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HIGH-ENERGY FORAGES AND FORAGE MIXED RATIONS

CONTRACT PRESENTATION

CONTRACTORS: W. C. MCNABB AND D.R. WOODFIELD

Can forages match concentrate diets for dairy production?

G.C. WAGHORN

AgResearch Grasslands, Palmerston North, New Zealand

ABSTRACT

Comparisons have been made between concentrate based total mixed rations (TMR) and grass dominant pasture for dairy production. Limitations to further improvement in cow performance have been indicated by the very high reticulo-rumen fill in New Zealand cows fed pasture, exceeding 22% of live weight, relative to United States cows fed either TMR or forage diets. The importance of high concentrations of structural fibre in ryegrass dry matter, moisture content of fresh forages and the very rapid eating associated with high utilization of pasture on New Zealand dairy farms will limit increases in feed intake and cow performance. Responses to ryegrass supplementation with high quality forages have been summarised together with suggestions for future research and farming systems to improve performance and profitability of cows fed forage diets.

Keywords: lactating cow, rumen fill, intake constraints

INTRODUCTION

The high milk production by cows in North America and Europe, relative to pasture fed cows in New Zealand is well known (Ulyatt & Waghorn, 1993). The reasons for high cow performance is partly due to a focus on individuals rather than a whole herd but mainly because cow nutrient requirements are met by offering rations formulated to balance requirements; total mixed rations (TMR). These grain and silage based diets have achieved an average production per cow of about 8000 kg/lactation in the United States compared to about 3500 kg/lactation for New Zealand cows. However, simplistic comparisons between dairying systems are not easy, because of differences in cow size, lactation length, reproductive performance, calving interval, attrition and veterinary intervention as well as nutrition. Genetic merit for milk production does not seem to be a major constraint to performance of New Zealand cows (e.g. Ulyatt & Waghorn, 1993). The principal limitation is nutrition and this paper will address some nutritional factors which limit productivity of cows grazing pasture.

New Zealand dairy farms have focused on an efficient harvest of a high proportion of the pasture offered, because this system has been low cost and profitable. Generations of management for high pasture utilization have resulted in cows which eat fast; the fastest eater gets the most pasture and the slowest has less to eat. The slow eater has a lower quality diet because it comprises less leaf, more sheath and stem and an increased likelihood of fungal endophyte and soil contaminants. Supplementation with maize or pasture silage has helped alleviate the nutritional stress placed on our cows (especially slow eaters, or those milked last) but we cannot predict the potential for forages to achieve high cow productivity unless feed is available *ad libitum*. A significant characteristic of TMR is that the feed never runs out– cows are given as much as they can eat.

Ad libitum feeding is the first requirement for forage evaluation, but this can make comparisons between pasture and TMR difficult because few grazing studies provide true *ad libitum* intakes. Fortunately a series of trials at Dexcel (Hamilton) have involved grazing treatments where pasture allowances have been 60 kg DM/cow/day and the extensive measurements of heifer and herd performance (Kolver *et al.,* 2000; Kolver, 2001) have provided data to illustrate some shortcomings of grass relative to a TMR (Table 1). The TMR contains about 50% concentrate (corn or barley grain with protein, vitamin and mineral supplements). These data are complemented by production data from recent trials in Hamilton and from the United States (Table 1) where pasture diets are being revisited because of costs, margins and reproductive problems associated with highly productive cows fed TMR.

Several factors stand out in a comparison between pasture and TMR.

1. Cows eat much more TMR than pasture. On an equal body weight basis, those fed TMR consume 15-50% more dry matter (DM) than pasture, with greatest

TABLE 1: Production characteristics of mature US Holsteins and New Zealand Friesian heifers fed either pasture or total mixed rations (TMR).

