USING RESEARCH TO REDUCE THE COSTS OF PRODUCING MILK

Review of research for AgriSearch
September 2004

AgriSearch
Farmer Funded Research

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AgriSearch was formed in 1997 to provide a mechanism through which dairy, beef and sheep farmers could have a direct involvement in near market research. Funds contributed to AgriSearch are used to commission research into the improvement and development of sheep, beef and dairy farming and to disseminate and publish the results. Dairy projects are recommended to the AgriSearch Council by a Dairy Advisory Group comprised of five people, of which three are farmers. The AgriSearch Council is comprised of ten people of which six are farmers."

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FOREWORD

Lower milk prices over the past few years have resulted in lower profit margins in dairying than during the late 1980's and early 1990's. The proposed enlargement of the European Union and the liberalisation of world trade are likely to maintain a downward pressure on milk prices over the next few years. Within this context, minimising the cost of milk production is vitally important in maintaining a profitable and vibrant dairy industry in Northern Ireland in the future.

High calibre research undertaken locally has played an important role in providing sound scientific and technical information which has been used to improve efficiency and reduce costs within the dairy industry. Research undertaken in other countries can also be of considerable relevance to milk producers in Northern Ireland. Consequently, AgriSearch has commissioned a review of research findings which are relevant to the Northern Ireland dairy industry.

There is often considerable variation in the results of individual experiments, depending on the type of cows involved, the management of the cows, the constraints imposed within an experiment and the climatic conditions, including the variation in climate from year to year within one location. Consequently results of an individual experiment may only be applicable to a situation with the same constraints and management which were in operation within that experiment. For this reason it is vitally important that milk producers have access to research information from as wide a range of experiments as possible, to obtain a good overall picture of what is likely to be applicable in a wide range of farm situations.

Consequently within this review, the results of approximately 600 experiments on dairying have been reviewed, and the results of 350 to 400 of these, which are considered to be relevant to the Northern Ireland dairy industry, have been summarised and presented in this book. The circumstances under which different responses to various inputs are likely to be obtained are also discussed. The information presented also relates to a wide range of systems of dairying, ranging from those based almost entirely on grass with modest milk yields, right through to high-input systems involving cows producing 10,000 to 12,000 kg of milk/cow.

Consequently the information presented in this review should be applicable to a very wide range of farm situations in Northern Ireland, although the constraints which apply within a particular farm can limit the applicability of general research findings to that individual farm. However the information presented in this review should provide a sound technical basis on which decisions can be taken which will help to reduce the cost of producing milk and thereby maximise the profitability of the dairy enterprise on most Northern Ireland farms.

NOTE

ALTHOUGH GREAT EFFORT HAS BEEN MADE TO ENSURE THAT ALL OF THE INFORMATION PRESENTED IN THIS REVIEW IS CORRECT, IT IS NEVERTHELESS NOT POSSIBLE TO GUARANTEE THE ABSOLUTE ACCURACY OF EVERY FIGURE PRESENTED DUE TO THE VERY LARGE VOLUME OF DATA WHICH HAS BEEN REVIEWED AND SUMMARIZED.

CHAPTER 1

FEEDING DAIRY COWS BEFORE CALVING TO PREPARE FOR THE NEXT LACTATION

The pre-calving period when dairy cows are dry is often viewed as a rest period between two lactations. However this view, and the fact that feed requirements are lower at this stage than during lactation can result in a lower standard of management for dry cows than for milking cows in many herds. The dry period should be viewed as a preparatory period for the next lactation, as management and feeding of cows during the dry period can have major effects on the health, welfare, fertility and production of cows during the next lactation. There are several important aspects to the feeding of dry cows and there is no single feeding programme which is suitable for all cows, because the optimum level of feeding before calving depends on the body condition of the cow at the end of the previous lactation and the diet and level of feeding which the cow will receive after calving.

The effects of feeding during the dry period have been extensively researched in several countries. The results of experiments which have investigated the effects of feeding during late pregnancy on subsequent production, health and fertility will be examined under the following headings:

1) The effects of level of feeding or energy intake during late pregnancy and body condition at calving of cows given high-energy diets during early lactation.
2) The effects of level of feeding during late pregnancy and body condition at calving of cows given high-forage diets during early lactation.
3) The effects of the level of feeding during late pregnancy on the performance and health of cows offered "medium energy diets" during early lactation.
4) The effects of protein supplementation during the dry period on subsequent performance and fertility.
5) The effects of including bulky feeds such as straw in the diet during the dry period on subsequent performance.
6) Mineral and vitamin nutrition during the dry period.

The effects of level of feeding or energy intake during late pregnancy and body condition at calving on the performance of cows given high-energy diets during early lactation

The results of 15 different experiments which have been carried out mainly in the UK and the United States of America to examine the effects of different levels of feeding during late pregnancy on the production, health and fertility of dairy cows during the next lactation are summarised in Table 1. These were undertaken by Davenport and Rakes (1969); Gardner (1969); Land and Leaver (1980 and 1981); Lodge and others (1975); Garnsworthy and others (1982, 1987, 1992 and 1993); Jones and Garnsworthy (1989); Treacher and others

TABLE 1 THE EFFECTS OF THE LEVEL OF FEEDING BEFORE CALVING AND BODY CONDITION AT CALVING ON THE PERFORMANCE OF DAIRY COWS OFFERED HIGH-ENERGY DIETS AFTER CALVING. (AVERAGE RESULTS OF 15 EXPERIMENTS)

	FEEDING LEVEL BEFORE CALVING	
	LOW	HIGH
Body condition score at calving*	2.2	3.5
Average recording period (days of lactation)	1 – 131	1 – 131
Total dry matter intake (kg/cow/day)	18.7	17.6
Milk yield (kg/cow/day)	28.1	27.2
Milk fat content (%)	3.94	4.08
Milk protein content (%)	3.13	3.09

* Body condition scores are on a scale of 0 to 5 which is used at Greenmount College, DARD, for assessing the body condition of dairy cows on Northern Ireland farms

(1986); Holter and others (1990); Tesfa and others (1999) and Mashek and Beede (2001). In five of the 15 experiments, the high and low levels of feeding were imposed only during the dry period while in the other ten experiments, high and low feed intakes were given during late lactation and the dry period to achieve major differences in the body condition of the cows at calving. For example, in the experiments undertaken by Garnsworthy and others at Nottingham University in England, the aim was to have cows calving with body condition scores as near as possible to 2.0 and 3.5, which required a fairly major difference in feed intake during late lactation and the dry period.

The cows involved in the 15 experiments were given 11 to 16 kg of concentrates/cow/day during early lactation, with an average intake of approximately 13.5 kg/day. This represented from 55 to 80% of total dry matter intake

On average over these experiments in which cows were given high-energy diets during early lactation, giving cows additional feed before calving to increase body condition at calving reduced daily feed intake after calving by 1.1 kg of dry matter and reduced milk yield by 0.9 kg/cow/day. The cows which were on the higher level of feeding before calving produced milk with a higher fat content and lower protein content compared to that produced by cows on the lower level of feeding before calving. The fact that the cows which were fatter at calving, consistently had a lower food intake during the early part of the subsequent lactation would appear to result from the intake of high-concentrate, high-energy diets being controlled by the amount of energy which the cow can consume and utilize. When given high-energy diets, cows in lower body condition are able to consume more energy than fatter cows, and hence the dry matter intake of the fatter cows is controlled to a lower level than that of cows with a lower body condition score.

