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Northern dairy feedbase 2001.
4. Feeding systems during winter and spring

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Abstract

The problem period for milk production in northern Australia is early autumn–late spring. Any change to the feedbase that improves the quality and quantity of the diet over this period will increase farm milk production by allowing increases in herd size and production per cow. Farmers will use a range of feed resources which must be integrated effectively to increase productivity (milk output/unit input) and profitability. These new farming systems must be sustainable in the long term.

Forage resources available to improve the feed supply during winter–spring are reviewed. Those with the greatest potential to increase farm productivity are irrigated temperate pastures and forage crops, and high quality silages produced from maize, grain sorghum and legume crops. High quality legume silages have a special role to play in increasing the protein supply on dairy farms. It should also be possible to produce silages of acceptable quality from the surplus growth from tropical-subtropical pastures. Integrating silage cutting with grazing management should significantly improve pasture utilisation and quality. Feeding this silage in combination with concentrates would allow an increase in stocking rate while maintaining production per cow.

Introduction

In the dairying areas of Queensland and northern New South Wales, the winter–spring period coincides with low forage production and low quality (nutritive value) of perennial tropical pastures (Fulkerson *et al.* 1993a). To maintain milk production in this environment, dairy farmers need to rely heavily on winter forage crops and pastures, conserved forages and concentrates to fill the feed gap.

In Queensland, the majority of winter forages must be irrigated to be productive, and only winter cereal crops can be grown satisfactorily under dryland conditions. A survey of the majority of Queensland dairy farmers in 1986–87 (Anon. 1988; D.V. Kerr and J. Chaseling, personal communication) showed that the average area of winter irrigation for all farms was approximately 0.07 ha/cow, or 0.14 ha/cow on those farms with irrigation (Table 1). This would provide approximately 22% of the diet for cows during winter–spring on the average Queensland dairy farm (Table 2). More recent work by D.V. Kerr and J. Chaseling (personal communication) showed that the area of winter irrigation per cow on approximately 100 farms has not changed over the period 1986–87 to 1990–91 (Table 2). Clearly, State averages can mask important production systems differences between dairying regions. It is evident from the above surveys (Table 1) that winter irrigation is more important in central Queensland and south-eastern Queensland dairying regions. This is also the case on the north coast of NSW.

Conserved forages, on average, account for a relatively small proportion (< 10%) of the diet on Queensland dairy farms (Tables 1 and 2). However, on farms in the Darling Downs region, hay usage is significant. Few farms in Queensland use silage (Table 1), although a recent survey

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Table 1. Supplements contributing to the winter-spring feed supply on Queensland dairy farms, 1986-87.[1]

	North Queensland	Central Queensland	Darling Downs & South Burnett	South-east Queensland	Whole State
No. of dairy farms	241	236	771	831	2079
Winter irrigation area (% farms)					
>0.132 ha/cow	28	46	23	39	32
0.04-0.132 ha/cow	25	16	9	23	17
Dryland	47	38	68	38	51
(ha/cow/yr)	0.064	0.080	0.046	0.090	0.070
(kg DM/cow/yr)[2]	640	800	460	900	700
Supplementary energy (kg grain equivalent/cow/yr)	884	731	724	736	748
Hay use[3]					
(% farms)	5	58	81	48	57
Good quality (kg DM/cow/yr)	5	160	289	116	172
Poor quality (kg DM/cow/yr)	2	43	322	58	148
Maize silage[4]					
(% farms)	2	1	2	2	2
(kg DM/cow/yr)	42	11	30	25	27
Other silage[4]					
(% farms)	<1	1	2	1	1
(kg/DM/cow/yr)	7	10	15	15	14

[1] No estimates available for dryland winter forages. Data from a survey of 95% of Queensland dairy farms (Anon. 1988; D.V. Kerr and J. Chaseling, personal communication).

[2] Assumes 10 t DM/ha consumed by grazing dairy cows.

[3] Good quality hay is lucerne while poor quality includes grassy or weather-damaged lucerne, summer forage crop, winter cereal and tropical grass hays. Hays assumed to have a DM content of 85%. Hay consumption estimates are mean values over all farms (rather than only those farms feeding hay).

[4] Silage data presented on a DM basis, assuming a DM content of 35% for all silages. Silage consumption estimates are mean values over all farms.

Table 2. Changes in supplement use on approximately 100 Queensland dairy farms, 1986-87 to 1990-91.[1]

	Average consumption			Proportion utilised in winter-spring[2]	Average diet composition in winter-spring[3]
	1986-87	1990-91	Change		
	(kg DM/cow/yr)		(%)	(%)	(%)
Irrigated winter forage	850	850	0	100	26 (22)
Supplementary energy (grain equivalent)	826	1427	+73	50	26 (14)
Hay — good quality	196	143	−27	60	3 (3)
— poor quality	166	169	+2	60	3 (3)
Maize silage	19	123	+547	80	3 (1)
Other silage	10	10	0	80	0 (0)
Other grazed forage[4]	—	—	—	—	39 (57)

[1] Survey of 104 farms in both years. Hay and silage data in 1990-91 based on 115 farms (D.V. Kerr and J. Chaseling, personal communication).

[2] Estimates only — no data available.

[3] Assume total daily DM intake of 18 kg. Values in parentheses calculated from data in Table 1.

[4] Balance of diet from dryland winter forage crops and basal tropical pasture.

of 115 farms in 1990-91 (D.V. Kerr and J. Chaseling, personal communication) indicated that 7% of farms used maize (*Zea mays*) silage and 6% used other silages. Since the 1990-91 survey the number of farms using silage has been increasing rapidly. For example, in central Queensland approximately 20% of farmers are now conserving silage (G. Chopping, unpublished data). There are limited survey data available for the north coast of NSW, but industry observers believe that the trend towards increased silage use recorded in the early 1980s (Hamilton and Griffiths 1984) is continuing in this region.

Energy supplements are an important

component of the diet of Queensland dairy cows, and in 1986–87 the average annual usage was approximately 750 kg grain equivalent per cow (Table 1).

On 104 dairy farms surveyed both in 1986–87 and 1990–91 (D.V. Kerr and J. Chaseling, personal communication) the use of energy supplements increased by 73% to approximately 1430 kg grain equivalent per cow (Table 2). It is important to note that 1990–91 was a drought year which probably influenced the use of energy supplements. Nevertheless, during this period milk production per cow and per farm increased by 21% and 27% respectively. Assuming a response of 1 l milk per kg grain equivalent it is evident that energy supplements accounted for the majority of this increase in milk production.

This review examines options for increasing dairy farm productivity during the winter–spring period, and focuses on the alternative feed resources available — winter forage crops and pastures, and conserved forages. The production and utilisation of conserved forages in subtropical and tropical dairying systems is covered in detail; the role of concentrates in improving farm productivity has been reviewed separately by Davison and Elliott (1993).

Pastures and forage crops

Irrigation and the development of productive winter–spring pastures have been major factors in the intensification of production systems on dairy farms in the tropics and subtropics. Irrigated winter–spring pastures complement the summer pastures which grow when rainfall is more reliable in the summer–autumn period. The combination of summer-growing and winter-growing pasture systems has allowed higher stocking rates because of an increase in forage supply, and higher production per cow because of the high quality of the winter pasture component. Increased areas of winter pasture have also allowed for year-round milk production and a break away from the seasonal calving patterns aligned with the production pattern of summer-growing pastures. Milk supply accordingly is also more uniform throughout the year with a better opportunity to meet market demand (Cowan 1985).

Only in the southern part of the subtropics does the amount and reliability of winter–spring rainfall allow the production of winter-growing pastures and crops without irrigation. The area available for, and the feed produced from irrigated pastures are amongst the most important factors affecting farm productivity (Rees *et al.* 1972). Effective water use is pivotal to efficient milk production during winter and spring. Often water is poorly utilised with no emphasis on water use efficiency or proper irrigation scheduling. Much more analysis of the cost of irrigation is required. Irrigation systems which deliver water more efficiently, and improved irrigation efficiency should provide more reliable pasture growth. Production under farm conditions would then be much closer to the potential production from the available water.

D.V. Kerr and J. Chaseling (personal communication) in their 1990–91 survey measured (by regression) the contribution of winter irrigated pasture to farm production in litres (l) milk per hectare to be: 5259 ± 1587 for north Queensland; 3738 ± 1373 for central Queensland; and 4138 ± 1081 for the Darling Downs. These estimates of the response to irrigation are low when compared with experimental data. In a current experiment at Rockhampton (G. Chopping *et al.*, unpublished data) 15 t/ha DM was produced from irrigated Concord ryegrass (*Lolium multiflorum*) pastures. If only 50% of this pasture was actually eaten by stock and the marginal response to ryegrass forage was 1.0 l milk/kg DM, the potential milk production would be 7500 l/ha. Cowan (1985) indicated that research milk yields from irrigated ryegrass or clover (*Trifolium* spp.) pastures, over 170 days in winter–spring, were 10 000–16 000 l/ha. The 1990–91 survey coincided with drought conditions and water supplies would have been restricted. Nevertheless the milk yield responses highlight the wide gap that can occur between potential production and on-farm production.

Irrigated winter pasture production is often restricted by the supply of water available, particularly in those areas where irrigation water is stored on farm and is not available from an irrigation scheme. The economics of 'harvesting' and storing water on farms to increase irrigation capacity requires careful evaluation. There may be high returns from these techniques (Crofts *et al.* 1963).

Despite the cost of irrigation and the inefficiencies in current irrigation systems, winter irrigated pastures are a relatively cheap source of quality feed (Cowan *et al.* 1993). This has been confirmed in a recent survey which showed that the cost of production on irrigated farms in central Queensland was 1–3 cents/l less than on dryland farms (G. Chopping, unpublished data). The Kerr and Chaseling 1990–91 survey showed that cows were on average obtaining 4–5 kg/d DM from irrigated pastures — approximately 20–30% of their diet. With increases in both irrigation efficiency and the amount of water available, the proportions of the diet from grazed winter irrigated pastures could be substantially increased on many farms.

A second major factor controlling the effectiveness of winter pasture systems is the seasonal spread of production. High summer temperatures, which inhibit germination and increase grass and weed competition, prevent sowing in the tropics until April and winter feed is not available until mid-May. The autumn–winter productivity of annual temperate pastures is very dependent on planting date. Delaying planting by approximately one month, from mid-April to mid-May, will reduce pasture yields to the end of winter by about 50%. In the subtropics plantings can be made as early as late February or March, and the period when low quality summer pastures are the only source of pasture feed is reduced accordingly. Again, delayed sowing significantly reduces yield (see Table 5). At the other end of the season, continuation of growth into the late spring and early summer in some irrigated winter pasture systems is truncated by diseases, particularly rust in ryegrass and Persian clover (*T. resupinatum*), and maturity in ryegrass and annual legumes.

Tropical pastures

Dryland perennial pastures in the tropics have a marked seasonal production pattern influenced by both rainfall and temperature. Up to 80% of their total annual DM yield is produced over the wet season between the opening rains (September–December) and March. Traditionally, milk production followed a similar pattern peaking in December–January and declining rapidly from February to July–August. Dairying has changed over the last 30 years from seasonal calving aligned with the rainfall pattern, to year-round calving to meet market demand. As a result, there has been a major input into increasing year-round pasture production. However, stocking rates on farms that rely heavily on tropical pastures need to be geared to their autumn–winter productivity and this leads to under-utilisation of pastures in summer.

Grass–legume pastures. The productivity of tropical legume–grass pastures can be increased by modifying the feed supply in the winter–spring period. Cowan and Stobbs (1976) applied 50 kg/ha N in the autumn and winter and increased the carrying capacity from 1.6 to 1.9 cows/ha. Most of the production gains were obtained in the winter–spring period.