	US Holstein			NZ Friesian		
	Pasture	**TMR**	**Sig.**	**Pasture**	**TMR**	**Sig.**
Days of lactation	Day 73 to 87		–	Whole lactation[a]		–
Body weight (kg)	562[b]	597[b]	0.01	436	470	0.05
Dry matter intake (kg)	19.0	23.4	0.01	12.5	17.4	–
NDF intake (kg/day)	8.5	7.6	NS	5.3	5.3	NS
Crude protein (kg/day)	4.9	4.7	NS	3.1	3.1	NS
Milk (kg/day)	29.6	44.1	0.01	12.71	18.8	0.01
Milksolids (kg/day)	1.87	2.72	0.01	1.07	1.42	0.01

US Holstein data from Kolver and Muller (1998), New Zealand Friesian data from Kolver *et al*. (2000).
[a] Lactation length was 261 days for pasture and 268 days for TMR
[b] Cows in both treatments had an initial body weight of 603 kg

TABLE 2: Composition of pasture and total mixed rations (TMR) fed to cows weighing 450-500 kg in early and mid lactation. Data are percentage of dry matter (DM) unless indicated.

	Pasture		TMR[a]	
	Early	Mid	Early	Mid
DM %	13-16	17-24	50-60	50-60
% concentrates	0	0	53	48
CP	24-28	15-18	17-18	16-17
RUP	30?[b]	25?[b]	35-40	35-40
NSC	8-24[c]	5-15	35-40	35-40
NDF	42-46	50-58	26-30	32-34
ADF	22-26	26-34	18-20	21-23
Lipid	4-6	3-4	3-5	3-5
ME (MJ/kg DM)	11.5	9.8	11.9	11.7
DM digestibility (%)	76	69	70	68
DM intake (kg/day)	17.6	14.0	19.8	22.2
WM intake (kg/day)	121	72	36	40
Milk (kg/day)	23	13	40	35

Abbreviations: CP, crude protein; RUP, rumen undegraded feed protein; NSC, non-structural carbohydrate; NDF, neutral detergent fibre; ADF, acid detergent fibre; ME, metabolisable energy; WM, wet matter. Sources of data: NRC 2001; Holmes, 1987; Kolver *et al*. 2000; Holmes *et al*., 1987; Moller *et al*. 1996.
[a] Typical ingredients: 15% immature legume silage, 33% corn silage, 34% ground high moisture shelled corn, 12% soybean meal, 2.5% tallow, 1.5% fish meal, 2% mineral and vitamin mix.
[b] Uncertain value associated with the method of measurement.
[c] Variability due to methodology (e.g. inclusion of pectin), time of sampling etc.

differences in mid-late lactation (Tables 1 and 2).

2. The DM content of TMR is often 2-4 fold higher than pasture (50-60% vs. 12-18%) so the volume of feed passing down the oesophagus is much smaller with TMR.
3. The particle size of TMR is much shorter than pasture because the grains are small and often processed, the protein supplements are powders and the silages are chopped to 1-2 cm in length.
4. The TMR has much less fibre, especially hemicellulose, more readily fermentable carbohydrate and less soluble degradable protein than high quality pasture. These differences result in a markedly different mixture of volatile fatty acids (VFA) and ratio of rumen bypass protein:ammonia compared to pasture (despite similar values for metabolisable energy content (ME)).
5. Principal consequences of a TMR compared to pasture are a higher peak lactation, a slower decline in milk production (4% vs. 9% per month) and a higher likelihood of metabolic problems associated with low fibre/high grain diets.

There are several characteristics of grass that prevent high intakes and digestion of grass leads to a different range of metabolites compared to grain based TMR. This paper will address constraints to intake and provide evidence that rumen-fill, and the need to physically break grass into small fragments to pass out of the rumen are major limitations to cow productivity. The importance of feeding the bacteria *vs*. using bacteria to digest recalcitrant fibre will be indicated because more than 70% of the cow's energy is bacterial waste–the VFA. Comparisons with TMR diets suggest forages should support bacteria which produce propionate at the expense of acetate and proteolysis to ammonia should be limited if high productivity is to be attained. The changing quality and digestion characteristics of maturing grass (Chaves *et al*., 2002) must be acknowledged and forages other than grass need to be evaluated (Burke *et al*., 2000, 2002) to indicate options for overcoming some of the limitations identified here.