The lower intake of dry matter and energy by the fatter cows during early lactation resulted in a much greater loss of weight and body condition by these cows than by those with the lower condition score at calving, despite the fact that the fatter cows produced slightly less milk. This in turn resulted in the fatter cows producing milk with a higher fat content, presumably due to the greater mobilisation of body fat to support milk production, and a lower protein content due to their lower energy intake during early lactation. Body condition scores were available for the cows in only 10 of 15 experiments. On average over these 10 experiments the body condition score of the cows on the lower level of feeding before calving was 2.2 compared to an average score of 3.5 for the cows on the higher level of feeding before calving.

The cows involved in most of the 15 experiments produced between 6,000 and 7,500 kg of milk over a 305-day lactation and consequently the results of these experiments are applicable to a large proportion of the herds in Northern Ireland which are given high inputs of concentrates during early lactation.

However it is also of particular interest to note that the cows used in the most recent experiment carried out in the United States by Mashek and Beede (2001) had a projected mature cow yield of over 10,000 kg and the results of this experiment are in close agreement with those from the earlier experiments involving lower yielding cows, in that the cows which had a higher condition score at calving produced 1.0 kg less milk/cow/day than those with a lower condition score at calving. Also in a further recent experiment in the United States, Domecq and others (1997) examined the relationship between body condition score at various stages of pregnancy and milk yield in a commercial herd of over 1,000 high-yielding Holstein cows. The rolling average milk yield for this herd was over 10,500 kg in 305 days and there was a negative relationship between body condition score at the beginning of the dry period and milk yield in the first 120 days of the next lactation. When body condition at the beginning of the dry period increased by one score (e.g. from 2.5 to 3.5) milk yield during the first 120 days of the next lactation was reduced by 300 kg/cow.

Including a high proportion of concentrates in the diet of dry cows during the last 3 to 4 weeks before calving can also have a detrimental effect on subsequent milk yield. For example, Holcomb and others (2001) offered high genetic merit Holstein cows total mixed rations containing either 30% or 72% concentrates for the last 25 days before calving on average, and found that the cows which received the high-concentrate diet before calving produced 5.9 kg less milk/cow/day during the first few weeks of the next lactation. However, Mashek and Beede

(2000) found that in a herd which was producing around 10,000 kg of milk/cow in 305 days, offering the cows a complete diet containing 79% forage and 21% concentrates instead of forage only for the last three weeks before calving did not affect milk yield or composition during the first 150 days of the next lactation.

From the results of the experiments which are presented in Table 1 it can be concluded that, when dairy cows with lactation yields ranging from 6,000 to 10,500 kg in 305 days, are given high-energy diets with high concentrate inputs (e.g. 11-16 kg/cow/day) during early lactation, calving cows with a body condition score of 3 to 3.5 rather than 2 to 2.5 is likely to reduce feed intake and increase weight loss during early lactation. Cows with the higher condition score at calving are also likely to produce slightly less milk with a slightly higher fat content and slightly lower protein content than that produced by cows with a condition score of 2.0 to 2.5 at calving.

The effects of different levels of feeding during late pregnancy on subsequent health and fertility of dairy cows has also been examined in several experiments. In most studies, higher levels of feeding during late lactation or the dry period, resulting in cows having a higher body condition at calving has been associated with a greater incidence of milk fever at calving and mastitis during early lactation. For example, in four experiments undertaken by Emery and others (1969), Johnson and Otterby (1981), Fronk and others (1980) and Treacher and others (1986), feeding concentrates during the dry period or calving cows in a higher body condition score (3.8 compared to 2.9) increased the incidence of mastitis during early lactation. Emery and others (1969) and Fronk and others (1980) also found that higher levels of feeding before calving increased the incidence of milk fever after calving, while Nocek (1995) reported that cows which are fat at calving have a higher incidence of metabolic problems.

Cows which are mobilising a lot of body reserves to support milk production during early lactation and consequently have a major loss of body condition at this stage have also been found to have poorer reproductive performance than cows which have lost less body condition during early lactation (Butler and Smith, 1989; Senatore and others, 1996; Studer, 1998; Pryce and others, 2001). As discussed above, cows which were fatter at calving and were given high-concentrate diets during early lactation, had lower food intakes at this stage and consequently lost more body condition than cows with a lower condition score at calving. This in turn may reduce reproductive performance. Consequently in several experiments, cows which were fat at calving have had poorer reproductive performance than cows with a moderate body condition score at calving (Butler and Smith, 1989). For example, Garnsworthy and Topps (1982) found that cows which had a body condition score of 2.8 at calving had better reproductive performance than cows with a condition score of 3.8 at calving, while Gearhart and others (1990) found that cows which were over-conditioned at drying-off and calving had more reproductive disease than cows in moderate body condition at drying off and calving.

However cows which were very thin at calving, with a condition score of less than 2.0, have also had poorer reproductive performance than cows with a condition score of 2 to 3 at calving (Garnsworthy and Topps 1982). There is also a lot of research information which shows that calving suckler cows with a condition score of less than 2 has been detrimental to subsequent reproductive performance (Steen, 2003). Feeding concentrates for a three to four week period before calving, generally has had only a small effect on condition score at calving because of the short feeding period, and consequently has generally not affected subsequent fertility of cows with either moderate (Johnston and Otterby, 1981) or high yields (Olsson and others 1998; Mashek and Beede 2001).

Overall, the results of the research which is summarised above show that when cows are given high-concentrate diets during early lactation, calving cows with an average body condition score of 3.5 rather than 2.2 reduced food intake during early lactation which resulted in a greater loss of body condition at this stage and a slightly lower milk yield. Cows with a body condition score greater than 3.5 or less than 2.0 have had poorer reproductive performance and health than cows with a condition score at calving within the range 2.0 to 3.5.

Taken together these findings indicate that for cows which are given high-concentrate diets during early lactation, aiming for a condition score as near to 2.5 at calving as practically possible should maximise profitability. A higher condition score at calving is likely to reduce food intake after calving with the associated problems of this, while aiming for a condition score below 2.5 may result in a proportion of cows having a condition score below 2.0, which is likely to reduce subsequent reproductive performance.

The available evidence indicates that the best approach is to aim to have the body condition of cows close to the optimum at the beginning of the dry period and then feed them to maintain this condition or have a slight gain in condition during the dry period. If some cows have a condition score of less than 2.0 at the beginning of the dry period it is likely to be economical to feed them to gain sufficient condition to achieve a condition score of at least 2.0 before calving, even if this requires concentrate supplementation. On the other hand, limited evidence available from Gearhart and others (1990) and Nocek (1995) would indicate that if cows are overfat at the beginning of the dry period it is better not to deliberately try to reduce their body condition score in the last few weeks before calving as this may increase the incidence of disease.

While the experimental results reviewed above relate mainly to cows in their second or later lactations, some experimental information is also available on the effects of feeding level during late pregnancy on performance of first calving heifers given high-concentrate diets during early lactation. For example, Land and Leaver (1981) fed heifers during late pregnancy to achieve body condition scores of 2.5 and 3.0 at calving. The heifers with a condition score of 3.0 produced 3.5 kg/day more milk and lost more body weight and condition during the first 8 weeks of lactation than those which had a condition score of 2.5 at calving. Lactation yields over 305 days were 782 kg higher for the animals with the higher condition score at calving. Similarly, Carson and others (2002a) found that increasing the live weight of high genetic merit Holstein heifers from 540 to 620 kg and body condition score at calving from 2.8 to 3.6 increased milk yield during the first lactation from 7222 to 7959 kg, an increase of 737 kg.