Another strategy is to use concentrates. Supplementing cows grazing glycine *(Neonotonia wightii)*-green panic *(Panicum maximum)* pastures at 2.6 cows/ha with 4 kg/cow/d maize–soybean concentrate allowed an increase in carrying capacity. Pasture intake was reduced by 0.9 kg/kg concentrate consumed, increasing the yield of pasture on offer from April–August (Cowan *et al.* 1977). Based on the results, 4 unsupplemented cows would consume as much pasture as 6 cows given 4 kg/cow/d concentrate. No allowance is made for any pasture lost due to senescence. Clearly, large increases in carrying capacity can be achieved when concentrates are fed. Similar results could be expected by using alternative energy sources such as molasses (Cowan and Davison 1978). Since the protein content of these pastures is usually low, protein supplementation is necessary to obtain the full response to energy supplements (Davison *et al.* 1982a).

The increased grazing pressure following the strategic use of N fertiliser or concentrates resulted in a loss of the legume component in the pasture, thus reducing the nitrogen supplied by the legume and increasing the demand for fertiliser nitrogen to sustain pasture productivity. A stable legume component can be maintained only at stocking rates ⩽1.6 cows/ha (Cowan and Stobbs 1976; Lowe and Hamilton 1985).

Tropical grasses. The productivity and carrying capacity of these pastures are dependent on the application of N fertiliser. Davison *et al.* (1985) obtained increases in milk production by increasing the N application to 200 and 400 kg/ha/yr on green panic pastures. Stocking rates of 2.5 cows/ha could be sustained during the lactation, but there was a high demand for conserved feed to maintain cows through the dry period. The increase in productivity occurred in all seasons. In contrast, Davison *et al.* (1986) obtained responses mainly in the autumn and winter following applications of 100 and 300 kg/ha N on Gatton panic (*P. maximum* cv. Gatton) pastures. Milk yields at 2.6 cows/ha were 3781 and 4176 l/cow/yr, respectively. The application of fertiliser N has also been successful in extending the growing season of Callide rhodes (*Chloris gayana*) grass in south-east Queensland (Cowan *et al.* 1986), and kikuyu (*Pennisetum clandestinum*) in NSW (Anon. 1977). However, with kikuyu there will still be a period of serious feed shortfall in the winter and early spring.

The next level of productivity increase in tropical grass pastures under dryland conditions is to oversow with winter-spring-growing species. Mulch sowings of annual ryegrass or perennial ryegrass–white clover (*T. repens*) can respond to favourable rainfall, increasing winter–spring productivity and carrying capacity. Results are extremely variable in the tropics, but in the subtropics this system is more reliable, particularly in the southern extremities with more reliable winter–spring rainfall. The potential for oversowing tropical grass pastures is limited by the reliability of autumn–winter rainfall and the need to delay planting date to avoid competition from tropical species during establishment. This delays the first grazing to mid-winter. In many situations, dryland oats (*Avena* spp.) is a more valuable option.

On dairy farms that rely heavily on tropical pastures, options to increase winter–spring feed supply which require further development, include:

- Strategic use of N in late summer–early autumn on tropicals to extend the growing system. This system can be used in combination with autumn saving to carry over a bulk of feed into winter.
- Use of N on grass on parts of the property to enable stocking rates on grass–legume pastures to be reduced to the level necessary for them to retain their legume component and remain highly productive.
- Use of high quality conserved feed (e.g. maize silage) as an integral part of the dryland tropical production system.
- Strategic use of limited irrigation.

These options are already used on farms, but responses in milk production have not been adequately quantified. The dryland tropical production system requires more development particularly in the winter component of the system. Nevertheless, combining tropical pastures with irrigated winter pastures and concentrates has allowed higher production per cow, with 7390 l/cow/yr being achieved in a current experiment at Kairi (Walker *et al.* 1992).

Winter forage systems

In dryland situations, forage crops such as oats are sown on clean seedbeds to augment winter feed supply. There are very few data on the milk production possible from these crops. In irrigated areas, annual and perennial ryegrasses boosted with frequent applications of N fertiliser, perennial ryegrass–white clover pastures, and annual legumes in high density clover sowings are the main potential components of feeding systems for increasing the winter milk production in the tropics and subtropics. The relative importance of the winter forage options is shown in Table 3. In 1990–91 there was a drop in winter irrigation area per farm due undoubtedly to the severe environmental conditions experienced during that year. The current winter irrigation area on dairy farms in central Queensland is approximately 1600 ha, not greatly different from the 1986–87 survey (G. Chopping, unpublished data).

Table 3. Areas sown to temperate pastures and forages in central Queensland and Queensland (1986–87 survey data).[1]

Pasture type		Central Queensland	Queensland
		(ha)	(ha)
Irrigated:	Ryegrass	482	5 885
	Ryegrass–clover	449	2 663
	Clover		849
	Lucerne	384	3 943
	Winter–spring crops	438	2 015
Dryland:	Lucerne	51	2 263
	Winter–spring crops	1 046	30 656

[1] Anon. (1988). See Table 1 for number of farms.

Ryegrass and nitrogen fertiliser. Annual ryegrasses are either sown into clean seedbeds, or direct drilled into existing pastures after the suppression of summer grass growth by slashing, mulching or herbicide use. Nitrogen fertiliser to 50 kg/ha N is applied at sowing and after each grazing. The potential productivity of these pastures has been demonstrated in a current grazing experiment comparing Tetila and Concord ryegrasses at Rockhampton (M. Martin and

G. Chopping, unpublished data). At the stocking rate used in this experiment (a relatively light 3.4 cows/ha), both varieties produced similar milk production from June–September (Table 4). At higher stocking rates, the 15% higher DM yield in Concord may have been converted into a small milk production advantage. From October Concord produced more milk due to a large difference in pasture production and an anticipated difference in pasture quality between the two varieties. Grazing of the Tetila by the milking herd ceased after the ninth grazing, whereas the Concord area could have been grazed at least once more.

Table 4. Milk production from Tetila and Concord ryegrasses — Rockhampton 1992.

Grazing no.	Tetila		Concord	
	Date	Milk yield	Date	Milk yield
		(l/cow/d)		(l/cow/d)
1	Jun 5	14.4	Jun 14	14.5
2	Jun 26	16.3	Jul 3	16.3
3	Jul 19	19.3	Jul 26	18.9
4	Aug 12	18.3	Aug 19	20.1
5	Sep 2	18.6	Sep 9	18.5
6	Sep 23	19.4	Oct 3	18.6
7	Oct 17	16.5	Oct 26	19.7
8	Nov 8	16.4	Nov 16	19.3
9	Nov 26	14.0	Dec 4	17.2

M. Martin and G. Chopping (unpublished data).

Similar results were obtained from an experiment comparing Tama and Midmar ryegrasses in south-east Queensland at 2 stocking rates, 4 and 7 cows/ha (Lowe *et al.* 1985). Average pasture on offer was 2.65 and 2.12 t/ha DM for Midmar and Tama, respectively, with the greatest differences occurring after mid-winter. From August onwards, Midmar produced higher milk yields per cow, its superiority increasing in November when Tama was maturing and severely rusted. Midmar produced 10.6 and 9.9% more milk at the low and high stocking rates, respectively. Both experiments highlight the importance of varietal differences on the productivity and milk production potential of irrigated ryegrass. Research should continue on identifying varieties with improved yield, seasonality of production and quality.

A well managed high density ryegrass pasture in the tropics will produce 1000–2000 kg/ha DM every 3 weeks, between May–September. From October–December, DM production will drop to 0–1500 kg/ha DM. At each grazing, stocking rate is the principal management factor affecting utilisation of this forage. At high stocking rates (7.5 cows/ha), utilisation can be as high as 60–70%, and at low stocking rates (3.8 cows/ha), utilisation will be between 30–40% of the forage on offer.

Stocking rate	% utilisation of "high-N rye"
7.5	60–70
6.25	50–60
5.0	40–55
3.75	30–40

Initial milk production trials used high stocking rates (7.5 cows/ha) to achieve high utilisation at each grazing (Chopping *et al.* 1982). More recently, with the emphasis being placed on increasing production per cow, lower stocking rates (5 cows/ha) are being used. Apart from their effect on production per cow, lower stocking rates promote more rapid pasture growth, higher yields "on offer" and a more stable paddock feed system. When assessing the profitability of alternative forage options, level of utilisation is an important consideration when calculating feed costs. Use of DM yield data alone can give misleading results.

Annual legumes. In addition to white clover, which can behave as an annual, annual legumes suitable for increasing milk production in tropical and subtropical areas include subterranean (*T. subterranean*), berseem (*T. alexandrium*), Persian, red (*T. pratense*) and balansa (*T. balansae*) clovers. Persian clover is late maturing and has the capacity to extend the availability of high quality feed well into the summer (Kelly and Mason 1986). However, the susceptibility of some varieties to rust and other diseases can substantially shorten their potential productive period in the subtropics and tropics.

Annual legumes vary in their reaction to grazing management. The regrowth of Persian clover is not affected by hard grazing or cutting for conservation because its growing points develop from the crown (Stockdale 1992a). In contrast, grazing of subterranean clover to 3 cm can induce seed set, increase disease and allow a rapid ingress of weeds (Stockdale 1986). Increasing defoliation height over the range 2–8 cm increased DM yield.

High feed quality is an important attribute of annual legumes. With subterranean clover, varieties vary in digestibility, N content and lignin content, and this could influence milk production. Plant components also vary widely in digestibility with leaves being less digestible than petioles and stems. There is also variation in quality between species. In experiments conducted by Mulholland (1990), the relative feeding value of annual legumes was: Woogenellup subterranean clover 100; Clare subterranean clover 84; Trikkala subterranean clover 106; Bigbee berseem clover 103; Paradana balansa 92. In this study the variation between subterranean clover varieties was as great as variation between species.

Legume forages produce large responses in milk production. For example, Stockdale (1992b; 1992c) assessed the marginal return of feeding subterranean clover to be 1.0–1.4 kg milk/kg DM consumed, depending on the stage of lactation. Similar responses would be expected from the other annual legumes in proportion to their quality.

Mixtures of annual and perennial clovers sown at high seeding rates perform the same tasks as annuals. These mixtures were developed to compensate for the slow down in ryegrass growth with increase in temperature in the late spring, particularly in central and north Queensland. The milk production potential of these pastures is higher than from the traditional ryegrass-N system. The advantages of high density clover over annual ryegrass-N pastures include:

- Higher quality, by 6.6 or more digestibility units, in northern Queensland (Goodchild *et al.* 1982).
- Lower cost of production with the elimination of nitrogen fertiliser.
- Less reliance on mineral nitrogen and reduction in the harmful effects of high nitrogen use to the environment.
- Longer growing season particularly when irrigation is available. In northern Queensland ryegrass pastures produce only to the end of spring. With irrigation clover pastures can produce through summer and autumn and plant populations can remain high enough for a second year's production.

The main disadvantage with high density legumes is the high bloat risk. Control measures are expensive in terms of money and labour. Moore (personal communication) assessed the cost of nitrogen fertiliser and seed for a Haifa white clover–Ellett perennial ryegrass pasture at $282.20/ha, while seed and bloat oil for high density clover cost $217.60/ha. The bloat oil cost $97.00/ha. Including a small component of ryegrass in high density clover pastures may reduce the risk of bloat and the cost of preventative measures (T.E. Launders, personal communication). Research is required on this subject.

High density clovers are slower to establish than ryegrass, the effect being greater with later plantings. A severe depression in winter yield was obtained in south-east Queensland with a delay in sowing time (Table 5). A delay in sowing date by one month effectively halved production. The effect on milk production is severe and much higher levels of supplementation are required to meet the shortfall. Broadleaf weeds can also be a problem. They are difficult to control in legumes and can compete strongly.

