
THE PROCEEDINGS OF THE
NEW ZEALAND SOCIETY
OF
ANIMAL PRODUCTION
VOLUME 62 2002

Proceedings of the N.Z. Society of Animal Production, 41: 16-27 (1981)

THE EFFICIENCY WITH WHICH FEED IS UTILISED BY THE DAIRY COW

C. W. HOLMES and A. W. F. DAVEY
Massey University, Palmerston North,
C. GRAINGER
Ellinbank Dairy Research Institute Victoria.

SUMMARY

The data reviewed indicate that in most cases there is reasonable agreement between theoretically derived estimates of energy requirements and those measured experimentally and they can therefore be used to predict the outcomes of different feeding methods. However the experimentally measured quantity of ME required to increase body condition of the dry cow by 1 condition score is about twice as large as that predicted theoretically.

The level of feeding at one time of the year can affect milk production at that time and at a later time; at least part of the latter carry-over effect is likely to be caused by changes in body weight and the occurrence and magnitude of such carry-over effects can be predicted from an understanding of energetics.

Despite the fact that the above carry-over effects are known to occur, the majority of feeding experiments are relatively short-term. There is an urgent need for long-term experiments to be carried out in order to measure the overall efficiency with which feed is converted into milk by cows which are fed at different levels at different times of the year.

INTRODUCTION

The purposes of this paper are:—

- to present estimates of various energetic parameters for dairy cows and to use these in the calculation of energy requirements.
- to review the results of recent experiments concerned with the feeding of dairy cows during the dry period and lactation and to evaluate these results in the light of the previously calculated energy requirements.
- and to provide a logical framework for understanding the effects of level of feeding on the productivity of dairy cows, based on their energetics.

ENERGETICS OF DAIRY COWS

The best estimates of various important energetic parameters are given in Table 1; although these are based on good experimental data there remains considerable uncertainty about the real validity of some of them in relation to the lactating cow. Some of these conceptual problems are discussed by Moe and Tyrell (1975) who also describe the mathematical partitioning which is necessary to provide some of these estimates.

TABLE 1: A LIST OF BEST AVAILABLE ESTIMATES FOR CERTAIN ASPECTS OF THE ENERGETICS OF GRAZING DAIRY CATTLE

Metabolisable energy required for maintenance : ME_M	(a)	dry: lactating:	0.55 MJ/kg$^{0.75}$/d 0.60 MJ/kg$^{0.75}$/d
Metabolisable energy required for pregnancy (above ME_M)	(b)	Day 100 Day 220 Day 280	0.01 MJ/kg$^{0.75}$/d 0.11 MJ/kg$^{0.75}$/d 0.31 MJ/kg$^{0.75}$/d
Net efficiency* with which ME is utilised above ME_M for synthesis of milk: k_L	(c)		0.65 (i.e. 1 MJ ME ≡ 0.65 MJ milk)
for synthesis of body tissue in lactating cows: k_G			0.65
in dry cows: k_G			0.55
for synthesis of milk from mobilisation of body tissue: $k_{G\text{-}L}$			0.83 (i.e. 1 MJ tissue ≡ 0.83 MJ milk)
Energy concentration of body tissues (Net energy retained per kg)	(d)		
Jersey milk			3.7 MJ ER/kg milk 70 MJ ER/kg milkfat
Friesian milk			3.1 MJ ER/kg milk 78 MJ ER/kg milkfat
Change in liveweight			20 MJ/kg liveweight change†
Metabolisable energy concentration in feed	(e)		
1 kg digestible dry matter			= 15.2 MJ ME
1 kg digestible organic matter			= 15.9 MJ ME
(assuming that ME = 0.82 x DE)			

(a) Van Es, (1976); Moe *et al.*, (1971); Trigg *et al.*, (1979); Joyce *et al.*, (1975).
(b) Moe and Tyrrell, (1972).
(c) Moe *et al.*, (1979); Van Es, (1976).
(d) Tyrrell and Reid, (1965); Bath *et al.*, (1965; Moe *et al.*, (1971).
(e) Joyce *et al.*, (1975).
* see text equation (1); the values for k assume that the diet contains more than 11 MJ ME/kg DM.
† see Cowan *et al.*, (1980); values reported 30 to 90 MJ/kg liveweight change.