Domecq and others (1997) examined the relationship between body condition at calving and milk yield in a herd of over 1,000 high genetic merit Holstein cows with a rolling average milk yield of over 10,500 kg. The 316 heifers in the herd had an average condition score of 2.7 at calving. For each 0.5 unit increase in body condition score at calving, milk yield during the first 120 days of lactation increased by 0.4 kg/day. Grummer and others (1995) fed high genetic merit heifers during late pregnancy to achieve body condition scores of 3.5 and 3.7 at calving. The heifers with the higher condition score had a lower feed intake during early lactation but they produced the same amount of milk as those which had the lower condition score at calving by mobilising more body fat and losing more condition to support milk production.

Together the results of these experiments indicate that the optimum body condition score for first calving heifers in terms of first lactation milk production may be somewhat higher than that for mature cows. Increasing condition score above 2.5 increased milk yield in the experiments undertaken by Land and Leaver (1981), Domecq and others (1997) and Carson and others (2002a), while there was no indication that increasing condition score at calving above 3.5 reduced milk yield as has been the case with mature cows.

However, Carson and others (2002a) found that heifers which were 620 kg live weight and had a condition score of 3.6 at calving had a longer calving interval (436 days) between first and second calvings than heifers which were 540 kg live weight and had a condition score of 2.8 at first calving, the calving interval for these lighter heifers being 394 days. Wathes and others (2001) also reported that heifers which had a body condition score greater than 3 at calving took longer to become pregnant again than those with a condition score of 2 to 3 at calving.

These results would suggest that the most appropriate condition score for heifers at calving is likely to be a compromise between maximising first lactation milk yield and reproductive performance. In situations in which achieving a calving interval as close to 365 days as possible is more important than achieving a higher milk yield during the first lactation, aiming for a condition score of 2.5 to 3.0 at calving is likely to be most

TABLE 2 THE EFFECTS OF LEVEL OF FEEDING DURING LATE PREGNANCY AND BODY CONDITION SCORE AT CALVING ON THE PERFORMANCE OF COWS GIVEN HIGH-FORAGE DIETS DURING EARLY LACTATION. (AVERAGE RESULTS OF SIX EXPERIMEN

	FEEDING LEVEL BEFORE CALVING	
	LOW	HIGH
Body condition score at calving*	2.8	3.4
Average recording period (days of lactation)	3 – 123	3 – 123
Total dry matter intake (kg/cow/day)	15.2	15.3
Milk yield (kg/cow/day)	23.4	25.4
Milk fat content (%)	3.87	4.10
Milk protein content (%)	3.15	3.18

* Body condition scores are on a scale of 0 to 5 which is used at Greenmount College, DARD, for assessing the body condition of dairy cows on Northern Ireland farms

appropriate. Higher condition scores at first calving have increased the interval to the second and third calvings and consequently has not increased milk yield per year of the cows productive life. However, if for some reason achieving maximum or near maximum milk yield during the first lactation is more important than the length of the interval between first and second calving or milk yield per year of the cows productive life, then a condition score of 3.0 to 3.5 at calving is likely to be most appropriate. Lower condition scores at calving have reduced first lactation milk yield, but have also reduced the interval to second calving, and consequently have tended to increase subsequent milk yield per year of the cows productive life (Carson and others, 2002b). Increasing condition of heifers above 3.5 at calving is unlikely to produce any further increase in milk yield and is likely to further reduce reproductive performance and may well increase the incidence of difficult calvings as a result of excessive fat deposition in the pelvis and consequently reduced pelvic area (Price and Wiltbank, 1978) and may also increase the incidence of metabolic diseases.

The effects of level of feeding during late pregnancy and body condition at calving on the performance of cows given high-forage diets during early lactation

The results of six experiments which have been carried out to examine the effects of level of feeding during late pregnancy and body condition score at calving on the performance of cows given high-forage diets during early lactation are presented in Table 2. These were undertaken by Gardner (1969); Grainger and others (1982); Jacquette and others (1988); McNamara and others (2000) and Keady and others (2001 and 2002c). In five of the six experiments, the cows were given grass silage (or hay in the case of the two experiments carried out in the United States) supplemented with approximately 7 kg of concentrates/cow/day.

In each of the five experiments, concentrates represented between 35 and 40% of total dry matter intake. In the sixth experiment, which was undertaken in Australia by Grainger and others (1982), the cows were at pasture after calving and did not receive any concentrates. In four of the six experiments, the cows were fed either forage only or forage plus concentrates during the dry period. In one experiment undertaken in the United States, cows were given either 8.5 or 11.7 kg of alfalfa dry matter during the dry period, while in the sixth experiment the cows were either tightly or laxly stocked at pasture during late lactation and the dry period to produce cows with different body condition scores at calving.

On average over the four experiments in which feed intake during early lactation was recorded, giving cows more feed before calving and achieving a high condition score at calving did not affect feed intake after calving. This result is in contrast to the results of experiments involving high-concentrate diets after calving, in which fatter cows ate less feed than cows with a lower condition score, as discussed in the previous chapter. This is because the intake of high-energy, high-concentrate diets is controlled by the amount of energy which the cow can consume and utilize and this physiological control mechanism in the cow controls the food intake of fatter cows to a lower level than that of leaner cows. In contrast to this, the intake of high-forage diets is controlled by the physical capacity of the cows gut and so in this situation the fatter cows ate the same amount of feed as the leaner cows.

On average over the six experiments, cows which received more feed before calving produced 2.0 kg more milk per day, either during early lactation or during the total lactation than cows which received less feed before calving. The cows which had a higher body condition score at calving also produced milk with a higher fat content and marginally higher protein content than cows which had a lower condition score at calving. The cows which had a higher body condition score at calving supported the higher milk production by mobilising more body reserves to support milk production during early lactation.

The responses in milk production and milk fat plus protein yield to a high level of feeding before calving were lower in the experiments undertaken by Keady and others at Hillsborough than the response obtained in the other experiments. However, the smaller response in the experiments at Hillsborough is likely to have been the result of the fact that the different levels of feeding were imposed for only 4 or 5 weeks in these experiments, and so there was little difference in the body condition of the cows which had been on the low and high levels of feeding before calving. In fact, the response in milk yield per unit increase in condition score at calving was as great in the experiments undertaken by Keady and others as it was in the other four experiments.

On average over the six experiments milk yield during early lactation increased by 3.5 kg/day for each unit increase in body condition score at calving (e.g. calving at a condition score of 3.5 instead of 2.5).

The six experiments listed in Table 6 were undertaken with cows in their second or late lactation. A further experiment was undertaken recently in New Zealand to examine the effect of the level of feeding during late pregnancy and hence on body condition at calving on the performance and fertility of first calving heifers (Chagas and others 2000). In this case, calving heifers with a body condition score of 2.8 rather than 2.2 increased milk yield by 560 kg over 224 days of their first lactation, when the animals were at pasture for the entire lactation.