Table 5. Effect of sowing date on the production (kg/ha) of a range of legumes in south-east Queensland.[1]

Variety	Sowing date		% of early-sown production
	April 10	May 14	
Tama ryegrass	8397	4717	56
Clare subclover	7314	3706	51
Bacchus Marsh subclover	6501	3110	48
Seaton Park subclover	5061	2426	48
Ladino white clover	5550	1497	27
Haifa white clover	5044	2102	42

[1] G. Chopping, unpublished data.

High density clovers support a lower stocking rate, so on farms with limited irrigation, ryegrass will remain the most important winter pasture source because of its highly flexible management possibilities. On farms with less restriction on irrigation, high density clover is likely to be more widely used. Legume pastures supply higher levels of protein which can be used to balance protein deficiency in high energy supplements such as maize silage or grain sorghum (*Sorghum bicolor*) silage. Research is required on the integration of legumes into feeding systems to identify strategies which optimise milk production.

Ryegrass vs clover. Highly productive annual ryegrass varieties will outyield high density annual clover pastures over the June–August period. In September and October yields will be similar while in November and December clovers can outyield ryegrass. In the study reported in Table 6, milk production per cow was higher

Table 6. Winter-spring milk and pasture production from annual irrigated ryegrass and clover pastures in central Queensland (stocking rate = 6.0 cows/ha).[1]

	Grazing 2 10/7-2/8	Grazing 3 3/8-26/8	Grazing 4 27/8-19/9	Grazing 5 20/9-13/10	Grazing 6 14/10-6/11	Grazing 2-6 10/7-6/11
			Milk (l/cow/d)			
Ryegrass	15.4	15.9	14.7	12.9	10.7	13.9
Clover	13.9	16.1	16.0	14.6	12.5	14.6
			Pasture on offer (kg/ha DM)			
Ryegrass	1869	2387	1739	1706	1648	9349
Clover	632	1642	1797	1650	1699	7420

[1] Murray *et al.* (1982).

from the clover-based pasture particularly in spring-early summer (Murray *et al.* 1982). This was probably due to a decline in the quality of the ryegrass with advancing maturity.

White clovers persist better than ryegrass in late spring-early summer and are more likely to persist for more than one year. The central Queensland results are supported by results of a milk production trial undertaken in south-east Queensland comparing ryegrass with clover-ryegrass at 2 stocking rates (5 and 10 cows/ha) (Moss *et al.* 1985). Pasture yield "on offer" from July-November at 5 cows/ha averaged 2.2 and 1.5 t/ha DM for ryegrass and clover-rye, respectively. Corresponding yields on offer at 10 cows/ha were 1.14 and 0.96 t/ha DM. Where intake is not restricted, milk production per cow will be 1.5-3.0 l/cow/d higher on clovers (Table 6; Moss *et al.* 1985). This is due to the combined effects of higher intake and higher quality of clovers compared with ryegrass.

Concern about bloat undoubtedly restricts the use of clover-dominant pastures. The problem does not seem to be as severe in the tropics as it is in the subtropics and temperate areas with most losses confined to the August-September period. Pasture spraying with antibloat oil is generally regarded as the cheapest and most effective means of control.

Perennial ryegrass-white clover pasture. Perennial ryegrass-white clover pastures are difficult to maintain over a long period owing to the ingress of summer grasses and poor survival of the ryegrass and clover over summer. These problems will have to be overcome if temperate perennial pastures are to have a significant impact on milk production. Effective irrigation scheduling, fertiliser use and grazing management may help to sustain these pastures (Fulkerson 1992; Fulkerson *et al.* 1993a). At the southern limits of the subtropics, the productivity and survival of temperate perennial pastures is better, but in the remainder of the subtropical and tropical dairying areas, annual pastures are likely to give superior winter production. Management of grazing intensity, duration and interval can have a significant impact on productivity (Fulkerson *et al.* 1993a). Further research is required to investigate the potential of these systems and their effect on milk production. In more favourable situations in the subtropics, the management principles developed in temperate environments may have direct application. Using the physiology and growth of pasture plants to determine when to graze pastures should be more effective than the time-driven grazing intervals currently practised (Curtis *et al.* 1992; Fulkerson *et al.* 1993b).

Costs and forage utilisation. The current total cost of growing and utilising irrigated winter temperate pastures over a full season (April-December: 8 grazings) is $978/ha for ryegrass and $828 for clover-ryegrass (Table 7). At the stocking rates recommended (5-6 cows/ha), about 50% of the feed on offer at each grazing would be utilised (2000kg/ha DM grazed to a residue of 1000 kg/ha DM) with milk production of 8 000-10 000 l/ha. This puts the feed-related cost of producing milk from this source at 10-12 cents/l.

Pasture utilisation as low as 40% has been measured in a study of 3 farms on the mid-coast of NSW. Low pasture utilisation was associated with grazings that were often made too late, with levels of pasture on offer before grazing above 2500 kg/ha DM (R. Kellaway *et al.*, personal communication). The low utilisation level contributed to a high cost of pasture consumed at

11 cents/kg DM from a ryegrass-white clover pasture. Management of all winter forage types to significantly increase their utilisation will have a significant impact on their cost per kg DM.

Table 7. Cost ($) of growing winter temperate pastures (sown April — 8 grazings).[1]

	Ryegrass	Clover-ryegrass
Machinery	65	65
Seed	50	100
Irrigation (water and pumping)	205	205
Nitrogen (Urea)	400	150
Phosphate (125 kg DAP/ha)	60	60
Potash (125 kg KCl/ha)	63	63
Growing costs	843	643
Capital costs of irrigation	135	135
Bloat control	—	50
Total costs	978	828

[1] G. Chopping (unpublished data).

Principles of grazing management based on the development and physiology of the plant are available from temperate environments for ryegrass, white clover and annual legumes. This management has significantly increased the milk production from all these pastures in temperate regions. Similar potential responses may be available in the subtropics and tropics. Effective pasture utilisation is based on minimising waste by ensuring senescence is restricted by grazing at the correct time, and maximising potential growth rate by not grazing for too long or too heavily (Fulkerson 1992).

Stocking rates will have to be sufficient to achieve these management goals. At this grazing intensity, production per cow is reducing while production per hectare is increasing. If the object is to increase both production per cow and production per hectare, supplementation with high energy supplements such as concentrates or conserved feed (e.g. maize silage) will be required. Supplements can be used as "buffers" to allow the adoption of pasture management systems which maximise pasture growth and allow 80% or more of the forage grown to be grazed or conserved for milk production. Research is required to determine the relationships between stocking rate, level of utilisation, pasture production, supplementary feeding and milk production. This information is essential to the development of profitable milk production systems for irrigated temperate pastures and forage crops in northern Australia.

Hay

Hay use is more prevalent in the inland dairying areas of Queensland, particularly on the Darling Downs where hay is also produced on dairy farms for sale. About 50–55% of the hay used is high quality lucerne (*Medicago sativa*, Tables 1 and 2). Lucerne hay is a valuable high digestibility, high protein feed, which when used in combination with concentrates can sustain high levels of milk production (Table 8). Quality can be variable, but early cutting at the bud stage of crop development, and hay-making procedures which promote rapid drying and minimise leaf losses will facilitate the production of high quality lucerne hay (Kaiser and Curll 1987). A number of studies have shown that milk production declines rapidly with delayed cutting of lucerne (Table 8).

It is evident that a high proportion of the hay used by dairy farmers is of low quality. Since the milk production potential of this material is low, its use in dairy feeding systems is probably uneconomic. The problem is due in part to the conservation of low quality species or cutting too late when quality has declined. However, adverse weather conditions also contribute to the low quality, either directly by damaging the hay or indirectly by delaying cutting. Hay preservatives can partially alleviate the effects of rain damage by allowing the baling of hay at higher moisture contents (Benham and Redman 1980; Kaiser and Curll 1987). With lucerne, baling at higher moisture content to reduce leaf losses at baling is possible when hay preservatives are used to prevent heating and mould growth. The effect of this strategy on milk production from lucerne hay needs to be investigated.

Although technologies exist to accelerate drying rates and permit baling at higher moisture contents, hay making still remains susceptible to losses due to rain damage, particularly in a high summer rainfall environment. Where hay production for sale is not a major consideration, dairy farmers can probably significantly reduce DM and quality losses by conserving silage rather than hay (Kaiser *et al.* 1990). For example with lucerne, Nelson and Satter (1990; 1992) found that cows produced more milk from silages than

Table 8. Effect of stage of maturity on milk production (kg/cow/d) from cows given lucerne hays and silages.

Reference	Hay or silage	Concentrate in diet (%)	Stage of maturity at harvest				
			Early bud	Mid-bud	Early flower	Mid-flower	Full-late flower
Donker and Marten (1972)[2]	Hay	0	—	—	14.1	—	7.9
	Hay	0[1]	—	—	15.7	—	10.7
Kawas *et al.* (1983)[2]	Hay	20	36.2[3]	—	30.9	26.0	23.7
	Hay	37	37.8[3]	—	31.4	28.4	25.2
	Hay	54	39.6[3]	—	35.1	30.1	29.4
	Hay	71	39.1[3]	—	35.1	29.4	31.6
DePeters and Smith (1986)	Hay	30	28.0	—	27.1	—	—
	Hay	50	32.0	—	28.4	—	—
Shaver *et al.* (1988)	Hay	40	38.0[3]	—	—	32.6	32.1
Nelson and Satter (1990)	Silage	45	23.5	—	23.8	—	22.0
	Hay	45	26.6	—	25.5	—	25.5
	Silage	45	27.2	—	27.0	—	27.7
Nelson and Satter (1992)	Hay	40	—	30.7	32.1	—	—
	Silage	40	—	33.6	33.4	—	—
	Hay	40	35.0	—	36.0	—	—
	Silage	40	38.1	—	37.0	—	—
Lee and Satter (1991)	Silage	25	—	26.0	23.6	—	—
	Silage	25	—	25.8	24.4	—	—
	Silage	45	—	27.9	26.8	—	—
Lee and Satter (1992)	Silage	25	—	27.0	25.3	—	—
	Silage	45	—	28.0	26.6	—	—

[1] 65% lucerne hay — 35% maize silage.
[2] Fat-corrected milk (4%).
[3] Pre-flower stage of maturity.

hays made from the same crop (Table 8). Given unfavourable weather conditions, the production advantage in favour of silage would be expected to be greater. Clearly a more detailed evaluation (benefit-cost analysis) of the role of hay in the Queensland dairy industry is required.

Silage

Silage fermentation in tropical forages

There is some evidence that the fermentation patterns in silages from tropical pastures may be different from those in temperate species. Acetate fermentations, often associated with high ammonia-N concentrations, appear to be more prevalent than the desired lactate fermentation (Catchpoole and Henzell 1971; Jarrige *et al.* 1982; Kaiser 1984). A number of factors could be responsible. The content of water-soluble carbohydrates is generally lower in tropical species (Kaiser 1984; McDonald *et al.* 1991), and possibly inadequate for a lactate fermentation, especially when unwilted forage is ensiled. Limited data available on buffering capacity indicate that tropical grasses appear to have values within the normal range for temperate species (McDonald *et al.* 1991). For example, kikuyu grown at Berry, NSW had buffering capacities of 375-496 m eq/kg DM, the higher values being obtained from N-fertilised grass (A.G. Kaiser and E.J. Havilah, unpublished data) (Table 9).

The more fibrous nature of tropical pastures could make consolidation difficult under field conditions, leading to inadequate exclusion of air (Catchpoole and Henzell 1971). With temperate forages, delayed sealing and inadequate air exclusion are known to produce poorly preserved silages with high levels of volatile fatty acids and ammonia-N (McDonald *et al.* 1991).

