported research in this area but is yet to launch a commercial system.

While efforts to minimise heat stress tend to be focused on lactating cows, it is important to realise that if dry cows are heat stressed, this may negatively impact:

- Mammary gland development before calving, resulting in fewer functional mammary cells at the onset of lactation, thereby compromising subsequent lactation performance (Tao *et al.*, 2013)
- Immune and metabolic function, and may also affect subsequent reproductive performance
- Foetal development in the uterus due to its effect on placental tissue, leading to a decrease in calf birth weight, and
- Passive immunity and cell-mediated immune function in newborn calves.

Dry cows should therefore be run in paddocks with adequate shade or housed in barns with access to evaporative cooling.

Flies

Flies can be a major source of irritation to cows and staff in the warmer months. The fly lifecycle requires that immature flies (i.e. eggs, larvae, pupae) live in manure, moist hay, spilled silage, wet grain, or a similar environment for 10 to 21 days depending on temperature and fly species. A high standard of barn hygiene, with minimal accumulation of manure, should therefore be the foundation of any fly control program.

Flies can be controlled using chemical and biological means. Chemical control options include space sprays, baits, larvicides, residual premise sprays, and animal sprays. Many insecticidal products are registered for use in and around animal sheds to control nuisance flies. Visit **infopest.com.au** for a list. Care needs to be taken not to overuse insecticides, as this will foster development of insecticide resistance.

Biological control options include predatory beetles and mites, parasitic wasps and other insects. Fly control can only be achieved using an integrated pest management approach.

5. INTEGRATED FACILITY FOR FEEDING AND HOUSING COWS: COMPOST BEDDED PACK BARN

Cows housed in compost bedded pack barns (CBP barns) benefit from increased area to rest and exercise vs. freestalls. These barns have the potential to improve cows' comfort, cleanliness, hoof health and milk yields. They also make heat detection easier. Other benefits claimed by farmers include increased cow longevity, less odour, fewer flies, lower maintenance costs, easier manure handling and improved manure value (Brewer *et al.*, 2012).

Factors which impact on cows' lying time and general level of comfort are:

- Bedding material used
- Bedding management (tilling)
- Resting space per cow
- Barn layout and fixtures
- Ventilation, and
- Shade and evaporative cooling

Bedding material used

Several bedding materials have been used in compost bedded packs. However, dry, fine wood shavings or sawdust have generally been preferred in the US (Barberg *et al.*, 2007; Bewley, 2012, Leso *et al.*, 2020).

Sawdust

Even when mixed with shavings, sawdust has enough structure to be able to be easily stirred and remain fluffy enough to assure oxygen transfer within the bedding material (Bewley, 2009). Sawdust provides a large surface area to volume ratio (3), is easier to till, and absorbs and holds liquids well. Kiln-dried sawdust performs well as long as the moisture content is less than 18% on entry to the CPB. Green sawdust is generally wet and may harbour Klebsiella bacteria and more bedding being required to maintain the composting process (Chamberlain, 2018).

Wood shavings

Especially when mixed with sawdust, wood shavings have the potential to improve handling, mixing, aeration, and biological activity due to their large size and ability to maintain air pockets and reduce compaction (Janni *et al.*, 2006). This increases the ability of microbial populations to grow and break down manure and urine added and prevents excessive compaction of the bedding between tillings (Endres, 2008). Shavings are generally used as a mix with sawdust to improve tillability and aeration.

Wood chips

Wood chips are less desirable than sawdust and wood shavings as they hold less water due to their lower surface area/volume ratio. If they have sharp edges, these may also injure cows.

Recycled bedding material

It is possible to allow the composting process to continue and be completed (like garden compost) by stockpiling material after the pack is cleaned out. This dry composted material can then be mixed with new sawdust to stretch the sawdust supply for new bedding.

Bedding materials found to be unsuitable for compost bedded packs include saw dust or wood shavings that have been sprayed with a chemical that inhibits bacterial growth, coarse hay and cereal grain straw, sand and crushed limestone, paper and cardboard.

Bedding management (tilling)

Compost barns succeed or fail primarily on the extent to which they provide cows with a comfortable, dry bedding surface. This relies on effectively managing the composting process, in which microorganisms use oxygen to break down organic matter and generate CO^2, water, and heat. Manure and urine provide the essential nutrients (carbon, nitrogen, moisture, and some microorganisms) for the bacteria to begin and continue the composting process. Heating and drying the pack provides a fresh, dry surface for cows to lie on (Shane *et al.*, 2010).

Regular mechanical tilling (fluffing up) of the bedding is required (Figure 11). This process exposes the bedding to air (oxygen) and allows it to infiltrate it, so that the composting process can continue with an appropriate balance of oxygen, moisture, temperature, and organic matter (Shane *et al.*, 2010; Chamberlain, 2018). While tilling at least twice per day is generally recommended, compost barns in some countries are only tilled once per day (Klaas *et al.*, 2010; Bjerg & Klaas, 2014). Tilling is done while the cows are out of the barn being milked. Some operators till the bedding in multiple directions (Figure 12). If possible, cows should be kept off the pack for at least an hour after tilling to enable the top layer to dry, especially during winter. Running fans after stirring may assist drying.

Figure 11. Steam rising during tilling is a good sign for air infiltration and to break up clumps

Figure 12. Tilling in multiple directions

Figure 13. Compost at ideal temperature

Figure 14. Compost too wet for sufficient temperature

(Bewley, 2012)

The depth of tilling varies, depending on the operator and the tool used, but 18–30 centimetres is typical (Janni *et al.*, 2006; Barberg *et al.*, 2007). Fixed tine tillers or rotary tillers are used. Fixed tine tillers generally have a deeper penetration (25–30cm), while rotary tillers develop a finer and more comfortable bed to a depth of (15–20cm). Some farms use rotary tillers twice daily, with deeper fixed tine tilling 2–3 times weekly (Bewley, 2013).

The heat produced by the composting process is essential not only to dry the pack but also to kill some pathogens, viruses, fly larvae and weed seeds which may be present. Pack temperature is the key indicator of the composting process (Figure 13). Ideally, the internal temperature for CPB at a depth of 15–31cm ranges from 43.3–65.0°C (Janni *et al.*, 2006; Bewley *et al.*, 2013). If the temperature is below this, it indicates that the composting process is too slow, and if it is above 65.0°C, the beneficial micro-organisms in the pack will die (Figure 14). Either way, the pack will become inactive, cows' urine and manure will not be broken down and the bedding will become wet. The pack should also have a pH below 7.5–8.0 and a Carbon/Nitrogen ratio between 25:1 and 30:1. If you can smell ammonia in the barn, the C:N ratio is likely to be below 25:1 (Bewley, 2012).

Signs of a healthy compost-bedded pack:

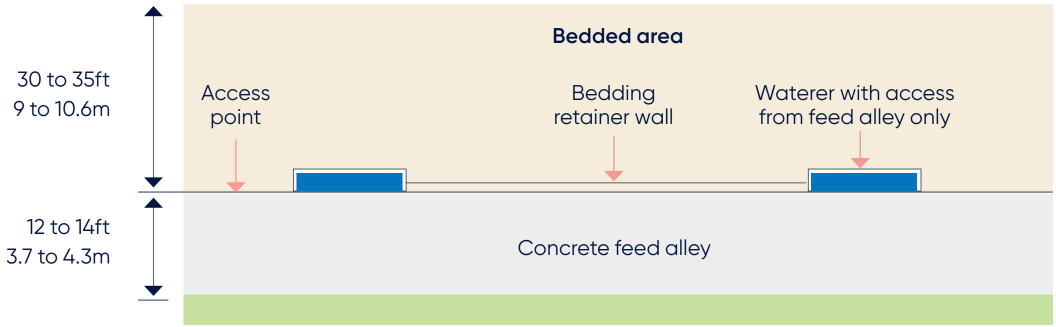
- Surface of pack is dry, fluffy and at ambient temperature, with no moist chunky areas
- At 15–30cm below surface, temperature is 45–60° Celsius (110–140° Fahrenheit) (hot to touch)
- Moisture content is 40–60%
- Steam is coming off surface of pack in morning (Bewley *et al.*, 2012)

Resting space per cow

An overstocked compost bedded pack barn can lead to serious problems: Wet pack, dirty cows, and high somatic cell counts. This is because more manure and urine is generated, increasing the pack's moisture content and slowing the composting process, and the bedding becomes more compacted, reducing airflow in the pack.

The recommended bedding area in a compost bedded pack is about 10m^2/cow. However, recommendations range from 7–30m^2/cow (Janni *et al.*, 2006). In facilities for special needs cows, at least 12 m^2 of resting space should be provided. Additional space increases cows' lying time per day. Tabara (2017) suggested that cows producing more than 40 litres/day require an area of more than 14m^2/cow for efficient composting to occur.

Figure 15. Typical compost bedded pack barn layout



Barn layout and fixtures

Well-designed compost bedded pack barns have the following features (Figure 15):

- Solid walls 0.6–1.2 metres separating the feed alley from the pack area and enclosing the entire pack area
- Multiple access points from pack area every 15 metres and at each end along the long side of the rectangular resting area to a concrete feed alley of adequate width (5 metres) and water troughs
- Feedbunk space, design and feed barrier (post and rail or head locks) as per in a freestall
- Access to water troughs only from the concreted feed alley
- Sidewall access for machinery for pack filling, tilling and removal, and
- Wide eaves to minimise rain reaching the pack and roof gutters to prevent water running off roof and blowing into barn onto pack.

Ventilation

Adequate ventilation is essential to remove heat and moisture created by cows and the composting process. Natural ventilation should be adequate if the barn is well designed with an adequate roof height at the sides, an adequate roof pitch and a continuous centre ridge vent with an adequate opening. Sidewall curtains should only be used in extremely cold and windy conditions and not impede air flow when open.

Fans assist air flow and pack moisture evaporation. They are particularly important in hot weather, when cows may be inclined to congregate in areas of the barn with higher natural airflow, leading to problems with maintaining a good pack. Small box fans may be used or High-Volume, Low Speed (HVLS) fans, so named due to their large size (2.5-7.3 metre diameter) and slow-moving speeds (45 revolutions per minute for a 7.3 metre fan). For a 7.3 metre HVLS (helicopter) fan, there should be a minimum of 20 metres between each fan if they span down the centre of the barn just over the feed alley. If used correctly, moisture, heat and odour can all be greatly reduced. However, HVLS fans often need the assistance of smaller fans, closer to the pack, to establish sufficient airspeed to dry the pack and cool the cows. It is important that there is enough clearance under fans for machinery.