The reticulo-rumen

The reticulo-rumen (rumen) is the first compartment of the ruminant stomach. It is a storage vat, enabling feeds to be degraded by bacteria (with protozoa and fungi) and is maintained between pH 6.0-6.8 through copious salivary secretions during eating and rumination. Under forage feeding systems, a high proportion of forage entering the rumen is long (5-20 cm) although chewing during eating will rupture 50-60% of plant cells so that 47% (grass)-61% (Lucerne) of DM will be reduced to a size able to pass a 2 mm sieve (Waghorn *et al*., 1989). Much of this DM will be soluble, accounting for 35-40% of DM in ryegrass of all ages (Chaves *et al*., 2002) and 40-50% of legume DM (Burke *et al*., 2000). Bacteria have immediate access to soluble DM, including access through damaged cell walls and succulent forage such as lucerne leaf will have been completely degraded in as little as three hours (Kelly & Sinclair 1989). However the remaining 40-50% of grass DM imposes a severe limitation on further feed consumption because it comprises tough fibre which must be reduced to a size able to pass through a 2 mm aperture in order to reach the omasum, abomasum and intestines.

It is the need to reduce feeds to this very small size (indicated by the consistency of faeces) which limits the intake of grasses. Fibre in grass is a tough lignified matrix of cellulose intertwined with hemicellulose and held together with lignin (Wilson, 1993). Lignin is not degraded by bacteria and cellulose and hemicellulose are only degraded by adherent bacteria. Hence the rate of fibre degradation can only be increased by increasing the available surface area for bacterial colonisation, and this is achieved largely by chewing during eating and rumination. Ruminants are able to live on forages with high concentrations of fibre but the rate of degradation is slow and the time required for the fibre to be physically reduced in size is the principal cause of low feed intakes and low performance of cattle fed grass dominant pasture.

Fibre, chewing and clearance

If forages are to match concentrate based diets, it is essential to clear residual fibre quickly. This could be achieved by more chewing during eating or development of a brittle fibre easily broken into fragments able to exit the rumen. The relatively ineffectual chewing during eating may be a consequence of our dairy management and the moist, soft and flexible nature of ryegrass leaves. Generations of breeding for efficient pasture harvest appears to have resulted in fast eaters more intent on tearing and swallowing grass than chewing it. Bolus formation for swallowing will be relatively rapid with long flexible leaves and the high moisture content of our pastures. It is surprising that as much as 50% of cells are ruptured during eating.

Contrast this with TMR. About 50% of the material needs no chewing, and one dilemma faced by ration balancers is to encourage efficient rumen fermentation rather than outflow. About 50% is roughage – either chopped hay or silage. The diet is about 50-60% dry matter (Table 2) and a rapid DM intake is possible with relatively little eating time. However lactating cows consuming a TMR spend about 300 minutes per day eating (in 10-12 bouts) and a further 450 minutes ruminating (12-13 bouts) (Dado & Allen, 1994; Shaver *et al*., 1988b). The cow carries out 40-50000 chews per day (Dado & Allen, 1994) to consume 44 kg of feed, half of which needs no chewing, and the remaining forage has been chopped to 1-2 cm lengths, so very considerable mastication and incorporation of saliva will have occurred with the TMR diet. Dado and Allen (1994) reported 90-103 kg rumen fill (15-17% of live weight) for cows fed TMR (Table 3). A cow eating pasture will swallow at least twice as much feed, and although a high proportion of the DM is soluble, the remaining fibre is long and requires extensive breakdown, but chewing records for lactating cows grazing (or fed) pasture do not appear to be available for comparison.

High-fibre TMR contain 35% neutral detergent fibre (NDF) and are avoided in early lactation because of constraints to intake. Contrast this with normal values for grass (40-55% of the DM; Tables 1 and 4) and the excessive NDF in grass is reflected in rumen digesta volumes. The NDF component in grass differs in structure and ruminal function to that of lucerne and maize; it is flexible, not scratchy and associations with “effective fibre” should be treated with caution.