The factors in Table 1 have been used to calculate the predicted ME intake required by cows from information about their liveweight, milk production and changes in liveweight from a number of recent nutritional experiments with lactating cows fed on pasture (Grainger and McGowan, unpublished; Bryant and

Trigg, 1979; King *et al.*, 1980; Glassey *et al.*, 1980). The values for predicted MEI divided by MEI measured experimentally, varied between 0.84 and 1.18. This represents reasonably close agreement between theory and practice, particularly when the large number of assumptions inherent in such calculations is considered; similar agreement was reported by Hutton (1971) for experiments at Ruakura since 1961.

Using the data given in Table 1, and the relation given below (equation 1) the estimates in Table 2 can be derived.

$$ER = (MEI - ME_M) \times k$$

where

ER = Total energy retained

MEI = Total intake of ME

ME_M = ME required for maintenance

k = net efficiency with which ME is utilised above maintenance

An important implication of the equation is that as MEI continues to increase above maintenance, so total energy retention by the lactating cow continues to increase in a linear fashion even at the highest levels of feeding. However, the form in which energy is

TABLE 2: A LIST OF ESTIMATES OF THE AMOUNT OF ME REQUIRED, ABOVE ME_M, FOR PRODUCTION

	MJ ME	*kg DM**
1 kg milk Friesian	4.8	0.42
Jersey	5.7	0.50
1 kg milkfat Friesian	120	10.6
Jersey	108	9.6
1 kg gain in liveweight		
in lactation	31	2.8
in dry period	36	3.3
1 unit of condition score (35 kg LWG)		
in lactation	1080	98
in dry period	1270	115
1 kg milkfat, produced by the mobilisation of body tissue; assuming that the body tissue had previously been synthesised in the dry cow.		
Friesian	170	15.5
Jersey	150	14.0

*Assuming : 18.4 MJ GE/kgDM
75% digestibility of energy
ME = 0.82 DE

retained is unlikely to remain constant at all levels of feeding; at low levels of MEI, energy retention as body tissue may be negative, whereas at higher levels of MEI, energy retention as both body tissue and as milk will be positive.

In evaluating the lactating cow's requirements for ME, it is therefore essential to consider both the milk produced and the associated changes in body tissues. An understanding of the principles of energetics can provide at least a partial explanation of many effects of feeding level on cows and help to clarify the thinking about these effects.

The Level of Feeding Before Calving; Body Reserves of Energy and Subsequent Milk Production

Cows are able to mobilise considerable amounts of body fat in early lactation and to utilise the resultant energy for the synthesis of milk (Flatt *et al.*, 1969; Grainger, 1980). However cows which are of light body weight or thin body condition appear to divert dietary energy away from milk synthesis and towards the synthesis of body tissues (Broster, 1974; Grainger, 1980).

It is to be expected, therefore, that the level of feeding before calving acting through its effect on body condition and liveweight, will influence subsequent milk production. Several recent experiments have shown that this is indeed true (Rogers *et al.*, 1979; Grainger, 1980). This effect on milk production is a type of carry-over effect arising from feeding at an earlier time.

Assessment of body condition may provide a better estimate of the body energy reserves than would be provided by measurement of liveweight. However, because body condition is assessed subjectively, considerable variability is inherent in values for condition; for example, 1 unit of condition score (CS) was shown to be equivalent to 15 kg liveweight (LW) (Bryant, 1980); 17 kg LW (King *et al.*, 1980) or 35 kg LW (Grainger, unpublished data). There is an urgent need to standardise the assessment of CS in order to avoid conflict and confusion. Some progress in this direction was outlined by Grainger (1978).

Feed requirements in relation to CS at calving

The quantitative assessment of CS is a recent innovation and measurements of condition were not included in earlier experiments. However some recent estimates for dry cows are presented in Table 3.