RECOMMENDATIONS FOR COMPOST-BEDDED PACK MANAGEMENT (CHAMBERLAIN, 2018):

- Ensure ventilation is appropriate and exogenous water does not enter pack (e.g. rain or water from water troughs or sprays) to wet the pack
- Ensure bedding material is suitable for composting
- Ensure air flow into the shed is sufficient, especially if using side curtains
- Ensure fans are working effectively and air movement at the cow and pack level is sufficient
- Till the pack twice daily
- Monitor daily for moisture, temperature, evenness of cow distribution, bedding pack consistency, smell at pack level (for ammonia), cow cleanliness, cow rumination and laying behaviour
- Act quickly to address pack moisture and temperature concerns (add new bedding, reduce stocking rate, address cow congregation issues), and
- Implement and maintain appropriate mastitis and milking management program, to reduce the risk of organisms from the pack causing increased cases of clinical mastitis, increased SCC and increased milk contamination

Shade and evaporative cooling

The first step is always to provide shade i.e. protect cows from direct exposure to radiant heat. Having provided shade, the next most important thing to consider is evaporative cooling, as evaporative heat loss is the most efficient way for cows to off-load heat. Cows can off-load three times as much heat through evaporation when the air is moving at 1 metre/second as when it is still. Sprinkling or soaking cows to the skin and then evaporating water off with supplemental airflow (fans) is therefore the most efficient method to remove heat from cows.

Using sprinkling in combination with supplemental airflow (fans) is superior to either a fan or sprinkling alone. Increasing airflow and wetting frequency has a dramatic effect on the evaporative heat loss from the skin of dairy cows. Both low-pressure and high-pressure systems that soak the skin are more effective than high-pressure systems that only reduce air temperature.

In concrete feed alleys, a sprinkler line can also be installed along the top rail at the feed bunk, to wet the cows' shoulders and back while eating, providing cooling over and above the evaporative system.

While efforts to minimise heat stress tend to be focused on lactating cows, it is important to realise that if dry cows are heat stress, this may negatively impact:

- Mammary gland development before calving, resulting in fewer functional mammary cells at the onset of lactation, thereby compromising subsequent lactation performance (Tao *et al.*, 2013)
- Immune and metabolic function, and may also affect subsequent reproductive performance
- Foetal development in the uterus due to its effect on placental tissue, leading to a decrease in calf birth weight, and
- Passive immunity and cell-mediated immune function in newborn calves.

Dry cows should therefore be run in paddocks with adequate shade or housed in barns with access to evaporative cooling.

Flies

Flies can be a major source of irritation to cows and staff in the warmer months. The fly lifecycle requires that immature flies (eggs, larvae, pupae) live in manure, moist hay, spilled silage, wet grain, or a similar environment for 10 to 21 days depending on temperature and fly species. A high standard of barn hygiene, with minimal accumulation of manure, should therefore be the foundation of any fly control program.

Flies can be controlled using chemical and biological means. Chemical control options include space sprays, baits, larvicides, residual premise sprays, and animal sprays. Several insecticidal products are registered for use in and around animal sheds to control nuisance flies. (Visit www.infopest.com.au for a list). Care needs to be taken not to overuse insecticides, as this will foster development of insecticide resistance.

Biological control options include predatory beetles and mites, parasitic wasps and other insects. Fly control can only be achieved using an integrated pest management approach.

5. INTEGRATED FACILITY FOR FEEDING AND HOUSING COWS: DAIRY DRY LOT

Dairy dry lots are generally more successful in dry climates. Constructed with the correct slope for drainage to a centralised manure system, a well-managed dairy dry lot provides cows with a comfortable, low stress environment. Feeding areas may be fitted with cooling infrastructure such as misters to make sure cows stay cool on hot days. Cows have freedom to lie down and rest and move around and socialise. Dry lots are though to be advantageous, in comparison to other intensive housed systems (e.g. freestall) because of lower disease prevalence (e.g. lameness and mastitis), better reproductive outcomes (USDA, 2010) and lower capital costs (Stokes & Gamroth, 1999).

Factors which impact on cows' lying time and general level of comfort are:

- Access to shade
- Bedding and management
- Dairy dry lot layout

Access to shade

Shade is important to protect cows from direct exposure to radiant heat and rain. Ideally, shade structures should be constructed parallel to the feed table and cow alleys in the centre of pens so that cattle can follow the shaded area as it moves across the pen during the day. The orientation of a shade structure should be north-south with the eastern side of the structure elevated to provide a 10–15° pitch (Figure 16). This allows better pen floor drying during the morning, provides more shade area during the afternoon and increases air flow under the shade structure. Shade roofs should be steel clad with a minimum height of 3.6m from the ground. Smith *et al.* (2006) recommend the installations of gutters on shades structures to remove water from the pens to allow the earthen surface to dry quicker after inclement weather. The total area of shade recommended is 4.6m^2 per cow. Cooling measures such as fans and water misters may be used beneath the shade. Major design considerations for shade structures including orientation, space, height and shading material are described in chapter 16 of MLA's "Beef cattle feedlots: design and construction" guidelines (Watts *et al.*, 2016).

Figure 16. Centralised shade shelters at a dairy dry lot with a north-south orientation

Bedding and management

The bedding in dairy dry lot shelters can be non-composting bedding packs, composting bedding packs (CBP), or packs that only actively compost occasionally. CBP needs to be managed to provide cows with a comfortable, dry bedding surface (Figure 17). CBP relies on an aerobic process to decompose cow waste (manure and urine) in the bedding. Tilling at least twice a day is generally recommended and can be timed when the cows are being milked. If possible, cows should be kept off the pack for at least an hour after tilling to enable the top layer to dry, especially during winter.

Regular mechanical tillering fluffs up the bedding and encourages the composting process drying the pack and killing some pathogens, viruses and fly larvae. A loose fluffy pack is a good indicator of a well-managed pack, especially if it feels warm below the surface, as it is aerated ad the microbes are active and generating heat (Chamberlain, 2018). Conversely, a compacted, cool pack results in chunky bedding indicating the pack is not well composted (Figure 18).

Figure 17. A well-managed CBP provides cows with a comfortable, dry bedding surface

Figure 18. CBP that is not well managed – over crowding results in a wet chunky, cold bedding surface

Dry lot layout

Sound design ensures optimum animal performance, good animal welfare and high standards of environmental performance (Figures 19 and 20).

Key considerations of well-designed pen layouts:

- Pens are constructed with 2-3% side slope and 0.5-1% down slope. Pens with a double slope are ideal with the shade located at the high point of the pen. Pen slopes less than 2% do not drain well and can emit odour at 50 to 100 times the rate of dry pen surfaces (Watts *et al.*, 2016). Wet patches also lead to discomfort of cows.
- Proper site drainage design. Construction of dairy dry lot so water drains outside of the pens in ideal. The slope of the pen will have a dramatic impact on how fast the earthen surface will dry (Smith *et al.* 2006).
- There should be 45 to 50m^2 of net space per cow in the dry lot if feed lane manure is scraped or flushed out of the system. If feed lane manure is scraped into the lot, then net space per cow should be increased to 60m^2 or higher (Jake Martin, Pers. Comm.).
- Feed table and feed alley design is as for a freestall with a north-south orientation in parallel to the shade structures. If sprinklers are used at the feed table, it is important that a nib wall is installed, and the alley is sloped towards to the feed table to prevent runoff from the sprinklers reaching the earthen surface of the pen.
- Wind breaks can improve cow comfort where the potential for severe weather exists.
- Water troughs design and specification is as for a freestall. Water troughs should allow dairy cows access to an adequate supply of good quality water for their survival, welfare and performance without causing environmental impacts on the feedlot (MLA 2016). The water trough system should:
  - Provide clean, cool, fresh water at an adequate volume of water to livestock
  - Provide sufficient access area to enable all cattle to drink regularly
  - Allow for easy and regular cleaning inside the trough
  - Not cause wet areas or drainage problems in pens or lead to pen maintenance issues.

Figure 19. Aerial image of a well-designed dairy dry lot with north-south shade structures and central feeding table

Figure 20. A leaking trough will cause drainage problems on the earthen dry lot pen

KEY TO SUCCESS: MAXIMISE COWS' DAILY FEED INTAKES AND MINIMISE WASTE

1. TEMPORARY FEED-OUT AREA

Strategies to maximise cows' daily feed intakes and minimise feed wastage when temporary feed-out areas are used are limited.

If feeding-out on a **grazed paddock**, it is recommended that:

- Feed-out in dry conditions
- Pasture is short to medium length (i.e. not too long)
- If feeding hay/silage, its chop length is less than 15cm (i.e. not too long)
- If feeding PMR, it comprises high quality feeds and has been correctly processed (i.e. it is not too dry, wet course, fine or dusty
- Feed looks and smells fresh, and is always highly palatable, and
- Cows have good appetites (i.e. cows are not suffering ruminal acidosis, heat stress or other health problems, and have not been fed large quantities of grain/concentrates or other feeds within the past 2 hours).

If feeding-out **on bare ground, in ring feeders, old tractor tyres or under a fence line,** it is recommended that:

- Feed-out in dry conditions
- If feeding hay/silage, its chop length is less than 15cm (i.e. not too long)
- If feeding PMR, it comprises high quality feeds and has been correctly processed (i.e. it is not too dry, wet course, fine or dusty
- Feed looks and smells fresh, and is always highly palatable
- Feeders used are large and deep enough to easily hold quantity of feed to be fed without spillage
- Feeders are not being over-filled
- Feeders have minimal residual feed in them after each feeding event
- Feed space of cow width + extra 10-30% is provided to each cow
- If using hay rings, adequate rings are provided so that no more than 20 cows share each ring, and
- Cows have good appetites (i.e. cows are not suffering ruminal acidosis, heat stress or other health problems, and have not been fed large quantities of grain/concentrates or other feeds within the past 2 hours).

2. BASIC FEED-OUT AREA

3. FORMED EARTHEN FEEDPAD

4. CONCRETE FEEDPAD

Factors which impact on cows' daily feed intakes and wastage of mixed rations on feedpads are:

- Feed bunk space
- Feed barrier design
- Feed availability, and
- Feed delivery frequency and timing.

The values in Table 11 are derived from the Dairy Australia Grains2Milk study in 2009 of feed wastage rates on 50 commercial dairy farms in the states of QLD, NSW, VIC and SA which used a range of different feed-out methods. This work was undertaken for Dairy Australia by Scibus. The study showed that within any feed delivery facility, feed wastage rates can vary substantially. Some farmers achieve very low wastage with careful management and attention to feed quality and palatability.

Table 11. Feed wastage rates* with different types of feed delivery infrastructure (under dry conditions)

	Min.	Typical	Max.
Basic feed-out area	5%	10%	20%
Formed earthen feedpad	2%	5%	10%
Concrete feedpad	0%	3%	5%

* Note – the feed wastage rates in this table may not reflect the full range of wastage that might occur under wet conditions.

A key concept is **feed 'refusal' and 'wastage'**:

- **Refusal** is the amount of feed that remains in the feed troughs, on pasture and on bare ground, and does not get consumed by cows after a certain period following the feed-out. The refusal may or may not be eaten at a later stage.
- **Wastage** is the amount of feed contaminated with urine or faeces and soil or spread out around the feed-out area and will not be eaten by cows at a later stage.