Ensiling method may have influenced silage fermentation in studies with tropical pastures. Many of Catchpoole's small-scale experiments (Catchpoole and Henzell 1971) were conducted with mown material passed through a chopper-chaff cutter and ensiled in silos maintained at 37 °C for the first 20 days of the ensiling period. Hand-harvested and processed forage has been used in other small-scale studies with tropical pastures. It is possible that this procedure encouraged acetate fermentations (Kaiser 1984).

Table 9. Effect of regrowth interval, nitrogen fertiliser application and wilting on the yield and composition of kikuyu grass and the resulting silages.[1]

		Regrowth interval							
		4 weeks				6 weeks			
Nitrogen fertiliser (kg/ha N)		0		100		0		100	
Wilting[2]		Nil	W	Nil	W	Nil	W	Nil	W
Pasture yield	(t/ha DM)	1.55		2.85		2.07		4.08	
Leaf content	(%)	60.8		61.3		56.8		54.3	
DM content	(g/kg)	196	454	162	290	207	426	183	332
Crude protein	(g/kg DM)	198	212	215	212	137	121	152	147
Water soluble carbohydrate	(g/kg DM)	27.7	32.2	23.4	21.7	31.5	31.1	35.6	28.4
Buffering capacity	(m eq/kg DM)	376	240	488	315	375	273	496	309
In vitro OMD	(%)	71.1	68.4	70.0	69.5	64.2	64.3	64.9	60.4
Silage pH	1	4.55	5.61	5.13	5.40	4.38	5.41	4.42	6.14
Silage ammonia-N	(g/kg total N)	93.5	51.7	116.4	93.3	69.0	99.4	77.7	174.7

[1] A.G. Kaiser and E.J. Havilah (unpublished data).

[2] 4 week regrowth wilted for 26 h and 6 week regrowth for 45.5 h. All forages harvested with a precision chop forage harvester.

In larger-scale Australian experiments many of the tropical pasture silages were made from unwilted long-chop (flail harvested) material. This could account for the poor silage fermentations obtained in most studies (Moss *et al.* 1984; Kaiser 1984).

It is generally accepted that intake, and consequently animal production, are depressed when animals are fed poorly preserved silages (see reviews by Kaiser 1984; McDonald *et al.* 1991). The exact cause of low intake is not known, but it occurs when there has been extensive breakdown of the protein fraction, coupled with a high level of volatile fatty acids. Intake has been shown to be negatively correlated with acetic acid and ammonia-N contents of silage. Consequently, Demarquilly and Dulphy (1977) have suggested that, if intake of silage is to approximate that of the parent forage, ammonia-N should be $\leqslant 50$ g/kg total N, acetic acid $\leqslant 25$ g/kg DM and the content of other volatile fatty acids should be approximately nil. Improving the silage fermentation will also improve the utilisation of dietary N (Kaiser 1984).

Given the generally poor preservation of tropical pasture silages reported in most Australian studies, it would appear that their milk production potential is low. However, most of these studies were conducted prior to 1975 and silage production technology has improved greatly during the 1970s and 1980s. Wilting, fine chopping and silage additives are technologies which have been shown to improve silage fermentation quality in temperate forages (McDonald *et al.* 1991). Rapid wilting to a DM content of 300–450 g/kg is likely to contribute significantly to the successful ensiling of tropical pastures and this is supported by results from small-scale ensiling studies with setaria (*Setaria anceps*) and rhodes grass (Catchpoole 1972a) and rapidly wilted kikuyu (Table 9). Wilting will be discussed in more detail later.

Fine chopping will improve consolidation and air exclusion particularly with wilted forage, thereby improving the silage fermentation in forage-harvested material. A satisfactory silage can also be produced from baled forage provided bale density is high and the bale is well sealed. Earlier work with silage additives showed that satisfactory preservation of tropical pasture silages could be achieved by applying high rates of molasses (Catchpoole and Henzell 1971). Since this time numerous silage additives have become available, but little is known about their efficacy when ensiling tropical forages.

Tropical pasture silage

Forage growth on tropical and subtropical perennial pastures often exceeds dairy cow requirements during summer and early autumn. The result is poor utilisation of available pasture (30–50%, Cowan *et al.* 1993), leading to considerable wastage. There has been considerable debate on whether this surplus forage can be conserved and used to partly fill the winter–spring feed gap. Silage has been suggested as the preferred conservation option as climatic conditions are considered unsuitable for hay making from tropical pastures.

Milk production from cows given tropical pasture silages has been low (Hamilton *et al.* 1978; Davison *et al.* 1984). Two factors have contributed to this lack of success. Firstly, silages are often poorly preserved with high levels of acetate and ammonia-N, and secondly, digestibility is usually low. It appears that most of the studies reported in the literature produced silages with metabolisable energy (ME) values no greater than 7.5–8.0 MJ/kg DM (Catchpoole and Henzell 1971; Hamilton *et al.* 1978; Cowan and Kerr 1984; Moss *et al.* 1984).

The above observations have led a number of research workers to conclude that it is not possible to produce silages of satisfactory quality from tropical pastures and that forage conservation from these pastures is uneconomic for milk production. However, this view could be unduly pessimistic as close scrutiny of the research on tropical pasture silages shows that in most studies, the forages ensiled were harvested too late at low digestibility. In addition, as discussed earlier, suboptimal ensiling procedures were used. Tropical grasses, if cut early at a leafy stage of growth, should produce silages with a DM digestibility of at least 60% (Hacker and Minson 1981; Minson *et al.* 1993), and digestibilities up to 70% have been observed in kikuyu (Jeffery and Holder 1971; Read 1981; Table 9). Early or frequent cutting may not be possible with tropical grass–legume pastures as Moss *et al.* (1984) reported a marked decline in legume content in the two years following conservation.

Conservation of surplus forage from tropical pastures in summer and autumn could be used in combination with other feeds to fill the winter-spring feed gap, allowing an increase in stocking rate and milk production per farm. In addition to the direct benefits from the silage, silage cutting will also influence the management and utilisation of tropical pastures. Strategic removal of surplus forage is likely to increase the proportion of forage utilised, maintain pastures at a higher digestibility, and provide better conditions for the re-establishment of temperate species in autumn. However, the impact of this more intensive management on total seasonal pasture yield and long-term persistence of tropical grasses is unknown. Research with temperate pastures in Victoria has shown that silage cutting strategy can have important effects on silage yield, total forage yield, silage quality and milk production from the silage (Table 10). Pasture utilisation during grazing, and the mean digestibility of the pastures during the pre-closure and regrowth periods were not measured in this study. Similar studies are required with tropical pastures to evaluate the full impact of silage production in dairy systems.

Forage crop silages

Summer crops. Sorghum x sudan grass hybrids (*Sorghum bicolor* x *Sorghum sudanese*), sudan grass and millets are generally grown for grazing during summer and autumn. They have the capacity to produce high yields of forage quickly (Minson *et al.* 1993), and this can often result in surplus forage which could be conserved as silage (Havilah and Kaiser 1992). However, the forage is generally considered to be of low to medium quality, and there is some concern that the milk production capacity of the silages is not sufficient to cover silage-making costs.

Time of cut is critical when ensiling summer forage crops, as digestibility declines rapidly with advancing maturity (Stobbs 1975; Wheeler *et al.* 1984; Havilah and Kaiser 1992). To achieve a digestibility greater than 60%, sorghum x sudan grasses would need to be cut earlier than 50 days from sowing. Time of cut is also important with millets, which generally have higher digestibilities than sorghum x sudan grasses (Stobbs 1975; Pritchard and Havilah 1984).

Mature crops of sorghum x sudan grasses and millets generally produce satisfactory silage fermentations (Catchpoole 1972b; Fisher and Burns 1987b), but digestibilities are generally low (Burns and Kimbrough 1981; Fisher and Burns 1987c). However, when immature, higher digestibility crops are ensiled, there is a risk of a poor fermentation (Catchpoole 1972b; Havilah and Kaiser 1992). In these circumstances wilting will probably improve the silage fermentation and reduce effluent losses.

Where sorghum x sudan grass and millet silages have been fed to cattle, there is evidence that with good management, a medium digestibility forage can be produced. Jaster *et al.* (1985) harvested a pearl millet (*Pennisetum glaucum*)

Table 10. Effect of spring management of perennial ryegrass-based pastures on pasture, silage and milk production.[1]

	Silage harvest date			
	October		November	
Duration of closure (weeks)	4	6	4	6
Date of closure	23/9	23/9	10/10	10/10
Pasture and silage yield (t/ha DM)				
Pre-closure (23/9 to 10/10)	—	—	1.8	1.9
Silage yield	2.4	3.4	1.6	2.0
Regrowth to 16/12	4.1	1.9	0.8	0.4
Total yield 23/9 to 16/12	6.5	5.3	4.2	4.3
Silage digestibility (%)	73.5	71.6	69.2	66.1
Intake (kg/d DM)	15.3	14.1	15.1	14.2
Milk (l/d)	12.3	11.5	11.4	9.9
Fat (g/d)	484	444	443	402
Protein (g/d)	391	357	362	348
Liveweight change (kg/d)	1.2	0.9	1.4	0.7

[1] From Rogers (1984) and Rogers and Robinson (1984). Total pasture yield from ungrazed, uncut area from 23/9 to 16/12 was 7.6 t/ha DM. Silages comprised 75% of the diet and high quality pasture 25%, for cows in mid-lactation.

crop 55 days after sowing and produced a high DM silage which sustained a DM intake of 2.4% of body weight and a DM digestibility of 64.3% in heifers. We have achieved a similar result with a crop of sorghum x sudan grass harvested 56 days after sowing (A.G. Kaiser and J.W. Piltz, unpublished data). In this study the wilted silage had a DM digestibility of 63.9% when fed to steers. With dairy cows, forage sorghum silage when combined with concentrates (58% of diet) produced 23.3 kg/d milk from animals in early lactation (Stanley and Fox 1985). This was 90% of the yield obtained from cows on a maize silage plus concentrate diet. High levels of milk production have also been achieved on diets containing a high proportion of pearl millet silage (Table 11).

In the future, sorghum x sudan grasses, sudan grasses and millets will be grown principally to provide forage for grazing dairy cows during the summer–autumn period. However, by integrating silage cutting with grazing management there is an opportunity to significantly improve the proportion of forage utilised, the mean digestibility of the forage (grazed and silage) consumed and subsequently the milk produced per hectare of crop. We believe that research on these aspects of crop management and utilisation is a high priority.

The other high priority area for research is breeding–selection to improve forage quality. An improvement of 5–7 digestibility units would substantially increase milk production from both grazed and ensiled forage. Increased digestibility can be achieved by selection within the normal plant population (Marten 1985; Havilah and Kaiser 1992) or by using brown-midrib (*bmr*) mutants. The *bmr* mutants of sorghum, sudan grass, sorghum x sudan grass and pearl millet have been found to have higher digestibilities than normal genotypes (Cherney *et al.* 1991). Limited animal production data are available for silages produced from the above *bmr* forages, but the *in vivo* digestibilities of sorghum and sorghum x sudan grass silages in heifers have been shown to be higher for *bmr* than for normal hybrids (Lusk *et al.* 1984; Wedig *et al.* 1987). In two experiments, Lusk *et al.* (1984) found that cows given *bmr* sorghum silage produced the same amount of milk as those on maize silage (see Table 15).

Winter crops. On most northern Australian dairy farms there is usually insufficient surplus forage available in spring from temperate forages for conservation. However, on large dairy farms located in inland districts, there is an opportunity to grow winter cereal or winter cereal–legume mixtures for silage production. Winter cereals will produce well preserved silages (Bergen *et al.* 1991), and van Dijk *et al.* (1986) found that cows given a wheat (*Triticum aestivum*) silage-based diet produced 92% of the fat-corrected milk yield of cows given a maize silage-based diet. Stage of harvest is an important factor influencing the quality of winter cereals and it appears that early cutting near the boot stage of crop development is required to achieve high digestibility (Ye *et al.* 1986; Roberts *et al.* 1989). This has been confirmed by a recent study at Wagga Wagga, NSW which showed that the organic matter digestibility of oats dropped from 68.8% at the boot stage to 62.6% some 21 days later at anthesis (A.G. Kaiser and B.S. Dear, unpublished data).