The level of feeding before calving did not affect the overall subsequent health of the cows in any of the seven experiments discussed above. However in the two experiments undertaken by Grainger and others (1982) involving cows, and Chagas and others (2000) involving heifers, the animals with the lower body condition score at calving had poorer subsequent reproductive performance, the effect being very pronounced in the case of the heifers. This is likely to have been due to the fact that the cows which had been on the lower level of feeding before calving in these experiments had lower condition scores at calving (1.7 for cows and 2.2 for heifers) than the cows on the lower level of feeding before calving in the other experiments. This again emphasises the fact that cows which calve with a condition score of less than 2.0 or heifers with a condition score down to 2.2, are likely to have poorer subsequent fertility than cows which calve with a higher condition score.

Furthermore, in a very large scale study involving over 30,000 cows on grass-based systems of dairying in Australia, Morton and others (2000) found that cows which calved with a low body condition score had a 40% conception rate to first service compared to a 56% conception rate to first service for cows with a condition score around 3 to 3.5 at calving. Similarly in a further recent study in New Zealand, Rhodes and others (2001) found that two-year-old heifers which had a higher condition score at calving had better subsequent reproductive performance than those with a lower condition score at calving, while in a recent study at Moorepark involving high-forage diets, Berry and others (2003) also found that cows with a higher condition score immediately after calving had better fertility.

Overall the results of the six experiments which are summarised in Table 2 above show that when cows have been given high-forage diets during early lactation, calving cows with an average condition score of 3.4 rather than 2.8 did not affect food intake in early lactation. However it increased milk yield by 2.0 kg/day and increased fat plus protein content of the milk slightly. As body condition score at calving had no effect on the health or fertility of the cows in these experiments, except when cows or heifers had a low condition score at calving, these findings indicate that for cows and heifers which are given high-forage diets during early lactation (i.e. up to 7.5 kg concentrates/cow/day), aiming for a condition score of 3 to 3.5 at calving should maximise profitability.

The effects of the level of feeding during late pregnancy on the performance and health of cows offered "medium energy diets" during early lactation

In the previous two sections diets containing over 55% concentrates or 11 kg/cow/day were described as high-concentrate of high-energy diets, while those containing less than 40% concentrates or 7.5 kg/cow/day were described as high-forage diets. Giving extra feed during late pregnancy has produced very different effects on milk yield and cow health and fertility in cows managed under these differing systems.

In a further eight experiments, undertaken by Johnson and Otterby (1981); Cowan and others (1981); Kunz and others (1985); Boisclair and others (1986); Jones and Garnsworthy (1988); Olsson and others (1998) and Ryan and others (2000), cows were given either a standard diet or the standard diet plus additional concentrates during late pregnancy. In this case, the cows were given diets containing 40 to 54% concentrates on a dry matter basis during early lactation. The average concentrate intake during early lactation over the eight experiments was 9.4 kg/cow/day. Body condition scores were reported for only five of the eight experiments. In these five experiments giving extra feed before calving increased condition score at calving by 0.7 of a unit within the range 2.0 to 4.0.

The results of these experiments were intermediate between those for the high-concentrate and high-forage diets. On average over the eight experiments, offering additional feed during late pregnancy resulted in a slightly lower feed intake during early lactation, but the cows given extra feed in late pregnancy produced 0.9 kg more milk/day than those on the lower level of feeding before calving. The level of feeding before calving had little effect on milk fat or protein contents or on the health or fertility of the cows in these experiments, except that in the experiment undertaken by Johnson and Otterby (1981) offering extra feed during late pregnancy increased the incidence of mastitis during early lactation.

The results of these experiments show that when cows are given about 8 to 10 kg of concentrates/day during early lactation, providing extra feed during late pregnancy had little effect on milk production or the health or fertility of the cows, providing that cows were not excessively fat or thin (condition score of less 2.0) at calving.

These findings indicate that the optimum body condition score at calving for cows given about 8 to 10 kg concentrates/day during early lactation is between 2.5 and 3.0, and that it is unlikely to be economical to feed concentrates to these cows during the dry period to increase body condition at calving, unless condition score is below 2.0. Again, having cows with a condition score of less than 2.0 at calving should be avoided as this is likely to result in poorer subsequent fertility.

SUMMARY OF THE MAIN POINTS FROM THE REVIEW OF RESEARCH ON FEEDING COWS BEFORE CALVING TO PREPARE FOR THE NEXT LACTATION

1. When cows have been given high-concentrate diets (i.e. at least 11 kg concentrates/cow/day) during early lactation, calving them with a condition score of 3.5 rather than 2.2 has reduced feed intake and increased weight loss during early lactation.
2. Cows with the higher condition score produce slightly less milk with a slightly higher fat content and a slightly lower protein content than that produced by the cows with the lower condition score at calving.
3. Cows which had a condition score greater than 3.5 or less than 2.0 at calving had poorer subsequent fertility and health than cows with a condition score between 2.0 and 3.5 at calving.
4. Taken together, these findings indicate that for cows which are given high-concentrate diets during early lactation, aiming for a condition score as near as possible to 2.5 at calving should maximise profitability.
5. When cows given high-forage diets (i.e. less than 7.5 kg of concentrates/cow/day) during early lactation had a condition score of 3.4 at calving they produced 2 kg more milk/cow/day with a higher fat plus protein content, than cows with a condition score of 2.8 at calving.
6. Cows with a condition score of less than 2 at calving, and in one experiment cows with a condition score of less than 3 at calving, had poorer subsequent fertility than cows with a condition score of 3 to 3.5 at calving.
7. Taken together, these findings indicate that for cows which are on grass-based systems of dairying, and given high-forage/low-concentrate diets during early lactation, aiming for a condition score of 3 to 3.5 at calving should maximise profitability.
8. With medium-energy diets (i.e. 8 to 10 kg concentrates/cow/day) the optimum condition score at calving has been within the range 2.5 – 3.0.

TABLE 3 TARGET BODY CONDITION SCORES FOR COWS AT CALVING

FEEDING LEVEL AFTER CALVING (KG CONCENTRATES/COW/DAY)	TARGET CONDITION SCORE AT CALVING
LOW less than 7.5	3.0 - 3.5
MEDIUM 8.0 -10.0	2.5 - 3.0
HIGH greater than 11	2.5

CHAPTER 2

THE EFFECTS OF THE TYPE OF DIET OFFERED DURING THE DRY PERIOD ON THE SUBSEQUENT PERFORMANCE, HEALTH AND FERTILITY OF DAIRY COWS

Recent debate regarding the most appropriate type of diet for dry cows has included the effects of the protein content of the diet, the inclusion of straw in the diet and mineral and vitamin supplementation of the diet.

The effects of protein supplementation during the dry period on subsequent performance and fertility

In pregnant cows a high proportion of the growth of the calf takes place during the last two months of pregnancy, which normally corresponds to the dry period in dairy cows. This creates a considerable demand for protein above the maintenance requirements of the cow. Consequently feeding a diet which is deficient in protein during the dry period requires the cow to mobilise body protein reserves to support the growth of the calf. This may reduce the availability of body protein stores to support milk production and reproduction during the next lactation. Several experiments have been conducted to examine the effects of offering cows a protein supplement during the dry period on subsequent milk production, health and fertility.