When feed is delivered on a feedpad (feed delivery infrastructure Type 3 and 4) with a well-designed concrete feed table, feed refusals should be able to be collected and fed to other cattle on the farm such as dry cows.

Feed bunk space

Unfortunately, specific guidelines to enable a farm to determine the most appropriate feed bunk space allocation for its circumstances based on cow breeds and liveweights, feedpad design, diets, feed quantities/meal, daily feeding regimes and other factors have not yet been determined.

However, Dr Pieter Raedts, researcher at the Tasmanian Institute of Agriculture (TIA), has suggested that feeding space allocation should be based on two parameters: cow size and cow social personal space:

- **Cow size:** Feeding space should be related to cow size and varies between 55cm for a 400kg cow, to 75cm for a 625kg cow and is correlated to the cow's 'empty' stomach width.
- **Cow social personal space:** This mostly depends on lactation stage, ranking order in the herd and grouping, and feed bunk design (head-locks, or bars/cables). Early lactation cows, heifers and lower ranking cows need more space, say 10–20% more with headlocks, and say 20–40% with bars/cables, to find a safe eating space away from dominant cows.

A reasonable cow eating space 'rule of thumb' would therefore be:

100% of cow width + extra 10–30% for social personal space

OR

55cm for 400kg cows to 75cm for a 625kg cow, + 10–30% depending on parity and stage of lactation of cows in the herd

Feedpad design

The feedpad's surface must be durable, hoof friendly, non-slip and easy to clean and maintain. Concrete aprons around troughs will prevent mud and slush reducing feed palatability and extend the life of an earthen feedpad.

If troughs are used, they must be wide and deep enough to easily hold the quantity of feed to be fed out without spillage and be safe for cows. Trough surfaces should be smooth to avoid build-up of waste feed, moulds, odours and be easy to clean. The feeding table's height should enable cows to eat with their head in their natural grazing position – about 10–15cm above the ground. This position also helps cows produce more saliva to help buffer their rumen.

The design of the feed barrier that separates cows from their feed impacts on competition between cows, and therefore their feed intakes. It also impacts on the proportion of feed that is wasted. The two main alternative feed barriers are the open-type feed barrier (electric wire, cables or post and rail) and headlocks (self-locking stanchions). Figure 21 illustrates alternative feed barriers.

An electric wire is a simple, inexpensive option for a basic feedpad with concrete troughs to prevent cows jumping into or over the trough from either side. Cables and post and rail are suitable for concrete feed bunks with a nib wall. To be effective, the cables or rail needs to be high enough above the floor so that each cow can stand and eat at the feed bunk comfortably without experiencing any pressure on her neck, but not so high that it enables the cow to step under it and escape into the feed alley.

In in a post-and-rail feed barrier, current recommendations for the height of the neck rail vary between 122–137cm (from the standing surface to the rail). At a higher placement, no offset is necessarily needed; however, at a lower placement (toward 122cm), an offset of 15–25+cm from the manger wall towards the feed may be necessary.

Cow dividers have been found to reduce aggressive interactions between cows when installed at post and rail barriers, as they create separation between the heads of cows and provide subordinate cows with better access to feed (Hetti Arachchige *et al.*, 2014).

Figure 21. Alternative feed barriers: Electric wire, cables, post and rail, headlocks

Endres *et al.* (2005) found that providing head locks for cows at the feed bunk instead of a post and rail barrier between cows and the feed bunk reduced the number of competitive interactions between cows during periods of peak feeding activity (i.e. the first 90 minutes from delivery of fresh feed) and subordinate cows were displaced less frequently, resulting in longer feeding times. Huzzey *et al.* (2006) also found that head locks were superior to a post and rail barrier. Head locks are a useful cow management aid as they also enable farm staff members to easily assess health and breeding status of individual cows without disrupting their daily routines.

For headlocks, the top rail of the headlock should be positioned at a minimum height of 122cm and tilted forward by 15–20cm from the cow side of the bunk wall (DeVries, 2019; Figure 22). For headlocks, the width of each headlock is important. If they are less than the width of a cow, e.g. 0.6 metres, then it is difficult to fit cows into every headlock, and cows tend to leave several head locks empty. It is therefore better to size them at 0.7–0.75 metres wide for larger framed cows, particularly for transition cows. Figure 23 illustrates a post and rail design with cow dividers.

Figure 22. Head locks

Figure 23. Post and rail with cow dividers

Feed availability

If feeding hay/silage, chop length should be less than 15cm. If it is too long, the cows will sort through it and waste more. If feeding a mixed ration, it should comprise high quality feeds and has been correctly processed (i.e. it is not too dry, wet course, fine or dusty). Follow the manufacturer's instructions. Use ration conditioners such as water, molasses, or oil to reduce fines, sorting of feed and rejection or wastage of feed. Feed should look and smell fresh and be highly palatable at all times. Any spoiled/mouldy feed ingredients should be discarded.

Feeds should be sequenced carefully during each 24-hour period. Cows should be offered the right amount of feed at the right time of the day, without over-filling troughs. It is important to ensure that cows have good appetites (i.e. cows are not suffering ruminal acidosis, heat stress or other health problems, and have not been fed large quantities of grain/concentrates or other feeds within the past 2 hours).

Feed palatability

There is wide variation in cows' preferences for different feeds, which contribute to differences in feed intake beyond those attributable to variation in digestibility. Feed palatability has implications for stocking rate, grazing management options such as pasture topping and mixed species swards, and the use of supplementary feeds.

- The palatability of a feed (i.e. a cow's preference for a feed) is determined by its taste, smell, appearance, temperature, texture and other physical characteristics
- Cows are more sensitive to the different characteristics of feeds when they have a choice between two or more feeds.
- Time spent grazing is often used to evaluate cows' preferences for pasture and other grazed forages.
- Animals seem to be quite good at relating the sensory characteristics of a given feed with its nutritional quality.
- There is individual cow variability in feed preference/palatability, just as there is in humans.
- Cows generally have a sweet tooth. Spraying products like molasses on feed or mixing it in feed will increase intake.
- As already discussed, cows have a naturally aggressive feeding drive.

Access to fresh drinking water

Lactating dairy cows are more sensitive to drinking water access and quality problems than other production animals because they require larger volumes of water per unit of body mass, their rumen pH needs to be maintained within a relatively narrow range for good rumen function, and their rumen function may be altered by water containing a high total bacteria count.

Restricted water access will lead to reduced feed intake.

When on a feedpad, cows should always have access to two water troughs. Cows appear to prefer larger, higher troughs to smaller, lower troughs. Large volume concrete troughs help keep drinking water appropriately cool during hot weather (Figure 24).

Many different microorganisms can survive in drinking water supply systems and are potentially hazardous. Water troughs are of particular concern as they can become readily contaminated with cud and manure, faeces from birds, rodents, recycled water, dust, feed, bedding material, and microbes entering through the water pipe. These contaminants can provide a nutrient-rich substrate for bacterial growth and survival at the bottom of a trough. E.coli count per 100ml is used as an indicator of faecal contamination and possible presence of pathogens in water. However, for dairy cattle there are no agreed acceptable levels for E. coli in drinking water, although acceptable levels for total coliforms of <0.5 MPN/100 ml and <50 MPN/100 ml have been suggested by Socha (2003) and Beede (2006). Trough hygiene should therefore be an important aspect of good water management. On many dairy farms overseas, water troughs are routinely cleaned and sanitised e.g. weekly, and being able to see the bottom of trough is expected. Yet in Australia we tend to give trough hygiene little attention.

Figure 24. Large concrete trough on feedpad

5. INTEGRATED FACILITY FOR FEEDING AND HOUSING COWS:

- FREESTALL

- COMPOST BEDDED PACK BARN

- DAIRY DRY LOT

For cows to perform optimally in dry lots and in freestall and compost bedded pack barns they must be designed and managed to maximise cows' daily intakes of the TMR. More milk/cow is a key profit driver.

Total daily feed intake is a function of the number of meals consumed daily and their size (kilogram per meal). Cows fed a TMR typically consume their daily feed intake in 3–5 hours per day, spread between 7–12 meals per day (DeVries, 2019). If cows consume more meals over a longer total time per day at the feed bunk, then increased daily feed intake can be achieved.

Factors which impact on cows' daily feed intakes of TMRs in barns are:

- Feed bunk space
- Feed barrier design
- Feed availability
- Feed delivery frequency and timing
- Feed push-up frequency and timing
- Time per day spent being milked
- Cow health (especially lameness)
- Cow grouping
- Feed palatability, and
- Access to drinking water.

Feed bunk space

In barns, cows must compete for feed as there is insufficient linear space at the feed bunk for all animals to feed together. Dominant cows spend more total time eating than cows of lower social rank (Olofsson, 1999). Overstocking the feed bunk increases aggressive interactions between cows and forces cows to change their feeding behaviour. They have reduced feeding time, eat more quickly, and consume fewer, larger, and longer meals each day. Greater feed bunk competition may also be associated with reduced rumination activity (Huzzey *et al.*, 2006; Crossley *et al.*, 2017; DeVries, 2019).

Recent studies have shown that altered feeding behaviour in cows competing for feed bunk space elicits a stress response, especially in first-calvers and subordinate cows (Huzzey *et al.*, 2012), and may also impact on cow reproductive function and performance (Schefers *et al.*, 2010). DeVries *et al.* (2004) found that doubling feeding space from 0.5–1.0 m per cow reduced the number of aggressive interactions while feeding by 57%, allowing cows to increase feeding activity by 24% at peak feeding times.

The traditional recommendation for linear feed bunk space has been 0.6 metres. However, recent recommendations are 0.7-0.75 metres. These recognise that Holstein cows have increased in frame size, and that bunk space must be adequate for peak periods of feeding activity, which in barns are when feed is delivered, and to a lesser extent, when feed is pushed up and when cows return from milking.

Feed bunk space per cow is a function of the length of the feed bunk, the number of cubicles in the barn and the cubicle stocking rate. The greater the number of rows of cubicles in a barn pen, the less feed bunk space is available per cow. Construction of pens with three or more rows of cubicles per feed bunk should be avoided, because these typically limit feed bunk space to 0.4–0.45 metres per cow or less with 100% cubicle stocking (DeVries, 2019).

Transition cows appear to be most adversely affected by overcrowding at the feed bunk, as it leads to increased incidence of health problems such as subclinical ketosis, metritis and displaced abomasum in the early postpartum period, with reduced milk yield (Huzzey *et al.*, 2007; Proudfoot *et al.*, 2009; Kaufmann *et al.*, 2016). More generous feed bunk space (>0.75 metres per cow) should be provided in pens of pre- and post-calving transition cows, and headlocks provided.