There are additional strategies for improving the quality of conserved cereal crops. Incorporating a legume, such as vetch (*Vicia* spp.) or peas (*Pisum sativum*), is likely to considerably increase nutritive value by raising digestibility and crude protein content (Sheldrick *et al.* 1987; Moreira 1989; Roberts *et al.* 1989). These crops can be very productive; at Wagga Wagga, oat–vetch crops can yield 12–15 t/ha DM, and in a recent experiment an oat–vetch silage supported a liveweight gain of 0.85 kg/d in steers (A.G. Kaiser, unpublished data). In an experiment in Denmark, Kristensen (1992) reported higher milk production on a pea silage than on a barley (*Hordeum vulgare*) silage (25.9 *vs* 23.6

Table 11. Milk production from mid-lactation cows given diets based on various silages.[1]

	Field pea-triticale, 50%; Maize, 14%	Pearl millet, 50%; Lucerne, 14%	Lucerne, 32%; Maize, 32%
Milk production (kg/cow/d)	25.3	24.0	24.5

[1] Messman *et al.* (1991). Total diet comprised 36% concentrates on all treatments.

kg/d FCM), and in the USA high levels of milk production were achieved in mid-lactation cows given a pea–triticale (*Triticosecale* spp.) silage (Table 11).

Another approach is to harvest cereal crops later when grain filling is well advanced and yields and DM content are higher. The crops can then be treated with urea or ammonia and the resultant alkaline reaction can significantly increase digestibility compared with normally fermented silage (Adamson and Reeve 1992; Tetlow 1992). Ammoniated whole-crop cereals can have ME values as high as maize silage (Adamson and Reeve 1992), although there has been some variation in nutritive value which could be due to variation in the efficacy of the alkali reaction. Phipps *et al.* (1992) compared perennial ryegrass silage, ammoniated whole-crop wheat and maize silage in an experiment with lactating heifers. Maize silage produced the highest milk yield, while the ammoniated whole-crop wheat produced a similar milk yield to that obtained on the ryegrass silage, but a higher yield of fat and protein.

There is much to learn about the management and utilisation of cereal–legume silages and ammoniated whole-crop cereals. Both could be valuable forages in dairy feed-year systems, and are worthy topics for research.

Silage crops 1. Maize

The maize crop combines high yield and high quality and the resulting silage is a valuable forage resource which has the capacity to significantly increase milk production per farm (Kerr *et al.* 1991). Maize silage has already generated considerable interest amongst dairy farmers in northern NSW and Queensland, and there is evidence that the area of crop grown is expanding rapidly. The cost of maize silage can be low (6–8 cents/kg DM or 6–13 cents/litre milk produced) making it very competitive with alternative feeds (Cowan *et al.* 1991; Davison *et al.* 1992).

Considerable progress has been made in understanding the agronomic requirements of the maize silage crop in southern Australia and in northern NSW, and high yields and quality are being achieved on farms (Havilah *et al.* 1992). The factors influencing the yield and quality of forage maize are summarised in Table 12. A recent study on dairy farms throughout NSW showed that 70% of farmers' maize crops fell into the high yield–high quality category (A.G. Kaiser *et al.*, unpublished data). Although some farmers are producing excellent crops (e.g. 35.4 t/ha DM crop at Biggara), there is still some capacity for improvement before the full potential of forage maize is realised on farms. However, less is known about the success of forage maize production in Queensland. Information is required on the areas suitable for maize silage production in Queensland, an appropriate agronomic management package, and the quality of maize silage produced on Queensland dairy farms (Minson *et al.* 1993).

Energy value. Maize silage is notable for its high energy value, but protein and mineral levels are low. Overseas *in vivo* data indicate that the metabolisable energy (ME) value of maize silage is about 10.5 MJ/kg DM. It appears that a

Table 12. Factors influencing the yield and quality of forage maize.

Low yield (<15 t/ha DM) **High quality (ME > 10 MJ/kg DM)**	**High yield (>15 t/ha DM)** **High quality (ME > 10 MJ/kg DM)**
• Early variety • Low plant population • Early harvest • High quality variety • Suboptimum management	• Mid-season variety or early variety at higher population • High yielding and high quality variety • Good management • Adequate rainfall–irrigation
Low yield (<15 t/ha DM) **Low quality (ME < 10 MJ/kg DM)**	**High yield (>15 t/ha DM)** **Low quality (ME < 10 MJ/kg DM)**
• Management failure • Poor variety • Drought	• Mid-season to late variety • High plant population • Low quality variety • Adequate rainfall–irrigation for crop growth • Stress during grain fill • Late harvest

similar value is achievable under Australian conditions for well managed crops grown throughout NSW and northern Victoria (Kaiser 1992). For example, in a recent study (A.G. Kaiser *et al.*, unpublished data) the mean predicted ME content of 40 farmers' crops grown over 3 years on dairy farms throughout NSW was 10.2 MJ/kg DM. The lower quality crops were either poorly managed or suffered moisture stress during grain filling. There is evidence that moisture stress during grain filling will reduce yield and grain content (NeSmith and Ritchie 1992). Numerous studies have shown that silage digestibility and animal production increase with grain content (Kaiser *et al.* 1991a).

Both the overseas and Australian literature show that there is considerable variation in the digestibility or ME content of forage maize and maize silage (Kaiser *et al.* 1991b; Kaiser 1992). There is a significant genetic component with differences in digestibility between hybrids being observed in European, north American and Australian maize (Deinum and Struik 1986; Carter *et al.* 1991; Kaiser *et al.* 1991a; Hunt *et al.* 1992). The hybrids with superior whole-crop digestibility have higher grain contents and/or stover digestibility. The genetic base for maize in Australia is considerably more diverse than that used in much of Europe and North America, where environmental constraints make it necessary to grow only short-season hybrids. For this reason greater variation in quality may exist in Australian hybrids.

The importance of climatic conditions on maize silage quality under Australian conditions is unknown. Some research workers cite experiments conducted under artificial conditions in a glasshouse as evidence that high temperatures depress digestibility in forage maize (Deinum and Struik 1986). However, there was no evidence of any influence of climatic zone or temperature on the digestibility of a set of maize hybrids grown at 16 sites in Europe, ranging from Sweden (latitude 56 °N; mean maximum 19 °C, mean minimum 10 °C) to Mediterranean countries (latitude 41 °N; mean maximum 29 °C, mean minimum 18 °C) (Deinum 1988). Caution needs to be exercised when relating these observations to Australian conditions, as our maize growing environments are more diverse, extending from latitudes 11–44 °S. Nevertheless, it is likely that local weather conditions rather than systematic climatic differences will have most influence on maize silage quality. High temperature (pollen blast) and moisture stress at critical stages of crop development are likely to be important (Minson *et al.* 1993) and should be investigated.

Stage of maturity at harvest is an important consideration when making maize silage. As the crop matures, grain content increases and digestibility of the stover fraction declines. The net effect in many European and north American studies is a relatively stable whole-crop digestibility or perhaps a small decline during grain filling (Deinum and Struik 1986; Kaiser and Havilah 1989). However in some studies whole crop digestibility declined with advancing maturity (Hunt *et al.* 1989), and this could be the more usual trend with the later maturing, higher yielding maize crops grown in Australia. Crop DM content also increases rapidly during grain filling and this influences the silage fermentation, intake, milk production and ensiling losses. Maize silage intake generally improves up to a DM content of 350 g/kg, with little change at higher levels of DM (Phipps 1990). In a recent review, Wilkinson (1991) concluded that ensiling losses can be minimised by harvesting the crop at 300–400 g/kg DM. In view of the importance of stage of maturity at harvest, it is important that farmers monitor crop maturity by milk-line scoring to determine optimum harvest date (Havilah and Kaiser 1991).

Some of the observed variation in the digestibility and predicted ME value of maize silage is due to differences between research institutions in experimental procedures. *In vivo* estimates can be influenced by level of feeding, class of animal and the provision of N and mineral supplements (Smith *et al.* 1980; Deinum and Struik 1986; Moran *et al.* 1988). Analytical procedures and a range of prediction equations also influence estimates of digestibility and ME content (Kaiser 1992). It is important that uniform procedures be adopted so that more reliable comparisons can be made between laboratories.

Protein content. Maize silage is generally recognised as having a low crude protein content, with 80 and 90 g/kg DM being representative values reported in the literature for USA and European forage maize, respectively. It appears that the crude protein content of Australian maize silage is lower. In recent experiments (A.G. Kaiser *et al.*, unpublished data) the crude protein content of farmers' crops grown throughout

NSW varied from 36–79 g/kg with a mean of 62 g/kg DM. The crude protein content of 26 varieties grown at Nowra and harvested at 3 stages of maturity varied from 57–88 g/kg with a mean of 72 g/kg DM. Similar results (range 63–85, mean 75 g/kg DM) were obtained in a series of variety comparisons at Taree, NSW (Launders 1991). Allen *et al.* (1990) found repeatable differences between varieties in crude protein content in the USA. Improvement in the crude protein content of maize hybrids would be worthwhile as, in situations where insufficient protein is available from other forage sources, protein supplements would have to be purchased. For example, 25 kg cottonseed meal ($300/t) would be required to raise the crude protein content of 1 tonne maize silage DM by 10 g/kg and is equivalent to a cost of $7.50/t DM.

Maize silage in dairy cow diets. Maize silage has been used extensively in dairy cow diets overseas. In the USA, maize silage is often used in combination with lucerne hay or lucerne silage. On high concentrate diets for high yielding herds, lucerne supplies the greater proportion of the roughage component of the diet (Wilkinson 1991). For lower yielding herds, maize silage is the dominant roughage source. In the UK and Europe, maize silage is used in combination with grass silage, and work by Phipps (1990) has shown that increasing the ratio of maize silage to grass silage can increase milk production or reduce the requirement for concentrates. Maize silage is likely to be used as a supplement for grazing cows on northern Australian dairy farms, but could also be used as a major component of feedlot dairy diets. Australian studies evaluating maize silage as a supplement for grazing dairy cows are presented in Table 13.

Combinations of high protein, high legume pastures with maize silage have tended to support the highest level of milk production (Table 13). This probably reflects improved protein

Table 13. Milk production (kg/cow/d) from dairy cattle given pasture with maize silage supplements.

Reference	Pasture type	Crude protein content of pasture	Level of supplementation		
			Low	Medium	High
		(g/kg DM)			
Davison *et al.* (1982b)	*Panicum maximum/Neonotonia wightii*	160	(3.0)[1]	(7.0)	—
			14.3	15.3	—
	+ protein supplement[2]		15.0	16.6	—
Stockdale and Beavis (1988)	*Lolium perenne-Trifolium repens*[3]	160	(3)	(7)	(10)
			18	19	20
	T. resupinatum[3]	210	(3)	(7)	(10)
			20	22	24
Hamilton (1991a)	*Pennisetum clandestinum*	—	(4.6)	—	—
	+ grain		15.6	—	—
	+ grain + protein supplement[2]		17.1	—	—
Hamilton (1991b)	*L. perenne*	—	(4.6)	—	—
	+ grain		19.2	—	—
	+ grain + protein supplement[2]		20.0	—	—
Stockdale (1991)	*T. resupinatum*	210	(3.8)	(6.5)	(8.3)
			26.7	26.4	26.3
Moran and Stockdale (1992)	*Paspalum dilatatum-L. perenne-T. repens*	150	(3.1)	—	(8.2)
			19.8	—	18.5
	+ protein supplement[2]		19.7	—	20.1
Moran and Jones (1992)	*T. subterranean-L. rigidum*[3]	210	—	(7.6)	—
			—	20.0	—
	T. repens-L. perenne	200	—	(7.5)	—
			—	22.7	—
Moran (1992)	*L. perenne-T. repens*	130	—	(6.6)	—
			—	14.0	—
Moran and Wamungai (1992)	*T. pratense*[3]	210	—	(6.3)	(8.2)
			—	22.2	19.3
	T. subterranean-L. rigidum	230	—	—	(10.8)
			—	—	20.9

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[1] Quantity of maize silage in parentheses (kg DM/cow/d).