TABLE 3: SOME EXPERIMENTALLY MEASURED AND THEORETICALLY DERIVED ESTIMATES OF THE METABOLISABLE ENERGY REQUIRED BY DRY COWS FED ON PASTURE

Metabolisable energy required: *To maintain constant body condition (except*) (MJ/kg $^{0.75}$/d)*	*To increase body condition score by 1 unit (MJ per cow)*	*Experimental details*
0.49	2,900	Stall fed on pasture; 5th month of pregnancy (1)
0.89	2,200	Grazed on pasture 8th month of pregnancy (2)
0.61* 5th month pregnancy 0.74* 8th month pregnancy	1,300	Theoretical calculations from data in Table 1

* Calculated for zero change in body energy content
(1) Grainger *et al.*, (1978)
(2) Holmes and McLenaghan (1980)

There are considerable discrepancies among the experimental estimates and between these and the theoretical calculations, in particular with respect to ME required for gain in condition. A number of possible reasons can be suggested but more research is clearly required on this topic; some useful data should be provided by the experiment of Gray and Robinson (1979).

Body condition at calving and subsequent milk production

A series of experiments, designed specifically to measure the effects of differences in CS at calving were carried out at Ellinbank and described briefly by Grainger, (1980). Some derived results are shown in Table 4.

The effect of an increase in CS of 1 unit at calving, measured in the first 20 weeks of lactation, was an extra 8.3 kg milkfat and an extra 0.27 unit of CS.

The value of 8 kg milkfat per 1 CS is within the range of 7 to 25 kg milkfat per 30 kg LW derived from New Zealand data by Scott and Smeaton (1980). However it is clear that the full importance of extra CS at calving cannot be assessed without considering the subsequent effects on both milk and body condition (see Townsley *et al.*, (1981).

TABLE 4: THE EFFECT OF VARIATION IN CONDITION SCORE AT CALVING ON SUBSEQUENT MILK PRODUCTION AND CHANGES IN BODY CONDITION*

	Condition score at calving			
	3	*4*	*5*	*6*
Milkfat weeks 0-20 (kg/cow)	92	100	109	117
Condition score at week 20	4.4	4.7	4.9	5.2

*These data were calculated for an intake of 14 kg pasture DM/d during weeks 0 to 5 of lactation. All cows were grazed together in weeks 6 to 20. See Grainger (1980) for details.

Using the experimental data in Tables 3 and 4 it can be calculated that an additional 0.73 units CS (1-0.27) is equivalent to an extra 8.3 kg milkfat. Therefore since about 2 500 MJ ME are required per 1 CS unit (Table 3), 220 MJ ME fed to increase CS are equivalent to 1 kg milkfat. The latter value is higher than that calculated theoretically, 160 MJ ME (Table 2).

Body condition at calving may also affect subsequent food intake (Land and Leaver, 1980); cows which were fatter at calving produced more milk than thinner cows, despite the fact that they ate less feed than the thinner cows in early lactation.

THE LEVEL OF FEEDING DURING LACTATION, MILK PRODUCTION AND CHANGES IN LIVEWEIGHT

During lactation milk is synthesised from that amount of ME which becomes available from the diet in excess of the costs of maintenance; however this amount of energy may either be supplemented by energy made available from the mobilisation of body tissue, or be reduced by the diversion of energy towards the synthesis of body tissues.

Therefore, in the short term, there may be no simple relation between MEI and milk production because of the important roles of body tissues in the overall balance of energy. Hence the conventional methods for expressing food conversion and marginal response to extra food (see below) may yield variable and misleading results because they take no account of the contributions which can be made by changes in body tissues.

$$\text{Food conversion} = \frac{\text{kg total dietary DM eaten}}{\text{kg milkfat produced}}$$

$$\text{Marginal response to extra feed} = \frac{\text{kg extra feed DM eaten}}{\text{kg extra milkfat produced}}$$

Some values for food conversion and marginal response have been calculated from the theoretical estimates given in Table 1 and these are presented in Table 5. The calculations provide an indication of the magnitude of values to be expected and the extent to which they may vary. In addition they show that, in the short term and on a particular level of feeding, a cow which is synthesising body tissue appears to be less efficient than one which is not and that a cow which is mobilising body tissue appears to be more efficient than one which is not. However, if account is taken of the future contribution towards milk synthesis that may be made by the synthesised body tissue and of the ME which was previously required to synthesise the body tissue, and which was mobilised, then the differences in efficiency between the different situations, measured over the long term, will be much smaller.