Table 3 summarises United States and New Zealand rumen volume data from cows fed either pasture or TMR.

TABLE 3: Rumen digesta pools, dry matter intakes (DMI) and milk production of North American and New Zealand cows fed either total mixed rations (TMR) or pasture diets *ad libitum*. Rumen parameters were measured in early/mid lactation after feeding to indicate likely maximum values.

Origin	Diet	DMI kg	Milk kg	Digesta kg	Digesta % LW	DM %
[1]USA	**40:60 concentrate : forage (cows 583 kg)**					
	Immature lucerne	23.3	38.0	67	11.5	13.8
	Mature lucerne	20.0	32.1	74	12.7	14.0
	Bromegrass	17.9	29.7	90	15.4	14.4
	Corn silage	23.7	36.5	67	11.5	16.3
[2]USA	**High and low forage TMR (cows 594 kg)**					
	Low forage, 25% NDF	22.8	37.0	90	15.2	14.3
	High forage, 35% NDF	18.7	31.4	103	17.3	13.0
[3]USA	**Pasture alone and with concentrate (cows 650 kg)**					
	Pasture+10 kg concentrate	19.8	30.4	71	11.0	15.7
	Graze-pasture	13.9	21.8	77	12.0	15.1
[4]USA	**Forage or silage with concentrate (cows 672 kg)**					
	Lucerne silage+7.6 kg concentrate	21.9	24.1	75	11.1	15.0
	Lucerne+6.2 kg concentrate	19.2	23.3	59	8.8	12.2
	Pasture+6.7 kg concentrate	17.7	23.8	61	9.1	13.2
[5]NZ	**Pasture fed cows (423 kg)**					
	Pasture	13.1	NA	71	16.7	8.8
[6]NZ	**Cows fed grass with silage, period A (cows 558 kg)**					
	Grass	16.3	15.8	123	22.5	12.4
	Grass+grass silage	16.5	15.8	120	22.5	10.3
	Grass+lotus silage	16.9	16.8	114	20.2	12.3
	Grass+sulla silage	15.2	16.4	112	19.0	11.4
[6]NZ	**Cows fed grass with silage, period B (cows 533 kg)**					
	Grass	13.6	13.0	92	16.9	9.4
	Grass+grass silage	15.0	14.2	110	19.9	10.4
	Grass+lotus silage	14.4	14.3	102	19.2	10.7
	Grass+sulla silage	10.3	12.3	99	19.7	11.1

Abbreviations: NDF, neutral detergent fibre; LW, live weight.

[1] Shaver *et al*. 1988[a]; [2] Dado & Allen 1995; [3] Reis & Combs 2000; [4] Depies 1994; [5] Curruthers *et al*. 1988;

[6] Woodward & Waghorn unpublished; 4 cows per treatment.

Principal observations are smaller rumen pools (% of live weight) with TMR than pasture fed with concentrates or as a sole diet in USA cows, and the very high values recorded with New Zealand cows fed pasture based diets. Care has been taken to select equivalent data sets, with rumen measurements taken 2-4 hours after feeding and between about 60-150 days of lactation. Only a few data are available for New Zealand cows but the mass of rumen contents must represent a limit to both productivity and to future selection for improvements in productivity of cows grazing grass.

The digesta in cows (Woodward & Waghorn, unpublished) were packed so tight as to prevent penetration (by hand) to the ventral rumen. This mass of packed digesta is supposedly mixed and must be reduced in size to that of faeces in order that more food be eaten. In contrast, rumen contents from cows fed TMR are viscous and mobile, probably easily regurgitated for rumination and much of it is small enough to exit from the rumen without further chewing. Intake and outflow for cows fed TMR may be regulated by intestinal and other metabolic feedback, but for pasture, control is almost certainly through rumen distension and chewing.