[2] Protein supplement provided with maize silage.

[3] Animal house experiment.

nutrition, and in some studies milk production responses to protein supplements were observed at medium or high levels of maize silage supplementation, but not at a low level of supplementation (Davison *et al.* 1982b; Moran and Stockdale 1992). A response to a protein supplement was also observed in 2 experiments where a pasture plus grain diet was supplemented with a low level of maize silage (Hamilton 1991a, 1991b).

These results highlight the importance of adequate protein nutrition when using maize silage as a supplement for grazing dairy cattle, and are in line with overseas work with housed dairy cattle on maize silage-based diets. For example, 2 studies have shown that cows need a whole-diet crude protein content of at least 17.1% and 13.4% in early and mid-lactation, respectively (Phipps *et al.* 1981; Kung and Huber 1983).

The milk production response per kg maize silage has varied considerably with pasture type, level of pasture availability, and level of maize supplementation. Responses of 0.8–1.0 kg milk/kg maize silage DM have been obtained where pasture supply is restricted (Stockdale and Beavis 1988; Hamilton 1991a, 1991b; Robertson and Lemerle 1991). With Persian clover, responses of 1.4 and 1.2 kg milk, respectively, were recorded when pasture intake was restricted (Stockdale and Beavis 1988) or unrestricted (Stockdale 1991). A poor response of 0.34 kg milk/kg maize silage DM was obtained by Moran and Stockdale (1992) when cows were given unrestricted paspalum–perennial ryegrass–white clover pasture and 3.1 kg/d DM of a low quality maize silage.

The future. It is clear from the above that there is considerable potential to increase farm productivity by incorporating maize silage into feeding systems. In view of its low protein content, care will need to be taken in balancing diets to ensure adequate protein intake. Improving the quality of forage maize is likely to improve its productive potential by either increasing milk production or reducing the level of concentrates in the diet. Higher animal production has been obtained by increasing grain content or stover digestibility (Phipps 1990; Carter *et al.* 1991; Kaiser *et al.* 1991a). In view of the late maturity and higher yield capacity of forage maize crops in Australia, it is likely that the response to improved stover quality will be greater here than in Europe or North America. Also, with lower levels of concentrate feeding, cows are likely to be more responsive to improvements in forage quality. There is sufficient variation in the normal maize population to breed hybrids with improved digestibility (Carter *et al.* 1991). Using the brown-midrib (*bmr*) gene is an alternative approach; improved digestibility, intake and milk production have been recorded with *bmr* hybrids (Kaiser *et al.* 1991a). The *bmr* gene is currently being used to improve the quality of Australian forage maize in a breeding program at Grafton, NSW (J.M. Colless, personal communication). Oram (1992), in a recent review of the genetic improvement of pasture plants for the dairy industry, recommended the agronomic and nutritional evaluation of *bmr* maize.

Silage crops 2. Grain sorghum

Owing to its higher yield and nutritive value, maize is generally the crop of first choice for silage production. However, a significant proportion of the dairying area in Queensland is poorly or marginally adapted for maize production. Sorghum is more widely adapted, and its capacity to grow under lower rainfall and in poorer soils offers farmers an alternative high energy crop for silage production (Havilah and Kaiser 1992). Indeed there is currently considerable interest in grain sorghum silage amongst central Queensland dairy farmers (G. Chopping, unpublished data).

Sorghums vary considerably in crop characteristics and composition, and in the USA some researchers classify them into 3 types (Table 14). The intermediate types are not widely used in Australia, although some plant breeders are considering using them to increase yield. Forage sorghums (often grain x sweet *S. bicolor* hybrids) tend to be taller growing, later maturing and with a higher sugar content. In the USA, sweet sorghums may be included in this category, although they would have considerably higher sugar levels than those shown for forage sorghums in Table 14.

Grain sorghums are generally lower yielding and have a high grain content and higher digestibility. Cummins (1971) reported grain contents of 51% and 57% in 2 grain sorghums harvested at the dough stage of grain development. Although the energy digestibility of grain sorghum silage in the USA varies little during

Table 14. Characteristics of sorghums (*Sorghum bicolor*) grown for silage.[1]

	Grain sorghum	Intermediate sorghum	Forage sorghum[2]
Sowing to harvest (d)	97	96	117
Crop composition at harvest			
DM content (g/kg)	325	266	242
Proportion seed heads (%)	45	33	8
Sugars (g/kg DM)	76	114	152
Starch (g/kg DM)	210	153	87
In vitro DM digestibility (%)	65.6	64.3	62.3
Silage composition			
pH	4.0	3.8	3.8
Lactic acid (g/kg DM)	62	73	80
Acetic acid (g/kg DM)	24	18	16
Ethanol (g/kg DM)	9	17	31

[1] Adapted from Fisher and Burns (1987a; 1987b; 1987c) for crops grown in North Carolina, USA. Each tabulated value is a mean for 2 varieties grown at 2 sites.

[2] Sweet sorghums could be included in this category but higher sugar levels would be expected.

grain filling (Goodrich and Meiske 1985), optimum stage of harvest appears to be during the dough stage as maximum yield and optimum DM content occur during this period (Smith and Bolsen 1985). Harvesting beyond the hard dough stage has been found to result in poorer feed conversion efficiency in steers and a decline in protein digestibility (Goodrich and Meiske 1985; Smith and Bolsen 1985).

Comparisons of grain sorghum silage and maize silage in the USA indicate that digestibility and crude protein content are generally lower in grain sorghum (Goodrich and Meiske 1985). Nevertheless, grain sorghum silage can support high levels of animal production. Smith and Bolsen (1985) reported growth rates of 0.96–1.02 kg/d in steers given a yellow endosperm grain sorghum silage and a concentrate supplement of 0.91 kg/d. At Wagga Wagga, steers given grain sorghum silage as the sole diet gained at 0.92 kg/d (A.G. Kaiser, unpublished data) which is approximately 91% of the growth rate normally obtained on maize silage (1.01 kg/d; Kaiser 1992). Goodrich and Meiske (1985) reported that grain sorghum silage supported 97% of the liveweight gain obtained on maize silage.

Varietal differences in quality. There is evidence of significant varietal differences in the *in vitro* digestibility of grain sorghum silages (Salako and Felix 1986). This could be due in part to grain characteristics, particularly seed coat and endosperm type (Havilah and Kaiser 1992). The digestibility of sorghum grain, particularly the protein component, is known to be inhibited by high tannin content (Harris *et al.* 1970; Schaffert *et al.* 1974). In a digestion study with heifers, Streeter *et al.* (1990) found that whole-tract digestibility of the ADF and N fractions in sorghum grain was significantly lower for high tannin sorghum. Apart from the effects of tannin on the grain component, there is also evidence that *in vitro* digestibility and crude protein content of the whole plant declines with increasing tannin level (Montgomery *et al.* 1986).

The effect of grain tannin levels on silage quality is not clearcut. There is evidence that tannin in the grain is broken down during the ensiling process, and that the digestibility of high tannin grain increases following ensiling (Cummins 1971; Burns and Kimbrough 1981). Ensiling has less effect on tannin in the stalks and no effect on tannin in the leaves (Cummins 1971), so these tannins would remain in the silage possibly inhibiting intake and digestibility. Further research is required on tannins in the various plant components of sorghum x sudan grass, sweet sorghum and grain sorghum to determine the effects on silage quality and animal production. It is clear that, owing to changes during the ensiling process, this work must be conducted with ensiled forage. Selection of sorghum lines with low levels of tannins, and specific phenolic compounds (Mueller-Harvey and Reed 1992), in the stover is likely to improve silage digestibility.

Endosperm type is another factor influencing the nutritive value of sorghum grain, and there is evidence that feed conversion efficiencies in growing cattle on waxy and yellow endosperm sorghums are superior to normal endosperm type sorghum (Rooney and Pflugfelder 1986). There are insufficient data available to assess whether these differences will influence the nutritive value or milk production potential of grain sorghum silage.

Whole-grain digestion. During the harvesting of grain sorghum for silage a higher proportion of the grain escapes damage by the forage harvester. As a result, the whole-grain content of grain sorghum is greater than that of maize silage. It has been suggested that one of the reasons for lower animal performance on grain sorghum silage than on maize silage could be poor digestion of the whole-grain component (Goodrich and Meiske 1985). However, Anthony *et al.* (1962) found that the digestibility of grain in sorghum silage was high (ca. ⩾90%) and declined only at high levels of silage intake. In a more recent study, where grain sorghum silage comprised approximately 90% of the diet, liveweight gain and feed conversion efficiency in steers were improved when the silage was rolled prior to feeding (Smith and Bolsen 1985). Further research is required to determine the effects of grain characteristics, stage of maturity, and the use of an abrasion or cracker plate in the forage harvester on whole-grain digestion and milk production on grain sorghum silage diets.

The future. In the future, grain sorghum silage is likely to become an important forage resource on northern Australian dairy farms. Although milk production is generally lower than that achievable on maize silage (Lusk *et al.* 1984), there are cases where a similar level of milk production has been achieved (van Dijk *et al.* 1986; Shirley *et al.* 1989; Table 15). Development of higher quality hybrids by using *bmr* mutants or improving other crop characteristics is likely to improve the milk production potential of the crop. A number of aspects of the production and utilisation of the crop require research. These include data on crude protein content. If crude protein levels are lower than in maize, as in the USA, diets must be formulated to provide adequate protein for milk production. It is likely that a combination of low crude protein content and possibly low protein availability owing to the presence of tannins could make grain sorghum silage a poor source of protein.

Silage crops 3. Sweet sorghum

In much of the USA literature, there is no differentiation between forage sorghums and sweet sorghums for silage production. Both crops are tall growing and high yielding, and generally provide one harvest for silage production. The sweet sorghums, which are also used as agro-industrial crops for ethanol production, have high sugar levels in the stalk and generally a low grain content.

Sweet sorghums can produce similar yields of DM to maize under favourable conditions, and can perform adequately in areas not suitable for maize (Havilah and Kaiser 1992). Compared with grain sorghums, they have a higher yield capacity but lower digestibility (Salako and Felix 1986). From a management viewpoint, one of the major advantages of sweet sorghums is a large harvest window, during which time yield and quality change little. A number of studies with fresh and ensiled forage have shown that digestibility changes little during grain filling (Black *et al.* 1980; Cummins 1981; Dickerson and Bolsen 1986; Havilah and Kaiser 1992). Unlike in maize, the DM content of sweet sorghums remains

Table 15. Milk production (l/cow/d FCM) on diets based on silages produced from a range of summer-growing crops.

Reference	Maize	Sorghum	Brown midrib sorghum	Grain sorghum + soybean	Sunflower	Maize + sunflower
Vandersall (1976)	22.1[1]	—	—	—	—	23.5
Baxter *et al.* (1984)	18.5	—	—	16.7	—	—
Lusk *et al.* (1984)	22.7	—	23.5	—	—	—
van Dijk *et al.* (1986)	25.1	25.6	—	—	—	—
Valdez *et al.* (1988b)	26.5	—	—	—	25.5	26.5
Shirley *et al.* (1989)	20.7	21.5	—	—	—	—
Fisher *et al.* (1991)	30.6	—	—	—	—	28.7
Harbers *et al.* (1992b)	20.0	—	—	20.5	—	—

[1] Maize silage + lucerne hay supplement.

relatively low and does not generally rise above 30-35% at the hard grain stage (Black *et al.* 1980; Cummins 1981; Dickerson and Bolsen 1986). The forage is therefore easy to consolidate in the silo, and this, together with a high sugar content, ensures a satisfactory silage fermentation (Black *et al.* 1980; Hill *et al.* 1987).