The results of 11 of these experiments which were undertaken in the UK and Ireland by Moorby and others (1996); Dewhurst and others (1996); Mayne (1997); Murphy (1999) and Dewhurst and others (2000), in Finland by Tesfa and others (1999) and in the United States by Van Saun and others (1993; Santos and others (2001) and Park and others (2002) are presented in Table 4. In most of the experiments a source of protein with a relatively low degradability in the rumen was used, including fish meal, animal protein and maize gluten meal. Maize gluten meal is also referred to as prairie meal and is a very different product from maize gluten feed which is readily available and is frequently fed in reasonably large quantities to cattle in Northern Ireland. Unlike maize gluten feed prairie meal normally has a high protein content of around 60%, which has a low degradability in the rumen. The diets which the cows were given without the protein supplement contained around 14.5% crude protein on average, but three of them used in the experiments undertaken by Van Saun and others (1993), Tesfa and others (1999) and Santos and others (2001) contained only about 12.6% protein, while the lower protein diet used by Park and others (2002) contained only 9.7% protein. The length of period during the next lactation when milk yield was recorded varied between experiments from only about the first eight weeks to the complete 305-day lactation.

On average over the 11 experiments, cows which were given a protein supplement in addition to a silage-based diet during the dry period produced 0.8 kg/day more milk with slightly higher fat and protein contents than that produced by the cows which received no protein supplement.

However it is important to note that the results of the 11 experiments were inconsistent. There was a substantial

TABLE 4 THE EFFECTS OF OFFERING DAIRY COWS A PROTEIN SUPPLEMENT DURING THE DRY PERIOD ON PERFORMANCE DURING EARLY LACTATION. (AVERAGE RESULTS OF 11 EXPERIMENTS)

	DIET DURING THE PERIOD	
	NO PROTEIN SUPPLEMENT	INCLUDING PROTEIN SUPPLEMENT
Body condition score at calving*	18.6	18.8
Average recording period (days of lactation)	28.0	28.8
Total dry matter intake (kg/cow/day)	3.90	3.92
Milk yield (kg/cow/day)	3.06	3.10

Note: Responses to offering a protein supplement during the dry period were very variable across experiments. On average over seven of the eleven experiments, offering a protein supplement before calving did not affect milk yield or milk protein or fat contents.

increase in milk yield as a result of offering a protein supplement in only three of the 11 experiments (those undertaken by Moorby and others (1996), Tesfa and others (1999) and Park and others (2002)), while there was a substantial increase in milk fat and protein contents in one other experiment (Moorby and others, 1996). However on average over the other seven experiments, offering a protein supplement did not produce a response in milk yield.

In the first experiment undertaken by Moorby and others in which protein supplementation increased milk fat and protein contents, the cows were offered a very wet (15% dry matter) poorly preserved (22% of nitrogen as ammonia) silage which would appear to have resulted in a very low silage intake. Consequently the cows lost one unit of body condition between the start of the dry period and just after calving. This large loss of body condition during the dry period is in contrast to the conclusions drawn from the research findings discussed in the previous chapter, that cows should not lose a substantial amount of body condition during the dry period, even if they are overfat at the start of the dry period, because this may increase the incidence of metabolic diseases (Gearhart and others 1990; Nocek, 1995). If this situation arose on a commercial farm, in which the silage offered during the dry period was so poor that the cows were losing a substantial amount of body condition, then they should be given a significant amount of concentrates to prevent this substantial loss of condition during the dry period.

In the second experiment undertaken by Moorby and others in which a protein supplement during the dry period increased milk yield by 2.1 kg/day during early lactation, the cows given the protein supplement had a substantially lower condition score, than those given no protein supplement, even at the beginning of the experiment. The higher body condition score of the cows which were given no protein supplement is likely to have contributed to the lower food intake and lower milk yield of these cows during early lactation than of those given a protein supplement during the dry period.

In the experiment undertaken by Tesfa and others the cows were given three levels of feed intake each either without or with a protein supplement during the dry period. During early lactation all of the cows were given a diet which contained only 13.7% protein.

Consequently it would appear that the cows in this experiment gave a large response in milk yield to protein supplementation during the dry period, because they were given a diet which was deficient in protein during early lactation. Consequently cows which were given extra protein during the dry period were able to mobilise the extra body protein which they had stored at that stage to support milk production during early lactation. Cows which had been on the highest level of feeding before calving, and so were the fattest at calving, gave a much larger response in milk yield to protein supplementation before calving. It is likely that these cows had a lower feed intake in early lactation because they were fat and so they produced a lower yield of milk with a high fat content because the diet given during early lactation was deficient in protein. The cows which were given the protein supplement during the dry period were able to sustain a higher yield of milk with a lower fat content because they were able to utilize the extra body protein which had been stored during the dry period.

However on commercial farms, it is likely to be more efficient, and much more convenient, to ensure that cows have an adequate supply of protein during early lactation rather than having the additional work of feeding concentrates to cows during the dry period and hoping that they will store the protein as body protein which can be utilized during early lactation.

In the experiment undertaken in the United States by Park and others (2002) high yielding Holstein cows were given diets containing 9.7, 11.7, 13.7, 14.7 or 16.2% protein during the dry period. Increasing the protein content of the diet given before calving from 9.7 to 13.7% increased the milk yield of mature cows during the subsequent 305-day lactation from 10,170 to 11,198 kg. However further increases in the protein content of the diet before calving to 16.2% reduced milk yield during the next lactation from 11,198 to 9,725 kg. The results of this experiment would indicate that for high yielding dairy cows, providing a diet containing 13 to 14% protein during the dry period is most appropriate as it should maximise milk yields and profitability during the next lactation.

In a further experiment undertaken in the United States by Robinson and others (2001), increasing the protein content of the diet offered during the last few days before calving, from 11.7 to 14.4% tended to increase the subsequent milk yield of heifers which produced over 10,000 kg in their first lactation, but did not increase the subsequent milk yield of mature cows which produced around 12,000 kg per lactation.

There would appear to be little experimental information on the effects of giving dairy cows extra protein during the dry period on health and fertility. In two experiments in the United States, Van Saun and others (1993) and Santes and others (2001) found that increasing the protein content of the diet during the dry period from about 12.6% to 15% did not affect the subsequent fertility of the cows. In their experiment, Santos and others used over 100 Holstein cows with a projected mature cow milk yield of over 10,000 kg in 305 days. However, Chew and others (1984) compared a very low protein diet, containing only about 9% protein with a high protein diet. In this case, feeding the very low protein diet during the dry period reduced milk yield during the first 200 days of the next lactation by 4.6 kg/day or a total of 927 kg/cow. Feeding the low protein diet during the dry period also tended to reduce reproductive efficiency, but otherwise did not affect the health of the cows.

From the results of the experiments which have been undertaken to examine the effects of giving cows a protein supplement during the dry period, it can be concluded that **when cows are given reasonable quality grass silage containing at least 13% crude protein or are at pasture during the dry period there is unlikely to be a benefit from giving them a protein supplement, providing they are given adequate protein during early lactation. However if dry cows are given silage with a protein content of less than 12%, then it may well be beneficial to give them sufficient quantity of a protein supplement to bring the protein content of the diet up to 13 to 14%.** If dry cows are given poor silage which results in a low intake and the cows are loosing body condition during the dry period, then they should be given sufficient concentrates to prevent this loss of condition.