TABLE 5: THEORETICAL CALCULATIONS OF THE MILKFAT PRODUCTION, FOOD CONVERSION AND MARGINAL RESPONSE VALUES WHICH ARE POSSIBLE FOR A 380 kg COW FED ON PASTURE CONTAINING 11.5 MJ ME/kg DM AND SHOWING DIFFERENT RATES OF CHANGE IN LIVEWEIGHT (USING DATA IN TABLE 1).

	Daily intake of DM (kg/cow)		*Marginal response to extra feed (see text)*
	10	*15*	
No change in liveweight:*	0	0	
Milkfat produced:*	0.58	1.11	10
Food conversion:*	17.2	13.5	
Changes in liveweight:	−0.5	+0.5	
Milkfat produced	0.70	0.97	19
Food conversion	14.3	15.5	

*Changes in liveweight and milkfat produced; kg/cow/d
Food conversion: see text

Values for food conversion and marginal response have been calculated for several recent experiments in which cows were fed or grazed on pasture (see Table 6) and there is reasonable agreement between these and the theoretical values in Table 5. All the experimental values for marginal response are, however, higher than the theoretical minimum "true" value of 10 (Table 5). This is to be expected, because the increase in food intake to the higher level of feeding was in all cases associated with an increase in the rate of gain in liveweight. On average, higher values were recorded in the experiments carried out in late lactation which is in accord with the expectation that the cows would have been synthesising relatively large amounts of body tissue at this stage.

If however, a supplementary feed is added to a basal diet of grazed pasture, the marginal response to the extra feed may appear to be inefficient, partly because cows are likely to substitute the supplement for some of the pasture that they had previously been grazing (Bryant, 1978).

The carry-over effect after a period of underfeeding in early lactation

The so-called carry-over effect refers to the effect of the change in level of feeding which is measured after the treatment had finished, expressed relative to the effect measured during the treatment period, and it is usually calculated as shown in Table 6.

TABLE 6: EXPERIMENTALLY MEASURED VALUES FOR FOOD CONVERSION AND MARGINAL RESPONSE FOR COWS FED ON PASTURE, AT DIFFERENT LEVELS OF FEEDING IN EARLY AND LATE LACTATION

Reference	*Food conversion on highest level of feeding*	*Marginal* response*	*Carry-over** effect*
Early Lactation			
Grainger and Wilhelms (1979) (10-week feeding period)	16	19	1.0
Bryant and Trigg (1979) (6-week feeding period)	14	21	0.8
Bryant (1980) (4-week feeding period)	15	20	Not available
Glassey *et al.*, (1980) (4-week feeding period)	22	43	0
Late Lactation			
King *et al.*, (1980)†	28	34	
Bryant (1978) ‡	32	72	

* Marginal response calculated for the increase in food intake between the lowest and highest levels of feeding

** Carry-over effect calculated as:

$$\left(\frac{\text{Total effect on milkfat produced} - \text{Immediate effect on milkfat produced}}{\text{Immediate effect on milkfat produced}}\right)$$

† Digestibility of pasture DM : 69%

‡ Digestibility of pasture DM : 64%

Broster (1972; 1974) reviewed the results of a large number of experiments including some carried out in N.Z. and concluded that the carry-over effect was likely to be 3 or 4 times as large as the immediate effects. However more recent work in N.Z., Australia and Ireland has measured much smaller values for the carry-over effect which have ranged from 0 to 1 (Bryant and Trigg, 1979; Grainger and Wilhelms, 1979; Gordon, 1976; 1977; Steen and Gordon, 1980).

It must be pointed out that in some of these experiments the levels of feeding of the cows from the different treatments were not controlled nor measured during the post-treatment period. If those cows which had previously been on a low level of feeding ate more than the other cows during the post-treatment period, as might be expected (Land and Leaver, 1980), this difference in intake would have reduced the size of any carry-over effect.