The future. The lower quality of sweet sorghums restricts their wider use in dairy feeding systems, maize and grain sorghum silages being the preferred options. However, quality of forage and sweet sorghums varies in terms of digestibility (Cummins 1981; Dickerson and Bolsen 1986; Salako and Felix 1986; Havilah and Kaiser 1992) and tannin content (Montgomery *et al.* 1986). Improving digestibility by increasing sugar content, reducing tannins and using *bmr* mutants could greatly enhance the role for sweet sorghum silage on Australian dairy farms. Further research is warranted.

Silage crops 4. Mixed crops

In an effort to raise the protein content of high energy silages, a number of research workers have investigated the production of mixed crops such as maize-soybean (*Glycine max*) or grain sorghum-soybean for silage production. The DM yield of soybean crops is considerably lower than that of maize crops, and 2 studies have shown that, in order to maintain high yields, it was necessary to maintain a high maize plant population in the mixture (Herbert *et al.* 1985; Ferrero and Cremonesi 1992). This reduced the proportion of soybean in the mixed crop so that the increase in crude protein content was small (<20 g/kg DM).

More work has been conducted with grain sorghum-soybean mixtures. In a number of studies, the yield of the mixed crops has been shown to be less than that of grain sorghum alone (Bolsen *et al.* 1992; Harbers *et al.* 1992a) or maize (Baxter *et al.* 1984). Crude protein content was higher in the mixed silages but there were only minor changes in digestibility (Harbers *et al.* 1992a). Bolsen *et al.* (1992) found that the liveweight gain and feed conversion efficiency of steers were lower on a grain sorghum-soybean silage than on a grain sorghum silage. In experiments with dairy cattle, Baxter *et al.* (1984) observed higher milk production on a maize silage-based diet than on a grain sorghum-soybean silage-based diet (Table 15). However, in a recent study Harbers *et al.* (1992b) observed little difference in milk production, although milk protein was higher on the maize silage diet. From the above studies there is little evidence that incorporating soybeans into mixtures with maize or grain sorghum will increase animal production from the crop. Indeed there is evidence of reduced crop yields in mixtures. It appears that alternative strategies for supplying protein in diets which contain maize silage or grain sorghum will be more productive.

For many years there has been an ongoing interest in the production of silage from sunflowers (*Helianthus annuus*), and early studies with taller varieties with lower grain content indicated that the feeding value of sunflower silage was about 80% of that of maize silage (Thomas *et al.* 1982). With the development of high grain, high oil cultivars there has been renewed interest in the use of sunflower silage in dairy cow diets. Sunflowers produce silages with higher crude protein and oil contents than maize, but yields appear to be lower (Valdez *et al.* 1988b; Fisher *et al.* 1991; Collar *et al.* 1992). In an experiment with dairy cows Valdez *et al.* (1988a) observed a lower digestibility for sunflower silage than for maize silage, but both crops were harvested at a low DM content (230-250 g/kg). Sunflower silage and sunflower-maize silage have been compared with maize silage in a number of studies with dairy cows. Generally there has been little effect of silage type on milk production (Table 15), and a similar result was obtained in a comparison of sunflower silage with lucerne-grass silage (Thomas *et al.* 1982). In all studies, the content of milk fat or protein in the milk was reduced, which led to a recommendation by Fisher *et al.* (1991) that sunflower silage should not be used as the sole forage in the diet. However, increases in the proportions of long-chain fatty acids (18:1 and 18:2) indicates that milk quality can be improved by feeding sunflower or sunflower-maize silages (Valdez *et al.* 1988b).

The future. The role of sunflowers on northern Australian dairy farms is unclear. While forage yield may be lower than with maize, the difference is likely to be considerably smaller when comparing sunflowers and grain sorghum. A high proportion of Queensland dairying districts are suitable for growing both grain sorghum and sunflowers (Weston *et al.* 1984). Little is known of differences in yield and quality amongst sunflower varieties. It does appear that the quality of sunflower silage is similar to maize silage, and in one study there was evidence that the efficiency of feed utilisation for milk production was greater on a sunflower-maize silage (Valdez *et al.* 1988b). There have been no comparisons of sunflower silage with grain sorghum silage, but sunflower silage may well have a superior nutritive value. Agronomic and animal production studies are therefore required to determine the potential value of sunflower silage as a supplement for grazing dairy cattle.

Silage crops 5. Legumes

On northern Australian dairy farms where tropical pastures, maize silage, grain sorghum silage, sweet sorghum silage and cereal grains comprise a high proportion of the diet during winter–spring, it is likely that the diet will contain insufficient protein to support high levels of milk production. In some areas, this problem can be overcome by providing sufficient quantities of high quality winter forage crops, or lucerne hay or silage. Protein supplements are a more expensive option than protein supplied from forages. An alternative strategy is to conserve summer forage legume crops as silage.

Attempts have been made to raise the protein content of high energy silages such as maize or grain sorghum (see earlier discussion) by intercropping with soybeans. This approach does not appear to be successful in terms of yield, silage quality (crude protein content and digestibility) and milk production. In addition it generates additional management considerations, for example weed control in mixed crops. Producing pure legume silages offers the farmer more flexibility at the time of feeding when adjusting the protein content of the diet.

No research has been conducted to evaluate the role for summer forage legume silages in dairy farming systems. A number of crops could be suitable for the production of high protein silages. Earlier work with dolichos lablab (*Lablab purpureus*) produced silages with a crude protein content of approximately 190 g/kg DM, but the digestibility in sheep was low (OMD <60%; Morris and Levitt 1968). Higher *in vitro* digestibilities were observed in soybean forage (Desborough and Ayres 1988), and there was evidence of varietal variation in yield, digestibility and protein content. Of the commercially available legume crops, there is evidence of considerable variation in yield, plant composition and regrowth potential (Muldoon 1985). In Muldoon's study, irrigated phasey bean (*Macroptilium lathyroides*) and peanut (*Arachis hypogaea*) showed considerable regrowth potential. This could provide more flexibility (grazing and silage), and more rapid wilting of lower yields of higher quality material at each cut for silage production. In addition to commercially available material, there is a wide range of other legumes which could prove valuable as silage crops, e.g. *Indigofera* spp., *Crotalaria* spp., *Vigna* spp. Little is known about the nutritive value of these crops, although some are known to contain toxic compounds (Minson and Hegarty 1984). However, previous experience with other plants has shown that it is possible to select or breed cultivars with reduced levels of anti-quality factors (Minson and Hegarty 1984; Marten 1985).

The future. High yielding, high quality legume forage crops could serve a useful role in dairy feeding systems by providing forage for conservation and grazing. Research should evaluate the wide range of commercial and non-commercial genera and species available in terms of yield and quality, their agronomic management requirements, optimum stage of harvest and suitability for silage production. The effective utilisation of legume silages within northern dairying feeding systems also requires research.

Silage production methods

A number of aspects of silage production in the subtropical and tropical dairying areas of northern Australia require research. These issues will be discussed only briefly here; the reader is referred to other reviews for a more detailed coverage of these topics.

No surveys have been conducted to assess the quality (fermentation and digestibility) of silages produced on dairy farms in northern Australia. It is therefore difficult to assess the extent to which farmers are conserving forages of high digestibility, and the success of preservation on farms as measured by silage fermentation characteristics. However many of the forages that could be used for silage production would be likely to be poorly preserved if direct-cut. These include tropical pastures, summer forage crops, lucerne and summer-growing forage legumes. Their high moisture content, low sugar content and high buffering capacity are likely to lead to a poor fermentation unless the forage is wilted or a silage additive is applied.

Wilting. Considerable research has been conducted with temperate forages on the effect of wilting on silage composition. Wilting has been shown to reduce effluent losses, increase field losses, improve the silage fermentation and generally increase intake. However, the effects on milk production have been variable (Gordon 1989; Kaiser and Havilah 1989; McDonald *et al.* 1991). A number of factors could be responsible for this variation and are listed in Table 16.

The question arises as to the role of wilting in subtropical and tropical environments. Clearly with problem forages, the ensiling of direct-cut material without any treatment is likely to produce poorly preserved silages, but will wilting overcome this problem? Overseas research has shown that the reliability of the wilting option is likely to be significantly influenced by weather conditions. If the wilting of high moisture forage is slow owing to poor drying conditions, field losses will increase significantly, and there will be an increased risk of a poor fermentation and reduced digestibility (Anderson 1983, 1985; McDonald *et al.* 1991). This appeared to be the case with the kikuyu grass silage produced from a 6-week regrowth of N-fertilised forage, and described in Table 9. The combination of lower sugar content in tropical forages and warm humid conditions during wilting could result in more significant biochemical losses (respiration and other enzymatic processes) during prolonged wilting than occurs with temperate forages. Hence research is required on the optimum degree and speed of wilt for tropical pastures and forage crops, mechanical and chemical means of accelerating wilting rates, and the impact of these treatments on silage quality and milk production.

Silage additives. Silage additives are widely used overseas and have been the subject of considerable research (Woolford 1984; McDonald *et al.* 1991). Wilkinson (1990) listed 126 commercial silage additives that were being sold on the UK market, and this did not include all the carbohydrate sources and other nutrients that are used as silage additives. In contrast, in Australia, wilting is the preferred option for manipulating the silage fermentation, and silage additives are not widely used by farmers. However, in recent years there has been increased promotion of silage additives.

Where satisfactory preservation of silage can be achieved with a rapid wilt, silage additives are unlikely to significantly improve silage quality or milk production. However, there are reports in the literature of animal production responses to silage inoculants even where the control silage has been well preserved (Gordon 1989). When conditions do not permit a rapid wilt prior to ensiling, silage additives may prove useful. The optimum ensiling procedure may involve a combination of a light wilt plus silage additives. Research is required to establish the efficacy of silage additives when ensiling tropical pastures and forage crops.

One application where silage additives are likely to play an important role in reducing silage

Table 16. Factors which may influence the response in milk production from wilting and finer chopping.

Factors	Likely to influence reponse to:	
	Wilting	Finer chopping
Those which may operate during silage making		
Weather conditions — speed of wilt	✓	—
Other factors influencing speed of wilt (e.g. forage yield, conditioning, raking-tedding)	✓	—
Type and composition of parent forage	✓	✓
Digestibility of parent forage	—	✓
Wilting (DM content or degree of wilt)	✓	✓
Chop length difference (cm)	✓	✓
Silage additives	✓	✓
Storage method	✓	✓
Management and animal factors		
Concentrate feeding	✓	✓
Proportion of silage in diet and total feed intake	✓	✓
Yield and nutritive value of basal pasture when silage is used as a supplement	✓	✓
Stage of lactation (intake during early lactation)	✓	✓

losses is the prevention of aerobic deterioration of carbohydrate-rich silages such as maize, grain sorghum and sweet sorghum during feeding out. The aerobic deterioration process is characterised by significant heating plus DM and nutrient losses from silage when opened and exposed to air (Woolford 1984; McDonald *et al.* 1991; Wilkinson 1991). Maize silage is known to be particularly susceptible to aerobic deterioration. Since the rate of deterioration is known to increase with ambient temperature (Woolford 1984), losses are likely to be greater in Australia than in Europe and North America. Observations by the authors confirm that aerobic deterioration of maize silage is a problem in NSW and Queensland during the warmer months, but the impact on milk production is unknown. There are a number of silage additives which could improve maize silage stability (Woolford 1984; McDonald *et al.* 1991), and their effects on silage losses and milk production should be evaluated under Australian conditions.