Feed barrier design

The design of the feed barrier that separates cows from their feed also impacts on competition between cows. Figures 25 and 26 illustrate the two main alternative feed barriers are the open-type feed barrier (post and rail) and headlocks (self-locking stanchions). Endres et al. (2005) found that providing head locks for cows at the feed bunk instead of a post and rail barrier between cows and the feed bunk reduced the number of competitive interactions between cows during periods of peak feeding activity (i.e. the first 90 minutes from delivery of fresh feed) and subordinate cows were displaced less frequently, resulting in longer feeding times. Huzzey et al. (2006) also found that head locks were superior to a post and rail barrier. Head locks are a useful cow management aid as they also enable farm staff members to easily assess health and breeding status of individual cows without disrupting their daily routines.

For headlocks, the width of each headlock is important. If they are less than the width of a cow, e.g. 0.6 metres, then it is difficult to fit cows into every headlock, and cows tend to leave several head locks empty. It is therefore better to size them at 0.7–0.75 metres wide for larger framed cows, particularly for transition cows.

For a post and rail feed barrier, the rail needs to be high enough above the floor that each cow can stand and eat at the feed bunk comfortably without experiencing any pressure on her neck, but not so high that it enables the cow to step under it and escape into the feed alley. Current recommendations for the height of the neck rail in a post-and-rail feed barrier vary between 122–137cm (from the standing surface to the rail). At a higher placement, no offset is necessarily needed; however, at a lower placement (toward 122cm), an offset of 15–25+cm from the manger wall towards the feed may be necessary.

For headlocks, the top rail of the headlock should be positioned at a minimum height of 122cm and titled forward by 15–20cm from the cow side of the manger wall (DeVries, 2019). Cow dividers have been found to reduce aggressive interactions between cows when installed at post and rail barriers, as they create separation between the heads of cows and provide subordinate cows with better access to feed (Hetti Arachchige *et al.*, 2014).

Figure 25. Head locks

Figure 26. Post and rail with cow dividers

Feed availability

The principle of a system in which a TMR is fed is that cows are fed *ad libitum*. In reality, farm managers must walk a fine line between offering too much feed, thereby suffering excessive wastage, and offering too little feed, thereby allowing the feed bunk to become empty for several hours per day and restricting feed intake.

Studies have shown that long periods with empty feed bunks impacts negatively on cow behaviour, feed intake and milk yield. The aim is to make feed available to cows for at least 23 hours per day, with very low refusal rates (<1-2%). To achieve this, feed bunks need to be closely monitored.

Feed delivery frequency and timing

The frequency with which TMR is delivered to cows at the feed bunk impacts on their feeding behaviour patterns and ruminal function. Several studies have shown that feeding two or more times per day (vs. once per day) leads to more even nutrient intakes by cows over each 24-hour period, which leads to more stable rumen pH, fibre digestion and possibly feed conversion efficiency. The risk of ruminal acidosis is therefore reduced. Subordinate cows are also better able to access feed when delivered feeding two or more times per day. Feeding two or more times per day also reduces feed sorting and increases daily feed intakes and milk yields (Hart *et al.*, 2014; Sova *et al.*, 2013).

Feeding more frequently per day requires additional labour and fuel costs. Benefits will vary from farm to farm but may certainly be significant if barn pens are highly stocked and/or weather is hot and humid.

The timing of TMR delivery during the day also impacts on cows' feeding behaviour patterns. Staggering the times of milking and feed delivery should stimulate greater feeding activity throughout each day (King *et al.*, 2016). However, provision of fresh feed or pushing up feed following milking has been shown to reduce the risk of mastitis, as it encourages cows to remain standing rather than going to a cubicle and lying down while their teat canal remains open and therefore vulnerable to an ascending infection (DeVries *et al.*, 2010).

Feed push-up frequency and timing

When eating, cows tend to sort the TMR and push some of it out of reach. Feed therefore needs to be pushed closer to cows in between feed deliveries to ensure that cows have continuous access to it i.e. that feed access is not restricted. Feed push-ups may be done manually using a tractor fitted with a rubber blade (Figure 27). Alternatively, automated push-up

Figure 27. Push-up using tractor

Figure 28. Push-up using a robot

systems may be used to push-up feed as often as 24 times per day. These systems may be hydraulic or cable, or wheel-mounted, battery-operated push-up 'robots' (Figure 28).

The most important time for feed push-up is in the first 1-2 hours after feed delivery when feeding activity is greatest. Feed push-ups should be done more frequently if cows develop lesions on the back of their necks from pushing against the neck rail to stretch out and reach feed, or if feed push-ups stimulate cows to come to the feed bunk and eat, indicating that they are hungry.

Frequent feed push-ups have other benefits. They serve to re-mix feed at the feed bunk and by re-forming feed piles with less surface area they reduce heating and shrinkage. (The aim is to push and roll the feed, not just push it, to aid re-mixing). Push-ups thereby help to reduce refusals and help to keep the feed bunk clean.

Time per day spent being milked

Greater time spent by cows per day out of the pen while being milked is associated with less time spent eating and therefore lower milk yields. It is important that the size of the dairy parlour and its throughput rate are proportional to the size of the barn. Distance between the barn and the dairy parlour is also important (Gomez & Cook, 2010).

Cow health (especially lameness)

If cows are forced to spend more time standing inactively waiting their turn at an occupied feed bunk, and therefore spend more time standing outside the stall on hard, wet floors, their risk of developing foot problems may be increased (Galindo *et al.*, 2000). Cows that are lame spend less time eating and have reduced feed intake. This is exacerbated in barns where feed bunk space per cow is sub-optimal.

Cow grouping

Azizi *et al.* (2010) found that first-calvers had a lower feeding rate, took more meals of smaller size, and spent more time feeding than older cows. In barns, lactating cows may be segregated into separate groups by parity or stage of lactation. If feasible, first calvers should be housed as a separate group as they are likely to suffer aggression from older cows when placed in mixed age groups and this may reduce their daily feed intake, particularly in barns where feed space per cow is sub-optimal. Grant and Albright (2001) found that when managed as a separate group, first calvers ate for 11.4% longer, ate 8.5% more meals per day, and consumed 11.8% more dry matter per day. It is important to remember that first-calvers are still growing, have a different shaped lactation curve to older cows, and therefore have different nutritional requirements.

In robotic freestall systems it has been found that when a group of cows comprises animals at all stages of lactation, robot utilisation is improved, as it appears that early lactation cows stimulate staler cows to visit the robot more often. Whether this occurs in conventional freestall systems is uncertain. Grouping cows also provide the opportunity to offer rations formulated specifically to meet the metabolic needs of cows which changes as cows progress through early/mid/late lactation (Allen, 2012).

Once a group of cows has been formed, introduction of new cows should be avoided as this forces a re-set of the group's social hierarchy, involving aggressive behaviour which reduces feed intake of some animals. This reduction in feed intake is likely to be exacerbated in barns where feed space per cow is sub-optimal.

Feed palatability

There is wide variation in cows' preferences for different feeds, which contribute to differences in feed intake beyond those attributable to variation in digestibility. Feed palatability has implications for stocking rate, grazing management options such as pasture topping and mixed species swards, and the use of supplementary feeds.

- The palatability of a feed (i.e. a cow's preference for a feed) is determined by its taste, smell, appearance, temperature, texture and other physical characteristics.
- Cows are more sensitive to the different characteristics of feeds when they have a choice between two or more feeds.
- Time spent grazing is often used to evaluate cows' preferences for pasture and other grazed forages.
- Animals seem to be quite good at relating the sensory characteristics of a given feed with its nutritional quality.
- There is individual cow variability in feed preference/palatability, just as there is in humans.
- Cows generally have a sweet tooth. Spraying products like molasses on feed or mixing it in feed will increase intake.
- As already discussed, cows have a naturally aggressive feeding drive.

Access to drinking water

Lactating dairy cows are more sensitive to drinking water access and quality problems than other production animals because they require larger volumes of water per unit of body mass, their rumen pH needs to be maintained within a relatively narrow range for good rumen function, and their rumen function may be altered by water containing a high total bacteria count.

Restricted water access will lead to reduced feed intake. The general recommendation for barns is to provide 10 linear centimetres per cow of water trough space. For example, in a 300-cow barn: 300 cows X 10cm per cow = 30m = 8 X 3.75m water troughs. Two of these troughs should be placed at each end of the barn and two at each of two cross-overs. The cross-overs should be wide enough for free cow flow to minimise aggressive behaviour by dominant cows and provide adequate access to drinking water. A minimum width of 2.4 metres is recommended. However, 3 metres may be better. Water troughs should be stainless steel (not concrete) and able to be tipped for easy cleaning on a regular basis (Figure 29). Water access at the exit of the milking parlour is believed to be worth 2–3 litres milk per day in hot weather.

Figure 29. Stainless steel trough in a cross-over

KEY TO SUCCESS: CONSTRUCT EARTHEN FEEDPAD WITH A DURABLE, LONG-LASTING SURFACE

2. BASIC FEED-OUT AREA

3. FORMED EARTHEN FEEDPAD

Four critical factors will help to extend the lifespan of an earthen feedpad from just a few years to 20+ years.

Surface material selected

The surface material for an earthen feedpad must be selected very carefully. It should be a uniformly blended mixture of coarse and fine aggregate (i.e. an evenly graded material) that is free from sharp stones, cobbles, stumps, roots, sticks etc. While gravel surfaces are more durable and can withstand higher loading, they are not as hoof friendly.

If the material on-site has low load-bearing strength because of an excess of clay, silt, or fine sand, adding a stabiliser such as hydrated lime or gypsum, or buying in a good quality material from a quarry, should be considered. Geosynthetics, which are thin, flexible, and permeable sheets of synthetic material used to stabilize soil, should also be considered. Cheap and resistant to moisture and bacteria, their filtration restricts movement of fine soil particles but allows some water to permeate. They also reinforce and stabilize soil to decrease compaction by stock.