The effects of including bulky feeds such as straw in the diet during the dry period

It has been suggested that the inclusion of straw in the diet of dry cows can stimulate the rumen and consequently increase feed intake during early lactation. Consequently three experiments, one in Scotland (Dewhurst and others 2000) and two at Moorepark Research Centre (Murphy 1999; McNamara and others 2000) have been undertaken to examine the effects of including straw in the diet of dry cows. The proportion of straw in silage-based diets varied from 20 to 40% of total dry matter intake. On average over the three experiments, the cows which were given straw as part of their diet during the dry period had a lower feed intake during the dry period, and produced 0.5 kg/day less milk with slightly lower fat and protein contents during early lactation, than cows which were given only silage during the dry period. **These results indicate that there is unlikely to be a benefit in terms of feed intake, milk yield or milk fat or protein contents from including straw in silage-based diets for dairy cows during the dry period.**

Effects of mineral and vitamin supplementation during the dry period

Although energy and protein are the two main components of dairy cow rations, ensuring that cows have the correct intake of minerals and vitamins during the dry period can have very important effects on the health and fertility of cows during early lactation. The recent increase in the number of bacteria which are capable of causing serious infectious diseases in humans and farm animals, and which are now also resistant to antibiotics, has created renewed emphasis on the need to reduce the use of antibiotics in farm animals. This in turn has greatly increased the importance of effective strategies on farms to prevent the occurrence of diseases and so minimise the use of drugs to cure diseases.

Recent research has shown that several minerals and vitamins have a crucial role in maintaining the immune system of cattle and hence their resistance to infectious diseases. For example, selenium, Vitamin E, ß-carotene, zinc, copper and manganese have all been found to be involved in achieving good immunity to disease (Mowat, 1993).

Consequently, Harrison and others (1984) found that giving cows additional selenium and Vitamin E during the dry period reduced the incidence of retained placenta from 17% of cows to zero, reduced the occurrence of cystic ovaries by over 60% and the occurrence of metritis by over 30%. Julian and others (1976a and 1976b) also found that supplementation with selenium and vitamin E greatly reduced the incidence of retained placenta in cows which were deficient in selenium. Ferguson (1996) reported that giving cows additional selenium and vitamin E reduced the incidence of retained placenta, the incidence of cystic ovarian disease and improved subsequent conception rate, while Keady and McCoy (2001) reviewed research findings which showed that giving cows a vitamin E supplement improved reproductive performance.

Smith and others (1984) found that providing extra selenium and vitamin E during the dry period, reduced the incidence of mastitis by 37%, and also reduced the duration of clinical symptoms when infection did occur so that the incidence of clinical mastitis times the duration of clinical symptoms for each infection was reduced by over 60%. Keady and McCoy (2001) also reported that giving cows extra vitamin E during the dry period could reduce the incidence of mastitis. Spain (1993) reported that providing dairy cows with supplementary zinc was associated with lower somatic cell counts in their milk, and that organically bound zinc was more effective in reducing the incidence of mastitis than inorganic zinc. Mowat (1993) reported that supplementing the diet with organically bound chromium may also be beneficial in reducing susceptibility to disease during periods of stress.

In a recent study at Glasgow University, Hemingway and others (2000) gave cows at the time of drying off two boluses containing selenium, copper, cobalt, iodine, manganese, zinc and vitamins A, D and E. The cows which were given the boluses had much lower somatic cell counts and required less treatment for mastitis with antibiotics than the cows which were not given a mineral and vitamin bolus as shown in Table 5.

Hurley and Doane (1989) reviewed research findings on the effects of minerals and vitamins on fertility in cattle and reported that deficiencies in copper, zinc, cobalt or iodine or vitamins A or D can cause poor reproductive performance. The results of research undertaken in Northern Ireland by Smyth and others (1996) have indicated that a high incidence of stillbirths and weak newborn calves is associated with low concentrations of selenium and iodine in the calves. Colostrum is the main source of the fat-soluble vitamins A, D and E for the newborn calf and so it is important that cows have an adequate intake of these vitamins before calving to ensure that there are sufficiently high concentrations of them in the colostrum to give the calf an initial boost (Keady and McCoy 2001).

Providing the correct balance of minerals and vitamins during the dry period has also been found to be extremely important in controlling the incidence of milk fever in dairy cows. Milk fever is caused by a low concentration of calcium in the blood, because the production of colostrum creates a very high demand for calcium at a time when cows have become accustomed to a much lower demand for calcium during the dry period.

High intakes of potassium and sodium have been found to increase the incidence of milk fever (Horst and others, 1997). Unfortunately, grass and grass silage from highly fertilized swards tend to have a high potassium content, and a high potassium content in forage has now been closely linked to the occurrence of milk fever in dairy cows (Horst and others, 1997). High intakes of phosphate have also been found to interfere with the absorption of

TABLE 5 THE EFFECT OF GIVING COWS MINERAL AND VITAMIN BOLUSES AT THE BEGINNING OF THE DRY PERIOD

	MINERAL AND VITAMIN BOLUSES	
	2 BOLUSES PER COW	NO BOLUS
Somatic cell count during first month of next lactation	97,000	220,000
Percentage of cows treated with an antibiotic	14	33

calcium and hence to increase the incidence of milk fever.

On the other hand, vitamin D is involved in minimising the incidence of milk fever (Horst and others, 1997). High intakes of magnesium during the dry period have been found to dramatically reduce the incidence of milk fever in cows which were receiving a diet with a high content of potassium (Van Mosel and others, undated).

On the basis of these research findings, mineral and vitamin supplements given to dairy cows during the dry period should not contain any potassium or phosphorus (phosphates) but should have a high content of magnesium and appropriate contents of copper, zinc, cobalt, selenium, manganese, iodine and vitamins A, D and E. Providing the correct amounts of each of these minerals and vitamins is essential because an excessive intake of one mineral can reduce the absorption and/or utilization of another mineral by the cow which can result in deficiency symptoms for that mineral.

In herds with a high incidence of milk fever, consideration should be given to providing specifically for dry cows, grass or silage which has a lower potassium content than other grass produced on the farm, by applying a very low or zero level of potash fertilizer to the swards which provide the grass or silage for feeding to the cows during the dry period. Consideration should also be given to feeding additional magnesium to cows during the dry period in these herds.

SUMMARY OF THE MAIN POINTS FROM THE REVIEW OF RESEARCH ON THE MOST APPROPRIATE TYPE OF DIET FOR DRY COWS

1. When cows are given reasonable quality silage containing at least 13% crude protein or are at pasture during the dry period there is unlikely to be a benefit from giving them a protein supplement, providing that they are given adequate protein during early lactation.
2. If dry cows are given silage containing less than 12% protein it may well be beneficial to give them a sufficient quantity of a protein supplement to bring the protein content of the diet up to 13 to 14%.
3. If dry cows are given bad silage which results in a low intake so that the cows are loosing body condition during the dry period, giving them sufficient concentrates to prevent this loss of condition is likely to be economically advantageous.
4. Including straw in the diet of dry cows did not improve subsequent performance.
5. Ensuring that dry cows have adequate and balanced intakes of minerals and vitamins during the dry period can result in substantial improvements in health during early lactation.

CHAPTER 3

USING OPTIMUM LEVELS OF CONCENTRATE FEEDING TO REDUCE THE COSTS OF MILK PRODUCTION

High quality grass silage or maize silage have considerable potential for milk production, but even the best silage is capable of sustaining only a limited yield of milk during the winter months, generally around 20 kg/cow/day. Consequently, in view of the increase in the genetic merit of dairy cows in the UK and Ireland over the past few years it is now generally necessary to supplement silage with substantial amounts of concentrates for cows which are in early lactation during the winter months. The optimum input of concentrates is determined largely by the genetic merit of the cow for milk production and by the quality of the silage which is available over the winter.