Forages for high intakes

Burke *et al*. (2000, 2002) have evaluated grasses, legumes, herbs and silages by measuring chemical composition, products of digestion using *in vitro* techniques and rates of microbial degradation with *in sacco* bags in the rumen. Data from that work show very low structural fibre concentrations in sulla (*Hedysarum coronarium*), chicory (*Cichorium intybus*), white clover (*Trifolium repens*) and birdsfoot trefoil (*Lotus corniculatus*) ranging from 22.4-28.2% NDF in the DM. These forages had very rapid rates of *in sacco* degradation (0.12-0.26 h^{-1}) relative to perennial ryegrass which ranged from 0.067 h^{-1} with young leafy material to 0.038 h^{-1} at 60 days of age (Chaves *et al.,* 2002).

Feeding trials with lambs (Ulyatt, 1981; Douglas *et al*., 1995; Burke *et al*., 2002) have provided an equal ranking for either white clover or sulla fed alone or mixed and *Lotus corniculatus*, all of which are superior to lucerne, *Lotus pedunculatus* and all grasses (Burke *et al*., 2002). Trials with lactating cows by Woodward (Harris *et al*. 1997, 1998; Woodward *et al*., 1999) have confirmed the superior feeding value of some of these forages relative to pasture (Table 4) but it will be necessary to determine rumen volumes and to measure outflow rates in order to understand limitations to performance. Whilst the chemical composition and digestion kinetics suggest potentially high intakes, the DM content of these forages are low; chicory, 8-10%; sulla, 12-14%; Lotus species, 12-16% and white clover, 16-18%. Verité & Journet (1970) demonstrated reductions in voluntary feed intakes when forage DM% was less than 16% for cattle, later confirmed by John & Ulyatt (1987). Wilting is able to increase intakes of wet material, supporting the importance of bulk (Ulyatt & Waghorn, 1993) and increasing the DM contents of these low fibre forages may be a viable challenge for molecular biology.

Optimal fermentation

TMR diets are associated with high ratios of glucogenic VFA (propionate (P)) at the expense of acetate (A) and butyrate. *In vitro* incubations (Burke *et al*., 2000) have shown A:P ratios of only 2.2 for sulla and 2.3 for white clover in contrast to values over 3.5 for most grasses (Burke, unpublished). These findings have been confirmed in trials with young lambs where rumen A:P ratios were 2.6 in lambs fed sulla, compared to 3.3 with white clover, 3.4 with lucerne and 4.1 when pasture was fed (Burke *et al*., 2002).

Although few forages contain high concentrations of readily fermentable or non structural carbohydrate, many

TABLE 4: Lactation responses by New Zealand cows to pasture supplements or feeding high quality legumes. All data from cows in the second half of lactation.

Dietary[a] treatment	DMI (kg)	Milk (kg)	MS (kg)	% MS to supplement	Composition of supplement or diet	DM %	CP	NDF	ME
[1] Pasture	–	10.4	0.87	–	Pasture	22.8	24.3	48.5	9.7
Pasture+turnips	–	11.3	0.99	+14	Turnip	9.0	16.0	21.1	(12.0)
Pasture+chicory	–	10.8	0.93	+7	Chicory	7.5	22.9	19.8	11.4
[2] Pasture	8.8	8.1	0.72	–	Pasture	–	19.7	55.9	–
Pasture+turnips	13.0	10.0	0.90	+25	Turnip	10.8	12	23	–
Pasture+sorghum	12.0	10.0	0.77	+7	Sorghum	14.2	9.6	65.0	–
[3] Ryegrass	10.9	9.0	0.84	–	Grass	21.0	14.3	61.8	9.5
Ryegrass+25% WC	11.1	11.1	1.01	+20	WC	15.0	24	34	11.5
Ryegrass+50% WC	11.5	11.9	1.09	+30					
Ryegrass+75% WC	11.6	12.4	1.10	+31					
[4] Pasture	11.3	11.7	0.90	–	Pasture	–	11.9	55.9	10.0
Grass+75% WC	14.6	15.4	1.15	+28	Diet	18.4	20.9	38.4	11.5
Grass+75% Lotus	13.0	16.7	1.28	+42	Diet	17.9	22.4	75.4	11.8
[5] Ryegrass	14.7	10.2	0.85	–	Ryegrass	22.4	18.2	52.9	10.6
Lotus–CT	16.7	13.8	1.13	+33	Lotus	14.1	25.6	30.4	11.4
Lotus+CT	16.8	16.5	1.40	+65					

[a] Cows in Trials 1, 2, 3 all received 25 kg DM pasture allowance.