However, based solely on a consideration of the energetics involved, it would be expected that if a period of underfeeding caused liveweight to decrease and that if this decrease in liveweight was subsequently repaired, then some dietary energy must have been diverted away from milk production and towards the synthesis of body tissue during this latter period (see Broster, 1974). This type of effect must account for at least part of the carry-over effects measured in many experiments although there may be other factors such as changes in mammary tissue or the endocrine system caused

TABLE 7: SOME THEORETICAL CALCULATIONS, USING DATA FROM TABLE 1 BASED ON THE MEASUREMENTS OF BRYANT AND TRIGG (1979); EXPT 2

(a) Weeks 0 to 6: High level : 13 kg DM/cow/d
Low Level : 7 kg DM/cow/d

— Difference in DM eaten = 269 kg DM/cow; equivalent to 24 kg milkfat if the liveweights of both groups remained equal.
— But the low level group lost 68 kg liveweight; equivalent to 15 kg milkfat.
— Therefore the low level group would be expected to produce (24-15) = 9 kg milkfat less than the high level group.
— The measured difference was 11 kg milkfat.

(b) Weeks 7 to 18: Both groups grazed together; intake not measured

— Previously low level group gained 73 kg liveweight; equivalent to 204 kg DM, or equivalent to 20 kg milkfat.
— Therefore if the low level group had the same intake as high level group they would be expected to produce 20 kg milkfat less than the high level group.
— The measured difference was 8 kg milkfat.
— The discrepancy between the calculated difference (20) and the measured difference (8) could be explained if the previously low level group had eaten 1.4 kg DM more than the high level group while grazing.

by the period of underfeeding but about which there is at present little information. An example of the way in which changes in liveweight (and body tissue) may contribute to milk synthesis and to a carry-over effect are provided in Table 7, based on calculations from the data of Bryant and Trigg (1979).

Carry-over effect after a period of underfeeding in late lactation

Underfeeding in late lactation would be expected to have little carry-over effect in the current lactation, because the lactation has nearly finished. However, just as in early lactation, it causes not only a small decrease in milk production but also a decrease in liveweight or body condition (King *et al.*, 1980; Bryant, 1978). The latter decrease in body condition would be expected to affect the cow's condition at the subsequent calving and consequently her milk production in that lactation; hence the majority of the carry-over effect would not become apparent until the subsequent lactation.

As an approximate guide to the probable magnitude of such carry-over effects it can be predicted that if a decrease in liveweight of 5 kg occurs at any stage of the year, there will subsequently be an associated decrease in milk production of about 1 kg milkfat at the time when the lost weight is regained by the cow, unless an increase in food intake occurs.

The Overall Efficiency with which Feed is Utilised From One Lactation to Another

The cow has considerable capacity to modify the immediate effects on her milk production of short-term changes in level of feeding by using her ability to synthesise or mobilise body tissues. The resultant changes in body energy reserves, or body condition, have been shown to influence milk production either later in the same lactation, or in the subsequent lactation. It is, therefore, difficult to predict from the results of conventional short-term experiments what the probable effects of a particular feeding strategy will be on the overall efficiency in the long term.

In all cases it is important to appreciate that ME eaten above maintenance must result in the synthesis of an animal product; for example:

10 kg DM → 1 kg milkfat
6-7 kg DM → 1 kg carcass weight
15 kg DM → 5 kg liveweight gain → 1 kg milkfat

Thus any economic evaluation of feeding strategies must take into account all of these products and their potential value both in the short and long term.

It is recognised that the present discussion based on the energy metabolism of cows ignores many factors which are likely to be extremely important in relation to the overall utilisation of feed on the farm; for example, availability and costs of feeds and the efficiency with which the cow is able to harvest the available pasture at various times of year.

REFERENCES

Bath, D. L.: Ronning, M,; Mayer, J. H.; Lofgreen, G. P., 1965. *J. Dairy Sci., 48:* 374.

Broster, W. H., 1972. *Dairy Sci. Abstr., 34:* 265.