The effect of the genetic merit of cows for milk production on the response to level of concentrate feeding

The results of a number of experiments carried out at Hillsborough and at Moorepark Research Centre have clearly shown that cows of high genetic merit for milk production give a much greater response in milk yield to additional concentrates than cows of medium genetic merit. For example, in a recent experiment at Hillsborough, Holstein cows of medium and high genetic merit were offered high quality grass silage and four different levels of concentrate supplementation during the first 84 days of lactation (Ferris and others, 1999). The results of this experiment are summarised in Table 6. Concentrate feed levels, which were fed as part of a complete diet, ranged from 7.8 to 18.4 kg/cow/day. The high genetic merit cows had an average Predicted Transmitting Ability (PTA2000) for milk of 255 kg, and an average PTA2000 for fat plus protein of 24.7 kg.

The medium genetic merit cows had an average PTA2000 for milk of minus 303 kg, and an average PTA2000 for fat plus protein of minus 17.6 kg.

The cows were turned out to pasture at the end of the 84-day winter feeding period. Milk yields were recorded for a further 98-day period at pasture as the winter feeding treatments continued to affect the milk yield of the high genetic merit cows during this period. When concentrate input was increased from the lowest to the highest level, an increase of approximately 10 kg/cow/day, silage dry matter intake was reduced by about 5 kg/cow/day, or 0.5 kg silage dry matter/kg increase in concentrate intake. Also, across the full range of concentrate inputs, the milk yield of the high genetic merit cows during the winter feeding period increased by 0.40 kg for each kg increase in concentrate intake, while the yield of the medium genetic cows increased by 0.36 kg per kg increase in concentrate intake, the response with the high genetic merit cows being 11% greater than that with the medium merit cows. However at the highest level of concentrate feeding, which was exceptionally high, there was a major depression in milk fat content and so the yield of fat plus protein at the highest level of concentrate feeding was actually lower than at the second highest concentrate input with both types of cows. Furthermore the high genetic merit cows which were given the highest input of concentrates during the first 84 days of the lactation, continued to produce slightly more milk after they were at pasture than those which had received less concentrates previously, even though the cows on all of the treatments were on the same diet at this stage.

On the other hand, the medium genetic merit cows which had been given more concentrates during the winter did not produce more milk after they had been turned out to pasture than those which had a lower concentrate intake during the winter. Consequently the total response in milk yield over the 84-day winter period and the first 98 days at pasture when concentrate intake was increased from 8 to 18 kg/cow/day during the winter, was 0.67 kg of milk/kg additional concentrates for the high genetic merit cows, and 0.40 kg of milk/kg additional concentrates for the medium genetic merit cows. Thus the overall response in milk yield to feeding the higher level of concentrates during the first 84 days of lactation was 68% greater for the high merit cows than for the medium merit cows. Furthermore, in terms of fat plus protein yield, the difference in the magnitude of the responses to additional concentrates between the medium and high genetic merit cows was even greater than the difference for milk yield.

Similarly, in a further experiment undertaken at Hillsborough by Keady and Mayne (2002), in which Holstein and Norwegian Red cows were given low and high inputs of concentrates, the response in milk yield to additional concentrates was much greater with the Holstein cows than with the Norwegian Red cows. Over the past 30 years the Norwegian cows have been selected for better health and fertility as well as for higher

TABLE 6 THE EFFECT OF CONCENTRATE FEED LEVEL ON THE YIELD AND COMPOSITION OF MILK FROM MEDIUM AND HIGH GENETIC MERIT HOLSTEIN COWS

	CONCENTRATE INTAKE (KG/DAY)			
High merit cows	8.5	12.1	15.5	18.2
Medium merit cows	7.8	10.9	14.8	18.4
SILAGE DRY MATTER INTAKE (KG/DAY)				
High merit cows	12.4	11.3	9.3	6.8
Medium merit cows	11.4	10.1	8.8	6.7
MILK YIELD DURING 84-DAY WINTER FEEDING PERIOD (KG/DAY)				
High merit cows	35.4	35.6	37.9	39.2
Medium merit cows	31.5	31.0	34.1	35.2
BUTTERFAT CONTENT (%)				
High merit cows	4.20	4.10	4.02	3.94
Medium merit cows	4.11	3.93	3.84	3.59
PROTEIN CONTENT (%)				
High merit cows	3.23	3.30	3.38	3.35
Medium merit cows	3.10	3.28	3.34	3.30
TOTAL MILK YIELD FOR 182-DAY WINTER AND PASTURE PERIODS (KG)				
High merit cows	6032	6055	6281	6565
Medium merit cows	5335	5180	5537	5679

milk yield, while the Holsteins have been selected almost exclusively for higher production, and consequently they now have much higher genetic potential for milk production than the Norwegian cows. The Holstein cows had a PIN2000 of £44 while the Norwegian Red cows had a total merit index of 10.1. In this experiment the response in milk yield per kg of additional concentrates consumed by the cows with the high concentrate intake compared to those with the low intake of concentrates was 58% greater with the Holstein cows than with the Norwegian cows.

In an experiment at Moorepark Research Centre (Dillon and Kennedy, 1999) cows of high and medium genetic merit were given three concentrate inputs, the highest concentrate intake being one tonne per cow more than the lowest input. In this case the response in milk yield to the additional tonne of concentrates was over 50% greater with the high merit cows than with the medium merit cows.

The results of these experiments at Hillsborough and Moorepark clearly show that the response in milk yield to additional concentrates is substantially greater with high genetic merit cows than with medium genetic merit cows. Consequently, the optimum input of concentrates from both nutritional and economic perspectives is likely to be substantially higher for high genetic merit than for the medium merit cows.

The results of the research at Hillsborough which are presented in Table 4 also clearly demonstrate the extra potential for milk production which cows of high genetic merit have compared to those of medium genetic merit. On average over the first six months of lactation the high genetic merit cows produced 4.4 kg/day or 15% more milk than the medium genetic merit cows. The high genetic merit cows consumed 1.2 kg/day or 6% more dry matter than the medium merit cows but they were also slightly bigger than the medium cows and so would have required slightly more food energy for maintenance than the medium merit cows. Consequently the extra feed which the high merit cows consumed, compared to the medium merit cows, was sufficient to produce only about a third of the extra 4.4 kg/day of milk. This may appear to indicate that the high merit cows converted food energy and protein to milk more efficiently than the medium merit cows. However the high and medium genetic merit cows actually utilize feed energy and convert it to milk with the same efficiency as the cows of lower genetic merit (Ferris and others, 1999b).

The extra milk produced by high merit cows is produced either from energy which they mobilise from their body fat reserves or else they partition more of the feed energy to milk production and less to live-weight gain than cows of lower genetic merit. In either case, when they are given the same diet, high merit cows have always been in poorer body condition after early lactation than medium merit cows. This has been confirmed in experiments at Hillsborough in which high merit cows lost about half a unit more body condition during early lactation than the medium merit cows. If the higher milk yield of high merit cows is to be sustained in the long term, then this loss of body condition during early lactation must be avoided by providing a more nutrient dense diet in early lactation or alternatively accepting a higher condition loss in early lactation but replenishing condition later by giving high merit cows more feed during late lactation and/or the dry period.