Abbreviations:

DM, dry matter; DMI, DM intake; CP, crude protein; NDF, neutral detergent fibre; ME, metabolisable energy; WC, white clover; Lotus, *Lotus corniculatus*; CT, condensed tannin (–CT indicates inactivation by daily administration of polyethylene glycol).

[1] Waugh *et al*. 1998; [2] Clark *et al*. 1997; [3] Harris *et al*. 1997; [4] Harris *et al*. 1998; [5] Woodward *et al*. 1999.

contain high concentrations of readily degradable protein. Total mixed rations may contain about 30% fermentable carbohydrate and 17% crude protein, (total 47%) of which about two thirds is digested in the rumen. White clover, sulla, red clover, lucerne and Grasslands Tama ryegrass (*Lolium multiflorum*) contain in excess of 35% readily degradable carbohydrate plus protein, and although less than TMR diets, this does provide a substantial highly fermentable substrate for bacteria. Good use could be made of these forages if protein degradation could be slowed, and this is readily achieved with diets containing condensed tannins (McNabb *et al*., 1996; Waghorn *et al*., 1999).

Principal constraints to production from forages

This resumé suggests that forages such as sulla, lotus species, white clover and chicory will have few nutritional limitations associated with intransigent fibre characteristic of ryegrass, but the very high moisture content of these forages is likely to limit intake. The growth habit of sulla, and risks of crown damage, suggest a cut and carry system may be an appropriate management, in which case chopping and possibly wilting may be considered, but wilting will result in a rapid utilisation of soluble sugars to respiration and is likely to lower the feeding value.

Current information from *in vitro* incubations and sheep trials suggest these diets will produce a range of VFA similar to those from TMR (A:P 2.5-3.2) and the inclusion of condensed tannin in these diets will reduce rumen protein degradation so the amino acid demands for milk protein synthesis could be met. High protein diets carry a cost associated with ammonia disposal to urea, and lower degradation (with diets containing tannin) will be beneficial.

These options must be tested in order to further progress, and it is particularly important that high quality forages be fed from calving to properly evaluate their potential. The rapid and excessive loss of liveweight and condition experienced by New Zealand cows grazing pasture during the first 6 weeks of lactation must be reduced, and high quality forages may be more important during this phase of lactation than during summer when many supplements have been tested (Table 4). The mixture of forages may best be determined with assistance of nutrition/metabolism based simulation models, such as CNCPS (Cornell Model) although current focus of many models is toward concentrate and silage based TMR.

Future opportunities

Use of existing cultivars will not achieve levels of production achieved with TMR because of moisture or fibre constraints, and feeding cows with low fibre rapidly degradable feedstuffs is not an optimal solution. However more information on rumen characteristics associated with digestion of legumes than discussed here, fed in mixtures with pasture, will form a basis for long-term progress in forage-based dairy nutrition. A longer-term vision must focus on forages which have a high DM production, and are persistent. Grasses meet these criteria, with persistence being an important attribute, especially in view of greenhouse gas emissions associated with annual cultivation, use of machinery, high fertiliser inputs etc (Robertson & Waghorn, 2002). The challenge to plant breeders is to modify our most valuable forage by altering its fibre so the plant remains upright, but the fibre breaks up readily to clear the rumen. Add soluble carbohydrates, reduce protein content and degradability and decrease the moisture content. We then must feed appropriate mixtures of the new grasses with our legumes or grains and our cows will be more healthy and produce more milk. There is a lot of work to be done!

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