Silage production systems. In recent years considerable interest has developed in round-bale silage systems. Although it is the most expensive form of silage production or forage conservation (Kaiser *et al.* 1990), it is popular with dairy farmers because of its convenience and suitability for conserving small batches of silage. Comparisons of round-bale silage with conventional fine-chopped silage have yielded variable results. Poorer silage fermentations with lower levels of fermentation acids and high levels of ammonia-N have been observed in some studies with round-bale silages (Kennedy 1989; Nicholson *et al.* 1991, 1992). However, Moate *et al.* (1985) measured similar milk production from mid-lactation cows given round-bale and conventional fine-chopped silages as supplements to pasture. In other animal experiments, variable results have been reported. Similar (Kennedy 1989) and inferior (Nicholson *et al.* 1991) liveweight gains have been observed in steers given round-bale silage. Insufficient data are available on the utilisation of round-bale silage in dairy cow diets, particularly for high yielding cows in early lactation. Feeding management (whole bales *vs* unrolled bales *vs* chopped baled silage) could also be important and should be investigated.

There has been considerable debate on the benefits of finer chopping of silage for milk production, and the results of comparisons of chop lengths have been variable (see reviews — Gordon 1989; Kaiser and Havilah 1989). A number of factors are likely to interact with chop length (see Table 16), and Gordon (1989) believes that interactions between chop length and silage fermentation quality and level of concentrate feeding are most important. He believes that a milk production response to finer chopping might occur only in the absence of concentrates. As yet it is not possible to conclude whether there is an optimum chop length for dairy cattle. However, the available data with temperate pasture species indicate that there is probably little advantage in chopping pasture finer than 5 cm (Kaiser and Havilah 1989; Savoie *et al.* 1992).

Detailed evaluation of alternative silage production systems is hampered by a lack of reliable information on the quality of silage produced, the milk production potential of the silage, and typical losses which occur in the field, during storage and feeding out. Further, silage production systems must be considered as part of a whole-farm management system, and it is important that any interactions between the silage and other components of the system (e.g. pasture management, concentrate replacement, stocking rate) be considered. If a meaningful economic assessment of the impact of forage conservation on whole-farm productivity is to be obtained, these issues will have to be addressed using a multi-disciplinary team approach.

Ammoniated forages

The improvement of forage digestibility following alkali treatment is well established. Much of the earlier research was conducted with cereal straws, and subsequent work has shown that significant improvements in digestibility can be achieved with a range of grasses, but not legumes, following treatment with sodium hydroxide or ammonia (Wilkins 1982; Kaiser and Curll 1987). The response to alkali treatment has been shown to be greatest with grasses with lower initial digestibility. In practice, treatment with anhydrous ammonia or urea, which is rapidly hydrolysed to ammonia, is likely to be preferred by farmers because it is easy to apply and is less hazardous to apply than sodium hydroxide. Ammonia is also a mould inhibitor and a source of rumen degradable nitrogen (treated forages usually have a low initial crude protein content).

Most of the research with ammonia treatment has been conducted with straw or baled hay. Improved digestibility and liveweight gain have been observed in cattle given ammoniated tropical grass hay (e.g. Brown 1988). There are few data available on the alternative procedure of treating grasses (urea treatment of forage-harvested grass with a DM content between hay and silage, 550–750 g/kg DM). This material is stored in a manner similar to silage and is sometimes called ammoniated forage. While not widely evaluated for grasses, this system has been used extensively in the UK with ammoniated whole-crop cereals (see earlier discussion). This method of ammoniation should be evaluated with a range of tropical grass species, at different stages of growth and at a range of urea and moisture levels.

One concern with the production of ammoniated hays and other ammoniated feeds is the occasional outbreak of hyperexcitability in cattle (Morgan and Edwards 1986; Perdok and Leng 1987). The toxic compound is thought to be 4 methyl-imidazole, but other compounds may well be involved. It is not known how widespread this problem is, although there are reports in the literature for a range of ammoniated feeds. However, when treating hay or straw, hyperexcitability has been reported only where ammoniated material has undergone heating (Perdok and Leng 1987; Conner *et al.* 1990). Perdok and Leng (1987) observed no cases of hyperexcitability when straw was "ensiled" with urea, and they recommended that raising the moisture content, replacement of anhydrous ammonia with aqueous ammonia or urea, and avoiding temperatures of 70 °C or greater should overcome the problem.

The toxic compounds associated with hyperexcitability are known to be transmitted through the milk and are apparently not destroyed by pasteurisation at 90 °C (Perdok and Leng 1987). This led Perdok and Leng (1987) to recommend that 'ammoniated feeds in general should not be fed to dairy cows until the risks of toxins being transmitted in milk are clarified'. While the dairy industry must be mindful of human health issues like this, the role of ammoniated forages in dairy cow diets is a contentious issue when one considers that there are methods of ammoniation (e.g. urea treatment–higher moisture–stored in a similar manner to silage) which appear to be safe. These methods are used extensively in the UK for the production of ammoniated whole-crop cereals (Weller 1992; Newman 1992) for beef and dairy cattle without any apparent animal health problems. Ammoniation or alkali treatment offers real opportunities to conserve surplus tropical grasses and at the same time raise their digestibility. We believe this subject is worthy of research, which should determine optimum treatment procedures and methods of utilising ammoniated forages in dairy cow diets. It is very important that this work also monitors animal health and the presence of any toxic compounds in treated forages.

Future developments in feeding systems

Feeding systems for dairy cows during winter and spring in the subtropical and tropical dairying regions will vary widely. The decision to use any one of the feed resources listed in Table 17 will depend on their milk production potential, cost and reliability. The combination of feeds selected will depend on local climatic conditions, but the availability of irrigation will have the greatest impact. Dryland farms, or those with limited irrigation, will have a considerably more volatile

Table 17. Feed resources available for feeding dairy cows in winter-spring in northern Australia.

Feed resources	Capacity to increase	
	Feed supply	Feed quality
Grazing		
Perennial tropical pastures	L	L
Dryland winter forage crops	M	M
Lucerne	M	H
Irrigated pastures and forage crops		
— ryegrass + N	H	H
— ryegrass-clover	H	H
— annual legumes	M	H
Conserved forages		
Hay	L	M
Tropical pasture silages	M	M
Maize or grain sorghum silage	H	H
Sweet sorghum silage	H	M
Summer forage crop silages	M	M
Summer legume silages	M/H	H
Winter cereal-legume silages	M	M/H
Ammoniated forages	M	M
Concentrates	H	H
By-products[1]	—	—

L, M and H indicate low, medium and high, respectively.

[1] The availability and quality of by-products both vary considerably.

forage supply, and to achieve productivity increases will need to rely more heavily on conserved forages and concentrates. Irrigated farms will have a more secure forage supply and will depend heavily on high quality forage produced from winter pastures or forage crops. It appears that maize silage will be competitive with irrigated pastures in terms of feed costs per litre of milk (Davison *et al.* 1992), so it will also play an important role in increasing the productivity of farms with irrigated pastures.

Of the grazed forages in Table 17, potential gains in productivity from perennial tropical pastures are very limited. The application of N fertilisers during winter–spring is probably the only means of increasing milk production from these pastures, but the response will depend on seasonal conditions. Data on milk production responses are needed to compare this strategy with alternatives.

Among the dryland winter–spring forage crops, oats in cultivated seedbeds is likely to be the best option. The success of these crops is heavily dependent on winter moisture supply, so they will be a more reliable forage source in southern areas. Lucerne will continue to be an important component of dairying systems on the Darling Downs and in parts of central Queensland, and dryland annual ryegrass or ryegrass–legume mixtures will also be used in the south.

It is difficult to predict the future role of irrigated winter–spring pastures on dairy farms without reliable information on the capacity for further expansion of the area which can be irrigated. There appears to be spare capacity in some areas, but in others, restrictions already apply. Economic studies on irrigated pastures and irrigation systems, including on-farm water storage, are required to assess future options. There is no doubt that irrigated pastures have a major impact on farm productivity. However, further productivity gains can be achieved through improvements in irrigation and grazing management, and research is required in these areas. In addition, research is required on the persistence of temperate perennial (2–3 year stand life) pastures, as they will provide a more reliable feed base than annual forages. Is this achievable and at what cost?

Irrigated annual legume crops provide a valuable source of high energy, high protein forage, and reduce N fertiliser inputs. However, because of the problem of bloat, legume–grass mixtures are likely to be preferred. As dairy farmers target higher production per cow, legume-based crops and pastures will play an increasing role in providing the higher level of protein needed in diets containing grain and high energy–low protein silages such as maize and grain sorghum. With any of the grazed temperate crops or pastures, the proportion of the forage utilised by the grazing herd is critical. Forage DM yields alone provide an unreliable estimate of the cost of grazed forage, and utilisation must be accounted for when calculating feed costs.

Conserved forages offer a cost-effective means of increasing productivity on both dryland and irrigated dairy farms. Apart from where it is a complementary enterprise, the future role for hay making on dairy farms in Queensland is uncertain. There may be a role for high quality lucerne hay, but in many situations silage will be a more reliable and flexible forage conservation strategy. A number of silage options are available, and these can be used alone or in combination (see Table 11) when developing feeding systems. We believe the silages with the greatest potential are maize and grain sorghum silages.

Research is required on their production, nutritive value, and integration into feeding systems. Sweet sorghum silage will become a more useful forage resource if plant breeders can improve its digestibility. Each of these crops has the potential to produce silages with a high ME content, but a low protein content. Dietary protein content can be balanced by using irrigated pastures if sufficient quantities are available, but in most cases expensive protein concentrates are required. Legume silages could play an important role in boosting the protein content of diets during the winter–spring period. These could be produced from summer forage legumes, and we believe this would be a useful area for research.

The production of silages (or ammoniated forages) from surplus tropical pastures is a means of improving pasture management and utilisation, while producing a worthwhile medium quality forage for feeding during winter–spring. Research is required on the integration of grazing management with conservation cuts, and on conservation techniques. Used in combination with higher quality feeds (e.g. concentrates or maize silage), significant increases in carrying capacity could be achieved.

The role of concentrates in dairy production systems in the tropical and subtropical areas of

Australia has been discussed by Davison and Elliott (1993). Concentrates will be an integral part of feeding systems as a quality supplement, to balance diets for energy and protein, and allow satisfactory levels of milk production per cow. They will also take on the role of a buffer feed when forage supplies are inadequate. While heavier use of concentrates may be justified where the combination of grain and milk prices is favourable, the most profitable feeding systems are likely to continue to be forage-based. The quality of the forage components will have an important effect on milk production and the need for concentrates. For example, Gordon (1989) reported a milk yield response of 0.37 kg/cow/d for each unit increase in digestibility of grass silage. He also found that concentrate inputs could be reduced by 0.67 kg/cow/d for each unit increase in silage digestibility. Other work has shown similar results with diets based on lucerne hay and concentrates (Kaiser and Combs 1989). The message is clear. As feeding systems are developed, research must focus on strategies which improve the quality of each forage resource.

Improvements in the feed supply can be used to increase farm milk production through increases in production per cow and/or stocking rate. When concentrates, hay or silage supplements are provided, cows often reduce their pasture intake. This substitution effect varies considerably (see reviews by Rogers 1984; Phillips 1988; Davison and Elliott 1993), and from a management point of view represents an opportunity to increase stocking rate. If this is not done, farmers will fail to achieve the full economic benefits from improved feeding systems.

This highlights the importance of research on the combination of the various feed resources into whole-year feeding systems. Detailed information is required on individual components of the system and how they interact to allow high levels of milk production per hectare and per cow. Emphasis should be placed on dryland and irrigated dairy production systems, both of which require further development. Research on feeding systems is long-term and requires an integrated approach, and the research team must include an economist.

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