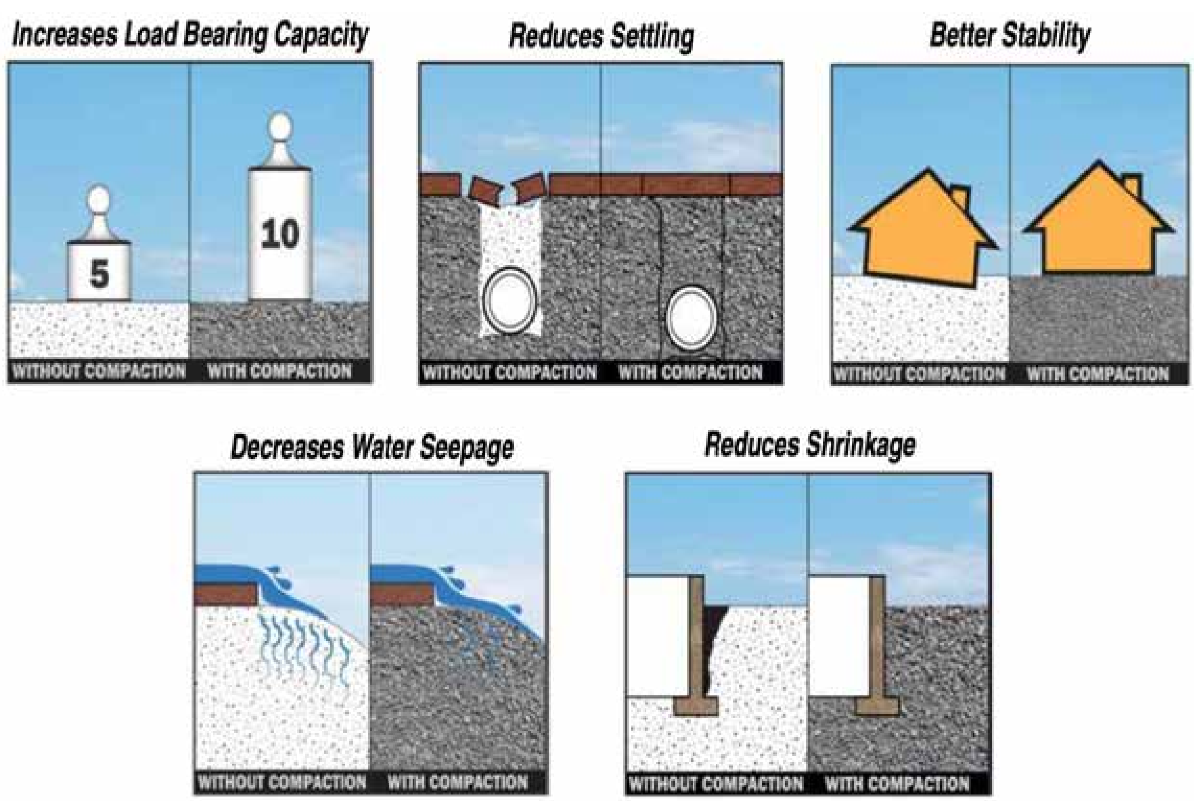
Compaction of material

Compaction of the material is necessary to increase its dry density and therefore its load-bearing capacity, durability, and water permeability. This is achieved with a vibrating or compression roller (as used in road construction).

Figure 30 illustrates the importance of a well compacted surface in terms of loadbearing capacity, settling, stability, water seepage and shrinkage.

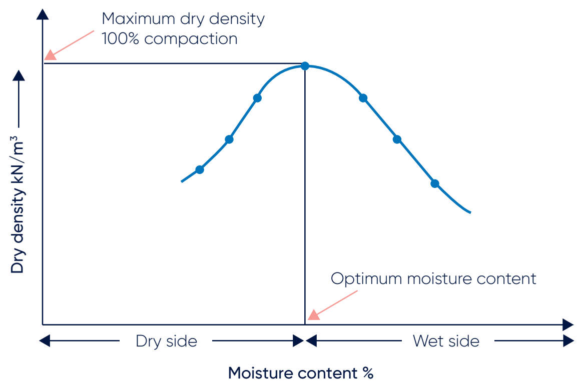
Each material has an optimal moisture content for maximising dry density with compaction (Figure 31). This is achieved with a water truck as used in road construction. The variation in optimal moisture contents between different materials (i.e. products CL, ML SM etc.) is illustrated in Figure 32.

Figure 30. Effects of compaction



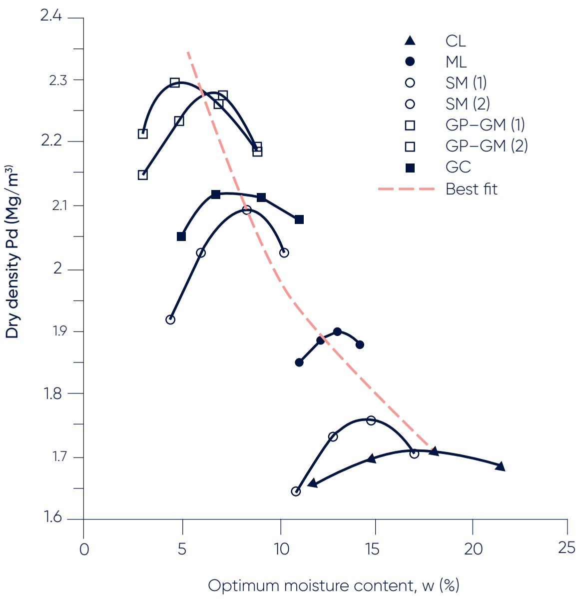
(MultiQuip Soil Compaction Handbook, 2020)

Figure 31. Optimal moisture content for dry density of a material



(www.theconstructor.org)

Figure 32. Optimal moisture contents of several materials



(Saroglou, 2009)

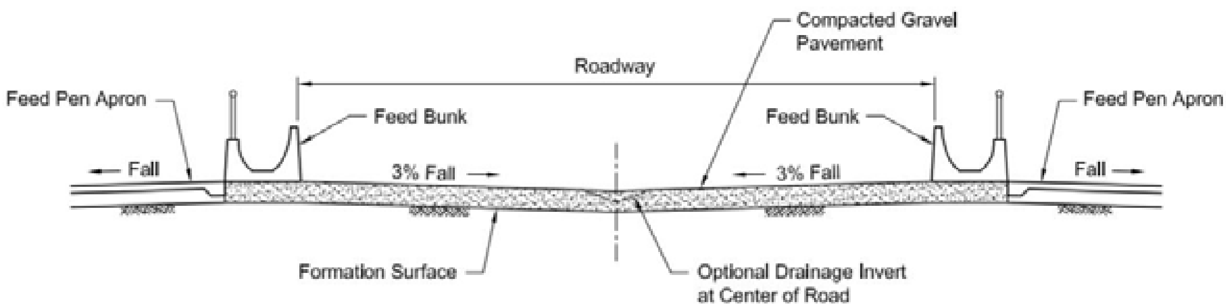
Thickness

Ensure that the surface layers of the feed pen and roadway are thick enough to spread the load of cow and vehicle traffic so that the underlying subgrade is not stressed. These thicknesses will depend on the load-bearing strength of the material used, the strength of the foundations, drainage and expected load of both cows and vehicles. A thickness of between 150–360mm may be required for feed pens and between 200–670mm for roadways (MLA, 2016).

Contours

The pad needs to be contoured with sufficiently angled slopes (3–5%) to carry manure and run-off away from the feeding table. Sub-surface drainage using slotted drainage pipes 1.5–2.0m apart should be overlaid by 20cm gravel (Figure 33).

Figure 33. Example of feedpad with contours for a central feed alley and pen aprons on either side



(MLA, 2016)

KEY TO SUCCESS: LAYOUT THE FARM'S 'KITCHEN' WELL

3. FORMED EARTHEN FEEDPAD

4. CONCRETE FEEDPAD

5. INTEGRATED FACILITY FOR FEEDING AND HOUSING COWS

When developing a feedpad, dairy dry lot, freestall or bedded pack compost barn, it is easy to get so focused on the design of the pad itself and its effluent system that the facilities for storing and mixing of feeds and delivering rations to cows get insufficient consideration. Figure 34 illustrates the components of a farm kitchen.

The farm's 'kitchen' needs to:

- Be in close proximity to feed storage facilities and feedpad or cow barns
- Provide all weather access for feed delivery trucks and all other vehicles
- Have adequate facilities to store conserved forages with minimal loss of dry matter and quality (Shrink is often under-estimated because it is difficult to measure)
- Have adequate facilities to store wet and dry co-products. These may include open air piled storage, straw and concrete block bunkers, bunkers with roll-over tarps and fixed roofs (Inexpensive feed storage facilities for wet and dry co-products may work well in the short term but they usually involve higher feed spoilage and wastage costs)
- Be situated with sufficient buffers from sensitive receptors (i.e. waterways, neighbors), and
- Contain all site runoff (i.e. storm water, leachates, sediment, nutrients).

Items of machinery used need to:

- Be easy and safe to operate
- Fit with existing farm infrastructure
- Deliver the same diet to all animals in the group
- Deliver a diet that adds to farm profit, and
- Be easy to maintain (having local mechanical support is important).

Figure 34. Busy feed kitchen with stationary mixer

KEY TO SUCCESS: MANAGE FEED PURCHASING WELL AND DESIGN WELL BALANCED DIETS

1. TEMPORARY FEED-OUT AREA

2. BASIC FEED-OUT AREA

3. FORMED EARTHEN FEEDPAD

4. CONCRETE FEEDPAD

5. INTEGRATED FACILITY FOR FEEDING AND HOUSING COWS

Australian dairy farmers are generally relatively unsophisticated feed purchasers, compared to stockfeed manufacturers and farmers in the poultry, pig and beef feedlot sectors, with many exposing themselves to significant price, quality and supply risks.

A majority of dairy farmers buy feeds on the 'spot' market, fully exposing themselves to market price volatility. Most buy grain/concentrates and fodder without always knowing its nutritional value (i.e. cents/MJ ME, $/kg crude protein) based on feed analysis, choosing to rely only on physical assessment and the price tag. Many do not confirm all the critical elements of a feed purchase agreement in writing with each feed supplier. Almost all dairy farmers buy their feed requirements independently. Most do not check the quality of each load of feed delivered to the farm and most do not reject out-of-specification loads at time of delivery or take steps to obtain compensation if accepted loads are subsequently found to be out-of-specification. The proportion of farms that feed diets formulated using a nutrition model is also low.

Farms using feed delivery and housing infrastructure use higher inputs of purchased feeds. It is therefore important that they use the methods and tools available to manage their feed price, quality, and supply risks, thereby avoiding being viewed by grain, fodder, and by-products suppliers as the "path of least resistance" for receival of loads of poorer quality parcels of feed. It is also important that they use methods and tools available to design diets that are nutritionally balanced and provide the optimal diet cost and milk income minus feed cost.

Feed budgeting

Feed planning (feed budgeting) has 3 main steps:

Step:	
1. Stock details	Describe animals to be included in the feed plan so their nutrient needs can be calculated
2. Feed details	Select feed types you wish to include in the feed plan for each class of stock
3. Diet details	Formulate a nutritionally balanced diet Calculate quantities of feeds required based on this diet

At each of these 3 steps there are values for parameters to be entered that need to be as accurate as possible.

The competitive advantages offered to Australian dairy farmers by the availability of moderately priced grain, fodder and other supplementary feeds are not being fully realised, in part due to dairy farmers' sub-optimal feed purchasing practices.

Many farmers do not apply a sound and rigorous feed budgeting method or tool before proceeding with feed purchases, and as a result may purchase feeds in insufficient or excessive quantities and/or at unprofitable prices. Only 57% of respondents in the Murray Dairy region to Dairy Australia's 2019 Feed and Animal Nutrition Survey Report claimed to do a feed budget (Dairy Australia, 2019a). Feed budgeting was performed by a much higher proportion of farms with herds over 300 cows than farms with smaller sized herds. Most farms that perform feed budgeting do so on a dry matter basis, rather than on a metabolisable energy basis.