Broster, W. H., 1974. *Bien. Rev. Nat. Inst. Dairying, U.K.:* 14.

Bryant, A. M., 1978. *Ag Link FPP163.* N.Z. Ministry of Agriculture and Fisheries, Wellington.

Bryant, A. M., 1980. *Proc. N.Z. Soc. Anim. Prod., 40:* 50.

Bryant, A. M., 1980. *Proc. N.Z. Grassld. Ass., 40:* 82

Bryant, A. M.; Trigg, T. E., 1979. *Proc. N. Z. Soc. Anim. Prod., 39:* 139.

Cowan, R. T.; Robinson, J. J.; McDonald, I., 1980. *Anim. Prod., 30:* 477. (abstr.).

Flatt, W. P.; Moe, P. W.; Munson, A. W.; Cooper, T., 1969. In *Energy Metabolism of Farm Animals* (Eds. K. L. Blaxter, J. Kielanowski and G. Thorbek), Oriel Press. U.K., p 235.

Glassey, C. G.; Davey, A. W. F.; Holmes, C. W., 1980. *Proc. N.Z. Soc. Anim. Prod., 40:* 59.

Gordon, F. J., 1976. *Anim. Prod., 22:* 175.

Gordon, F. J., 1977. *Anim. Prod., 25:* 373.

Grainger, C. 1978. M. Agr. Sc. Thesis, University of Melbourne.

__________ 1980. *Dairyfmg. A.: 65.*

Grainger, C.; Wilhelms, G., 1979. *Austr. J. exp. Agric. Anim. Husb., 19:* 395.

Grainger, C.; Wilhelms, G.; McGowan, A., 1978. *Ann. Rep. Dairy Res. Inst.* Ellinbank, Victoria: 37.

Gray, R., Robinson, I., 1979. *Ann. Rep. Dairy Res. Inst.* Ellinbank, Victoria: 55.

Holmes, C. W.; McLenaghan, R., 1980. *Dairyfmg. A.,:* 60.

Hutton, J. B., 1971. *Proc. N.Z. Soc. Anim. Prod., 31:* 211.

Joyce, J. P.; Bryant, A. M.; Duganzich, D. M.; Scott, J. D. J.; Reardon, T. F., 1975. *N.Z. Jl Agric. Res., 18:* 295.

King, K. R.; Stockdale, C. R.; Patterson, I. F., 1980. *Aust. J. exp. Agric. Anim. Husb., 20:* 389.

Land, C.; Leaver, J. D., 1980. *Anim. Prod., 30:* 449 (abstr.).

Moe, P. W., Tyrrell, H. F., 1972. *J. Dairy Sci., 55:* 480.

Moe, P. W., Tyrrell, H. F., 1975. *J. Dairy Sci., 58:* 602.

Moe, P. W., Tyrrell, H. F.; Flatt, W. P., 1971. *J. Dairy Sci., 54:* 548.

Rogers, G. R.; Grainger, C.; Earle, D. F., 1979. *Aust. J. exp. Agric. Anim. Husb., 19:* 7.

Scott, J. D. J.; Smeaton, D. C., 1980. In *Sheep and Cattle Nutrition.* (eds. J. D. J. Scott; N. Lamont; D. C. Smeaton and S. J. Hudson) Research Division N.Z. Ministry of Agriculture and Fisheries, p 21.

Steen, R. W. J.; Gordon, F. J., 1980. *Anim. Prod., 30:* 39.

Townsley, R. J.; Grainger, C.; McGowan, A. A., 1981. *Proc. N.Z. Soc. Anim. Prod., 41:* 28

Trigg, T. E.; Jury, K. E.; Bryant, A. M.; Parr, C. R., 1979. *Proc. 8th Symp. Energy Metabolism,* EAAP Publ. No 26: 345.

Tyrrell, H. F.; Reid, J. T.; 1965. *J. Dairy Sci., 48:* 803.

Van Es, A. H. J., 1976. In *Principles of Cattle Production* (eds. H. Swan and W. H. Broster) Butterworths, Lond. p 237.