Table 12. Methods for collecting the most representative feed sample possible

Grain/ concentrates and co-products	Supplied in semi loads • Collect several samples from at least 6 locations from the front to the rear • Use a slotted grain probe that is long enough to penetrate at least ¾ the depth of the load
Grain/ concentrates and other feed ingredients	Supplied in bags • 1–10 bags – sample all bags, collecting at least five probes • 11 or more bags – sample 10 bags at random • Stand each bag upright, insert the probe into the top corner and move diagonally through the bag to the bottom corner opposite the top corner and withdraw sample
Hay	Small square hay bales • Sample 10–20 bales, selected at random, using a probe or corer (grab samples are not good enough). • Take one core from each bale, near the centre of the 'butt' end, at right angles to the surface. • Ensure that the corer doesn't get too hot. Large round or square bales • Sample 10 bales, selected at random, using a probe or corer (grab samples are not good enough). • Take one core from the middle of the curved surface of each round bale taken through the middle of the bale. • Take one core from each side of each square bale, at right angles to the surface and at different heights. Hay cubes or pellets • Select a handful of cubes or pellets from at least 6 locations or bags.
Silage	Bunkers and pits • Ideally, collect a sample before opening the bunker or pit, using a long coring device that extends deeply into the pit or bunker. • Alternatively, take random handfuls from at least 10 locations across a freshly cut face of the bunker or pit (understanding that the silage face represents only a small proportion of the silage in the bunker or pit, so it may not provide a good representative sample). Wrapped bales • Sample 10 large bales, selected at random, using a coring device as for large round hay bales. Take great care to immediately reseal the holes made in the plastic by the corer.

Managing risks when buying feed

When buying in grain and other supplements, farmers tend to get very focused on the price tag. Yet there may be many more dollars at stake if a feed buyer fails to also manage feed quality and supply risks.

i. Quality risk

Feed quality needs to be managed:

- When agreeing to buy from a feed supplier
- When receiving each load of feed, and
- When feed is fed out to cows

When assessing a particular feed to buy, its physical quality should be assessed first, using a representative sample. Most dairy farmers are very good at physically assessing feeds but need to understand that chemical analysis at a feed lab is the only way to be certain as to a feed's cost per unit energy and protein, other nutritional attributes, and likely performance in a diet.

Feed analysis should then be done at a reputable feed laboratory. While some feeds are highly variable and need to be tested often, others are not worth testing because they are very consistent and/or are used at only a low inclusion rate in the diet. Given that the nutritional quality of forage varies much more than that of concentrates, testing forages should be a priority. Dairy Australia's 2019 Feed and Animal Nutrition Survey Report found that 67% of respondents in the Murray Dairy region used feed testing at least once per year to assess forage quality before purchase. This compared to 65% of respondents nationally (Dairy Australia, 2019a). Farmers more likely to feed test when buying forages were those with a feedpad and those with larger herds.

Feed sampling method is the greatest potential source of variation in feed lab results, so time should be taken to ensure that a truly representative sample is collected. It is much harder to get a representative sample of some feeds (especially hays) than others such as grains, so the methods described in Table 12. should be followed. A hay corer is essential for sampling hay and silage bales.

Guidelines for how to prepare a feed sample and get it to lab safe and sound are provided in the Dairy Australia feed planning fact sheet 'Managing quality and supply risks when buying feed'.

Key nutritional parameters for which values are usually reported on a detailed feed test report are described in Table 13. For different types of feeds, different nutritional parameters are important (Table 14).

Table 13. Key nutritional parameters on a feed test report:

% Dry Matter	
MJ ME	= megajoules metabolisable energy
% Crude Protein	= % Nitrogen multiplied by 6.25
% ADICP	= proportion of protein bound into the ADF fraction of carbohydrates. Indicates how protein in silage and hay is unavailable due to heating
% RDP	= proportion of crude protein which is rumen-degradable (remainder is UDP)
% ADF	= % less digestible fibre fractions i.e. cellulose and lignin. Indicator of a feed's total digestibility and its energy value
% NDF	= digestible and indigestible fibre fractions i.e. some pectins, hemi-cellulose, cellulose and lignin
NDF Digestibility	= proportion NDF digested in rumen at 12/24/30/48/240 hours
% Lignin	= % totally undigestible part of ADF and NDF
% Water Soluble Carbohydrates	= almost all the sugar fractions (simple and more complex) in a feed
% Starch	= the main storage carb Feeds have different ratios of two types of starch: amylopectin (floury) and amylose (flinty). Amylose is more resistant to ruminal digestion
% Fat	

Table 14. Nutritional parameters of importance for different types of feeds

Feed type	Important nutritional parameters
Grains/concentrates	Dry matter, metabolisable energy, crude protein, starch, sugars, fat
Protein sources	Dry matter, metabolisable energy, crude protein, RDP/UDP
Standing forages	Dry matter, metabolisable energy, crude protein, ADF, NDF, NDFD
Conserved forages	As per standing forages plus: • pH (indicates extent of fermentation during ensiling) • ammonia-N as % total silage N (indicates quality of fermentation during ensiling) • ADICP
By-products	Dry matter, metabolisable energy, crude protein, starch, sugars, fat, ADF, NDF, NDFD, pH, ADICP

The feed's physical and chemical characteristics should be compared with the applicable feed purchasing standards. Trading standards can be accessed from the Grain Trade Australia webpage: **graintrade.org.au/commodity_standards** for the following types of feeds: Grains, pulses, oilseeds, by-products, fats and oils and fodder.

ii Supply risk

The certainty of feed supply and predictability of feed costs can be increased by confirming verbal agreements with feed suppliers in writing i.e. by mail, fax or email. The key points a feed purchase agreement should cover are:

- Quantity
- Quality
- Price (including delivery costs)
- Delivery period
- Delivery location, and
- Payment terms.

It is good practice to convert a verbal purchase agreement to writing in some form, so that if later clarification is required there is documentation to refer to, rather than having to rely on memory. It protects both parties from the risk of unnecessary disputes down the track. Grain Trade Australia (GTA) has resources available explaining GTA Rules and contracts which can be used for any feed, not just grain visit **graintrade.org.au/contracts**

An AFIA fodder vendor declaration form should also be obtained from each feed supplier visit **afia.org.au/wp-content/uploads/2021/04/2020_Vendor_Declaration_Form.pdf**

iii Price risk

Key points farmers must remain aware of when buying feed are:

- Prices are volatile for both dairy farmers and grain and fodder suppliers, offering opportunity and downside risk
- Factors influencing grain and fodder prices are often beyond farmers' control
- Grain prices are not always a function of Australian grain production
- Buyers and sellers have different needs, and
- Price does not necessarily mean value.

Without a crystal ball it is very hard to know what feed prices will do in the year ahead. There are only three things you can do about price. You can either use a:

- **Floating price,** where you accept the market movements in your feed costs i.e. you are totally exposed to price volatility
- **Fixed price,** where you are not exposed to price movements in feed costs (forward contract), or
- **Price range,** where you put some boundaries around what movements you are prepared to bear on your purchased feed costs.

Dairy Australia's 2019 Feed and Animal Nutrition Survey Report found that only 10% of all grain and other concentrates were purchased using forward contracts by farms in the Murray Dairy region (Dairy Australia, 2019a). This was much lower than in several other regions. Forward contracting was used as a price risk management tool far more by farms with herds over 500 cows than farms with smaller sized herds.

Diet formulation

Designing nutritionally balanced diets for milkers involves three steps:

1 Calculate daily cow nutrient requirements

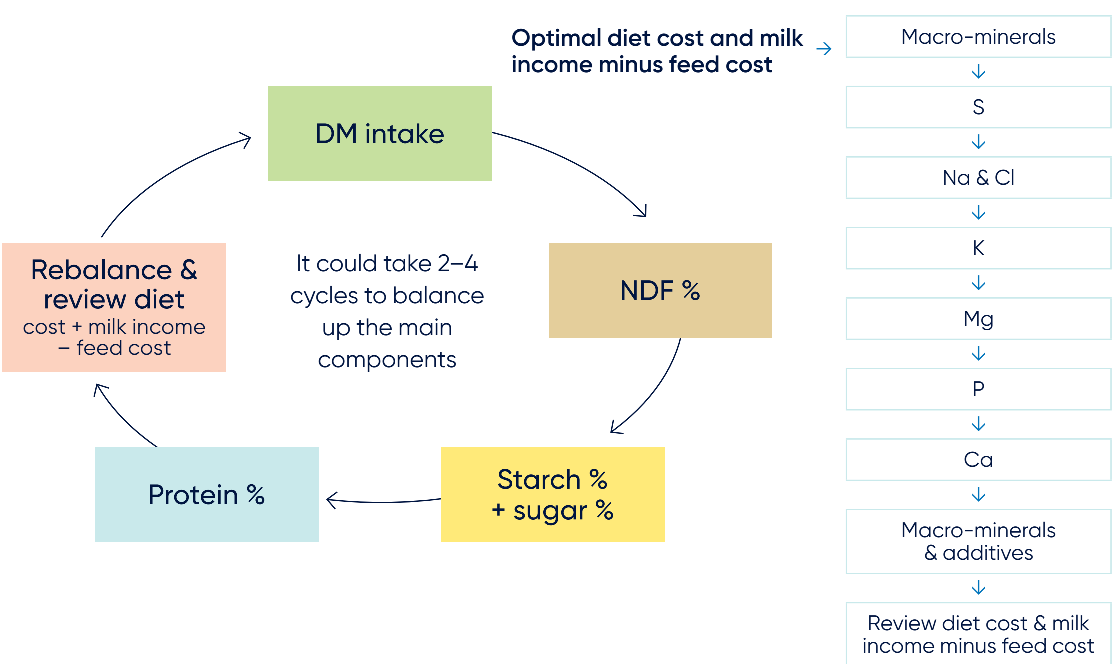
2 Consider feeds available, and

3 Formulate the diet.

To do this successfully, daily cow nutrient requirements need to be calculated accurately to account for:

- Cow bodyweight and age
- Growth
- Stage of lactation
- Pregnancy
- Activity (walking and grazing)
- Changes in body condition
- Milk yield and composition, and
- Environmental conditions.

Figure 35. Feed formulation process



'Adapted from Hannah and Barber, 2007'

Feeds then need to be selected, based not only on their nutritional specifications, cost per unit energy and protein, and specific role to be played in the diet, but also on:

- Consistency of quality and supply
- Possible risks of chemical residues, contaminants, mycotoxins
- Expected dry matter and nutrient losses during storage, mixing and feed-out
- Increased capital requirements required to handle
- Extra labour required to handle, and
- Other costs.

When formulating the diet, the aim is to meet formulation targets for key nutritional parameters without excesses, within the cow's feed intake limit, with good feed conversion efficiency, and with optimal milk income minus feed cost.

Avoiding supply of excessive amounts of nutrients is important as it may affect cow health, reduce feed conversion efficiency (kg of milk per kg of feed) and reduce margin over feed costs. Underfeeding will impact performance and cow health and fertility if severe. Formulating a diet which is nutritionally balanced and also provides the optimal diet cost and milk income minus feed cost is an iterative process, as shown in Figure 35.

Many computer-based dairy nutrition models have been developed and are available to help nutrition advisers and farmers evaluate and formulate diets. Most of these models have been developed by 'champions' with a specific interest/focus as a tool to help them improve their understanding of nutrition and rumen physiology. They are then released for wider use.

Nutrition models can be used for:

- Scenario testing to achieve the optimum milk income minus feed cost, assessing:
  - Diets and ingredient costs
  - Range of ingredients
  - % of forage in the diet, and
  - Seasonal vs annual scenarios
- Assessing nutritional management strategies (e.g. split herds and differentially feeding), and
- Developing feed budgets that feed into financial budgets.

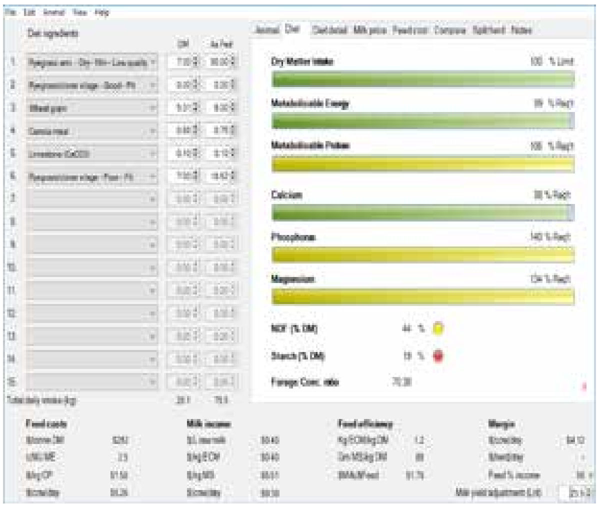
Little *et al.* (2009) emphasised that nutrition models vary in many ways:

- Technical sophistication
- Level of technical expertise required to use it
- User-friendliness
- Applicability to various feeding systems
- Inputs required
- Sensitivity of values entered for different inputs
- Feed library provided
- Ability to predict milk yield accurately, and
- Level of technical support provided by developer/marketer.

Rumen8® is an intermediate-level dairy nutrition model developed in Australia which is free, very user-friendly and well supported (available at **rumen8.com.au**). It is designed to be used by both dairy nutritionists and farm managers.

It is also important to understand that most models do not predict grazed pasture intake of cows. A value for pasture intake must be entered into the model. This is not an issue when using a TMR.

Figure 36. Input page of Rumen8*, a dairy nutrition model



KEY TO SUCCESS: ENSURE FEEDPAD CAN BE FURTHER DEVELOPED IN FUTURE IF DESIRED

2. BASIC FEED-OUT AREA

3. FORMED EARTHEN FEEDPAD

4. CONCRETE FEEDPAD

When designing and building a feedpad, there are a number of important things to consider ensuring it can be further developed in the future. If this is not done, a farm may find itself a few years down the track having to construct a new feedpad from scratch at another site on the farm to meet its needs (with many costs being incurred again) and find another purpose found for the old feedpad (e.g. as a calving pad).

Site the feedpad so that it can be readily expanded

Select a site for the feedpad which provides:

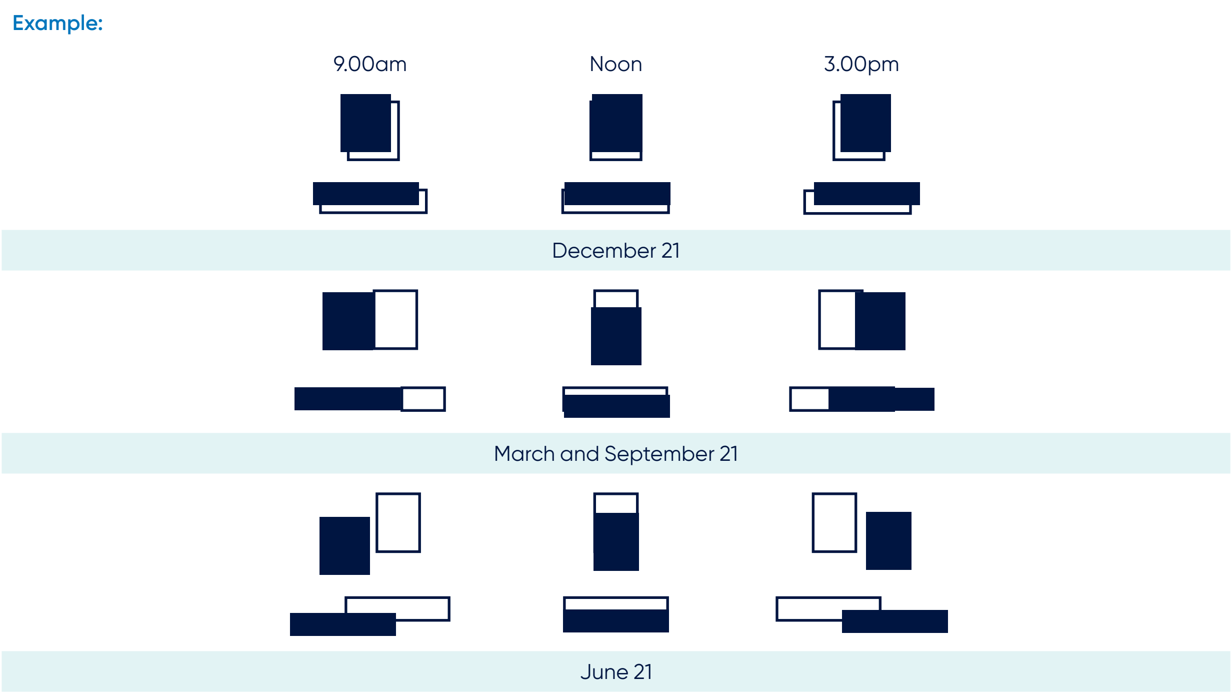
- Scope to expand the feedpad's area and further develop the effluent system
- Easy vehicle access
- Easy cow access to the dairy and main laneways
- Easy access to feed storing and mixing facilities
- Good access to stock water and power
- Good drainage, and
- Minimal risk of generating excessive odour, dust and noise.

Consider carefully whether to orient feedpad north-south or east-west

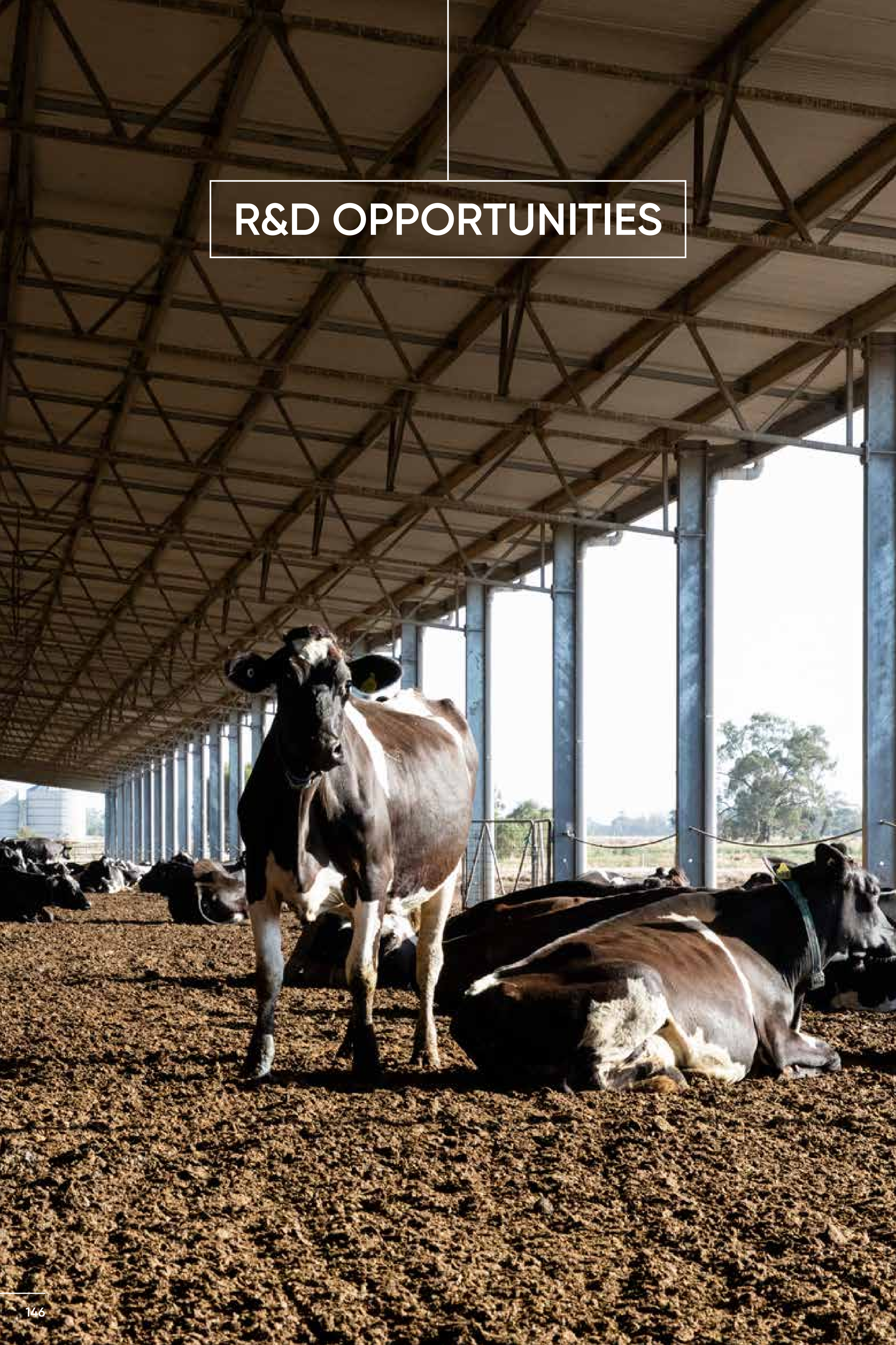
With a compacted earthen feedpad with a roof over it, a north-south orientation works well because the sun strikes every part of the floor area under and on either side of the roof at some time during the day. This helps to keep the floored area dry and restricts pathogen build up. However, with a concrete pad with a roof over it, an east-west orientation is ideal from a heat stress management viewpoint, because provided the roof is wide enough, it will ensure that the feed table and water troughs are in shade at all times (Figure 36).

Given the effort and cost to re-orient a feedpad, whether a roof will be placed over the feedpad initially or at some later stage should be carefully considered, when deciding in which direction to orient the pad.

Figure 37. Shed profiles at 9am, noon and 3pm at four different times of the year



R&D OPPORTUNITIES



PRIORITY RATING
High Moderate Low

Silage storage infrastructure

Evaluate costs and wastage of alternative silage storage systems	D	Term: Medium	Priority: Low

Much information on silage storage is available from Kaiser *et al.* (2040, Mickan (2020) and Watts *et al.* (2016) which is still applicable today. However, there is little published information on the capital and operating costs of different silage systems, including newer systems for storing bulk silage. It may be worthwhile to collect information on the costs and expected wastage of various silage storing systems to provide the dairy farmer with quantitative information on the relative merits of the various silage storing systems.

Evaluate silage inoculants	D	Term: Medium	Priority: Low

There may be an R&D opportunity to evaluate the use of inoculants and their application rates to improve quality and reduce wastage of silages. But much of this comparative work is already conducted by commercial companies, albeit not totally independent.

Feed mixing infrastructure

Develop on-farm audit system for feed mixing	D	Term: Medium	Priority: Moderate

To make most efficient use of the mixer wagon to deliver a consistent ration to dairy cows, the main skill that the farmer should obtain is the ability to mix a consistent ration each day to the cows. Is the ration formulated the same as the ration that is mixed, and the same ration that is pushed out and the same ration that the cow consumes? Some type of check on the consistency of the ration mix would improve the process of mixing rations in a mixer wagon.

The dairy industry should explore alternative methods to establish an on-farm audit system to determine (and reduce) the variation between ration mixes. Several systems have been used, particularly in US.

- The Penn State Particle Separator, which is a series of sieves, is used to measure the consistency of samples of the mix collected across the wagon and in the trough (Penn State Extension, 2016).
- Analysis of a number of samples along the mixer or along the feed trough for nutritive value and comparing with the expected nutritive value based upon analysis of raw ingredients may be another way of checking the efficiency and consistency of the ration mix.
- The tracer method may provide a quick and easy indicator of the mixing quality on farm. This involves using a tracer (e.g. popcorn) in the mix to see whether the tracer is evenly distributed in the ration eventually offered to the cows.

This type of analysis of the mixing consistency of dairy rations could become part of a larger audit type program for the industry which should provide reassurance to the dairy farmer that the mixing process is operating at near maximum efficiency.

Develop detailed farm case studies on feed mixing systems	D	Term: Short	Priority: Moderate

The preparation of case studies from dairy farms that have successfully adopted new technology is an excellent way of providing good quantitative information to the dairy farmer. Further case studies that provide good data on the likely performance and profitability of different feed mixing systems and the experiences of dairy farmers in the Murray Dairy region should be complied and distributed to the industry.

PRIORITY RATING

High | Moderate | Low

Feed delivery and housing infrastructure

Close major advisory service gaps for feeding and housing infrastructure design, planning approval and construction	D	Term: Long	Priority: High

Close major service gaps in each dairy region so farmers have ready access to:

- Local consultants who can coach them through development of a business case and the *whole* facility planning, design and construction process (as available in other animal sectors)
- Advisers across all the relevant disciplines – FBM, herd nutrition, facility design, effluent system design etc. Several of these are already available in the dairy industry, eg. FBM, nutrition
- Advisers well equipped to help them comply with the planning requirements imposed by the relevant local, state and federal agencies. Advisors with this expertise are within the intensive livestock industries and could readily adapt their knowledge to the dairy industry.

Evaluate key feed delivery and housing infrastructure fittings and items of equipment	D	Term: Short	Priority: Moderate

Apply engineering and animal behaviour expertise to conduct a series of objective, detailed comparative evaluations of key feed delivery and housing infrastructure fittings and items of equipment commercially available to farmers such as:

- Feed and water troughs
- Hay feeders
- Mixer wagons
- Feed storage facilities
- Materials for constructing earthen feedpad surfaces
- Shade structures
- Effluent systems

  using a set of criteria, including:
  - Fitness for purpose
  - Cow welfare friendliness
  - Ease of use
  - Capital and operating costs
  - Longevity

Identify needs and opportunities to develop better designed fittings and equipment based on these evaluations and prioritise.

Design better feed delivery and housing infrastructure fittings and items of equipment	R	Term: Medium	Priority: Moderate

Apply engineering and animal behaviour expertise to design and test prototypes of feed delivery and housing infrastructure fittings and items of equipment that function better and are more cow welfare friendly than those commercially available to farmers. These may include:

- Pre-cast concrete water troughs with larger drainage plugs to facilitate regular flushing
- Steel hay rings which minimise feed wastage
- Steel hay feeder panels which minimise feed wastage
- Pre-cast concrete modular feed troughs which minimise feed wastage

Develop detailed farm case studies on using feed delivery and housing infrastructure and moving from one type to next	D	Term: Short	Priority: High

Develop detailed case studies of farms which demonstrate how savvy farmers in the region have:

- adopted differing patterns of use of feed delivery/housing infrastructure to help them achieve their personal and business goals
- dealt with key success factors specific to their chosen type of feed delivery/housing infrastructure which relate to its design, construction and/or use
- moved successfully from one type of feed delivery/housing infrastructure to the next, addressing the challenges involved.

PRIORITY RATING
High Moderate Low

R&D areas related to feed delivery infrastructure Types 1 to 4 are covered above. There are several potential areas for R&D specific to feed delivery infrastructure Type 5. i.e. freestalls and compost bedded pack barns.

Develop farm workforce training programs in TMR and housing management	**D**	**Term: Medium-Long**	**Priority: High**

Farms transitioning to Type 5 systems have a need for higher skilled employees operating under a systems approach (i.e. more regimented processes and procedures to ensure consistency). Improved herd handling and monitoring, skills, machinery operation, feed ration preparation and problem solving.

There is an opportunity to consult a range of farms who are at various stages of Type 4 and 5 developments to capture firsthand the programs, services and technical capabilities they are seeking.

Develop energy efficient technologies and on-site renewable energy systems for freestalls and compost bedded pack barns, aiming for carbon neutral dairy production	**R, D**	**Term: Medium-Long**	**Priority: High**

Barn systems are energy intense. However, they offer greater energy-saving potential than for grazing systems. A New Zealand study found that optimal energy consumption were 35% for barns vs. 23% for grazing systems. (Alyas *et al.*, 2020)

There is growing interest in achieving carbon neutral dairy production in US freestalls (e.g. Uni. Minnesota).

Develop energy efficiency upgrades and renewable energy systems including:

- Solar PV
- Wind turbines
- Methane digestors

Identify and compare performance of alternative materials available in Murray Dairy region for use as bedding in freestalls and compost bedded pack barns	**R**	**Term: Short**	**Priority: High**

Evaluate the physical, chemical, and biological properties of various alternative and conventional bedding materials for dairy cattle for use in compost bedded pack or freestall systems, using:

- Physical properties – particle size, water holding capacity, porosity, moisture content, bulk density, dry bulk density
- Chemical properties – total N, total organic C, and C:N ratio
- Biological properties – *Escherichia coli* count, total bacteria count, coliform count, and *Klebsiella* spp. count

Note – Availability of wood-based products for use as bedding material in compost bedded packed barns may become limited in future. This may increase operating costs substantially. Therefore, need to evaluate alternative materials, including different types of straws.

Identify methods to reduce gaseous Nitrogen losses from compost bedded pack barns	**R**	**Term: Medium**	**Priority: Low**

Compost bedded packed barns emit more than twice as much gaseous Nitrogen than freestalls. Most of the Nitrogen is emitted from the bedded pack rather than manure in the slatted feed alley. Look to other more intensive livestock industries for opportunities that have potential
Assess potential for additives to help inhibit.

Explore innovative methods to improve cow comfort through ventilation and cooling systems in freestalls and compost bedded pack barns	**R**	**Term: Medium**	**Priority: High**

Evaluate potential for tunnel ventilation and low profile cross-flow barns in specific dairy regions, given different climatic conditions.

Develop and evaluate innovative methods to improve cow comfort through ventilation and cooling systems in freestalls and compost bedded pack barns. Example: Retractable roof over compost bedded pack barn which can be opened on mild, fine days to improve ventilation of bedded pack.

PRIORITY RATING

High | Moderate | Low

Explore strategies to reduce cow lameness problems and mastitis in freestalls and compost bedded pack barns	**D**	**Term: Medium**	**Priority: Low**

Evaluate overseas information on managing risks of lameness and mastitis to cow health and welfare in freestalls and compost bedded pack barns and how it applies to specific dairy regions.

Evaluate strategies to manage the risk of environmental mastitis in compost bedded pack barns, especially in more humid environments.

Explore systems for drying manure and value-adding manure and composted bedding materials	**R, D**	**Term: Short**	**Priority: Moderate**

Develop systems for:

- Drying manure efficiently
- Cultivating and value adding composted bedding materials

Again, look to other more intensive livestock industries for ideas.

Evaluate potential of 'cow gardens' as an alternative 'freewalk' housing system to compost bedded pack barns	**R**	**Term: Long**	**Priority: Moderate-Low**

Form a multi-disciplinary team (engineers, animal scientists) to:

- Gain an understanding of the 'cow garden' freewalk barn design from European developers and continuing research and development being conducted in The Netherlands, Germany and elsewhere.
- Consider how the concept could be adapted to suit climatic conditions in the Murray dairy region and other regions (roofing design and materials, cow cooling systems, ventilation, appropriate species of plants, manure collection methods etc.)
- Construct a pilot barn and assess its performance

Develop an advanced farm development program for both farmers and project managers targeting Type 4 & 5 systems	**D**	**Term: Long**	**Priority: Moderate-Low**

There is a definite merit in the industry developing an advanced farm development program for both farmers and project managers targeting Type 4 and 5 infrastructure developments. Not to build technical skills, but to provide greater depth of knowledge and insight to manage the project and better understand the journey.

Recycled effluent pathogen loading	**D**	**Term: Long**	**Priority: Moderate**

The current lack of research discourages the use of recycled effluent in yard hydrant systems due to the unknown impacts to humans. With a significant emphasis on recycling effluent to minimise water consumption and reduce effluent pond footprints, a great depth of knowledge is required. Australia has already adopted the US Closed Loop Effluent System, which will introduce many challenges in Type 5 systems. Therefore, foreseeing potential risks will be beneficial long-term, given EPA's refocus on human health and the environment.

A project specifically sampling manure streams to determine pathogenic loading and long-term implications is a priority.

Farm environmental planning	**D**	**Term: Long**	**Priority: Moderate**

Farms entering Type 5 systems will have an expectation from government agencies to have a significant higher accountability for environmental planning, with a need to undertake Environmental Impact Standards aligned to industry codes and guidelines.

In Victoria, this advance planning information can be incorporated into the Navigating Farm Development Platform, however, there is an opportunity to build information upfront to the industry before they enter the planning phase.

Agriculture Victoria is contemplating an advanced planning course for agricultural consultants who specifically advise Type 4 and 5 developments.

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