High merit cows have been found to consume about 6% more feed than medium merit cows when given the same diet. This is partly because they are bigger than the more traditional medium merit cows and partly because their higher milk yield generates a greater hunger drive to consume more feed. In experiments at Hillsborough, high merit cows have been 50-60 kg heavier than medium merit cows and consequently have required about 7% more feed for maintenance of body functions than medium merit cows. Cows with higher milk yields also have been found to have poorer fertility and may also be more susceptible to health problems than cows with lower milk yields as discussed in Chapter 13. This factor needs to be taken into account when the advantages of high genetic merit cows are being considered.

Effect of level of concentrate feeding for cows of medium genetic merit

As dairy cows in Northern Ireland are normally housed for 4 to 7 months of the year, depending on location and climate, feed costs during this period represent a large proportion of total feed costs for the year, and indeed a major proportion of the total annual costs of milk production. The quantity of concentrates given to autumn- and winter-calving dairy cows during this indoor period can have a major effect on the overall profitability of milk production during the winter months, because the intake of concentrates affects silage intake, milk yield and milk composition and may also affect the health and fertility of the cows. The results of over 30 experiments which have been carried out to examine the effects of giving dairy cows of medium genetic merit different quantities of concentrates in addition to silage offered ad libitum are summarised in Tables 7 to 10. Eight of these experiments were carried out at Hillsborough and the remainder were undertaken in Great Britain, Moorepark Research Centre, in several European countries and in the United States and Canada. The cows used in these experiments produced around 5000 to 7000 kg of milk per 305-day lactation with an average yield of about 6000 kg.

It is important to note that there is a large variation between experiments in the magnitude of the response in milk yield to additional concentrates. Several factors may contribute to this variation including the chemical composition of the silage and concentrates which can influence the effect which offering additional concentrates has on silage intake, the yield potential of the cows, the management of the cows and the conditions and system under which they are housed and fed. Consequently, it is vitally important to take a broad overview of the results of a large number of experiments which have been carried out under different conditions in order to obtain a good

TABLE 7 THE EFFECT OF GIVING DAIRY COWS OF MEDIUM GENETIC MERIT LOW OR MODERATE LEVELS OF CONCENTRATE FEEDING DURING EARLY TO MID LACTATION WHEN THEY WERE GIVEN HIGH DIGESTIBILITY SILAGE.
(AVERAGE RESULTS OF 15 EXPERIMENTS; THE D-VALUES OF THE SILAGES USED IN THESE EXPERIMENTS RANGED FROM 68 TO 76% WITH AN AVERAGE D-VALUE OF 71%)

	EFFECT OF INCREASING AVERAGE CONCENTRATE INTAKE FROM 3.5 TO 7.2 KG/COW/DAY
Milk yield	Increased by 3.5 kg/cow/day
Milk yield	Increased by 0.96 kg/kg extra concentrates
Milk protein content	Increased by 0.16%
Milk fat content	Reduced by 0.01%

overall picture of what is likely to be applicable in a wide range of farm situations. Concentrating on the results of only one experiment may give a very specific result which is only applicable to the specific circumstances under which that experiment was carried out.

The results of the experiments have been divided into those in which the cows were given reasonably high or high digestibility silage and those in which the cows were given medium to low digestibility silage.

The results of experiments in which cows were given low or moderate levels of concentrate feeding in addition to reasonably high or high digestibility silage are summarised in Table 7, while the results for cows given moderate or high levels of concentrate feeding in addition to good silage are summarised in Table 8. These experiments were undertaken by Everson and others (1976); Steen and Gordon (1980b); Bertilsson and Burstedt (1983); Gordon (1984); Mayne and Gordon (1985); Phipps and others (1987a); Poole (1987); Clements and others (1989); Mayne (1989); Gordon and Small (1990); Faverdin and others (1991); Mayne (1992a); Smith and others (1993); Aston and others (1994a and 1995); Sutton and others (1994); Agnew and others (1996); Ferris and others (1999a) and McNamara and others (2000). The D-value of the silages used in these experiments ranged from 68 to 76% with a mean value of 71% for the experiments which are listed in both Tables 7 and 8.

On average over the 15 experiments which are summarised in Table 7, the low level of concentrate feeding was 3.5 kg/cow/day while the moderate level was 7.2 kg/cow/day. Although there was considerable variation in the size of the response in milk yield to feeding extra concentrates in the different experiments, on average increasing concentrate intake from 3.5 to 7.2 kg/cow/day increased milk yield by 3.5 kg/cow/day or 0.96 kg for each kg increase in concentrate intake. Increasing concentrate intake had no consistent effect on milk butterfat content but increased protein content by 0.16%.

For each kg increase in concentrate intake in the experiments listed in Tables 7 to 10, the cows consumed about 0.34 kg less silage dry matter. If the cost of concentrates, including all the costs of storage and feeding, is taken as £153/tonne and the cost of silage dry matter as £105/tonne, on the basis of the costings given in Table 28 in Chapter 9, then each kg increase in concentrate intake costs 15.3 pence minus 3.6 p (for the saving in silage) or a net cost of 11.7 p. If the price of milk is taken as 18 p/litre then a response of 0.67 kg of milk is needed to cover the cost of increasing concentrate intake by one kg. In addition each 0.1% increase in milk protein content is valued at 0.32 p/litre while each 0.1% increase in milk fat content is valued at 0.18 p/litre.

In the experiments listed in Table 7, the value of the extra milk plus the increase in milk protein content, produced by increasing concentrate intake from 3.5 to 7.2 kg/day was £117/cow over a 160 day winter period while the cost of the extra feed required to produce it was £71, so in this case increasing concentrate intake from 3.5 to 7.2 kg/day produced a good economic response and increased profitability per cow by about £48 over a 160 day winter period.

The effects of further increasing concentrate intake from 7.1 to 10.5 kg/cow/day for cows given good quality silage are summarised in Table 8. On average over the 12 experiments listed, increasing concentrate intake from 7.1 to 10.5 kg/cow/day produced a very small response in milk yield of only 0.21 kg per kg increase in concentrate intake. In this case increasing concentrate intake reduced milk fat content by 0.08% but increased protein content by 0.10%. In this case the value of the extra milk and the change in milk composition produced by increasing concentrate intake from 7.1 to 10.5 kg was less than half of the cost of the extra feed required to produce it (i.e. £27/cow compared to a cost of £64/cow over 160 days).

Consequently, taken together the results of the 27 comparisons which are summarised in Tables 7 and 8 clearly show that the optimum intake of concentrates for medium genetic merit cows given good quality silage ad libitum is around 7.0 kg/cow/day. The fact that the response in milk yield when concentrate intake was increased up to this level was high and very economical, while the response to increasing concentrate intake above this level was very low and totally uneconomical, means that even a substantial change in the ratio of the prices of concentrates and milk would not change this optimum level of feeding.

Therefore, on the basis of the research results given in Tables 7 and 8, over a relatively wide range of concentrate to milk price ratios, the most economical level of concentrate feeding for medium genetic merit cows given good quality silage was 7 kg/cow/day.

The results of 15 experiments in which medium genetic merit cows were given low or moderate levels of concentrate feeding in addition to medium to low quality silage are summarised in Table 9, while the results for cows given moderate to high levels of concentrates are summarised in Table 10.

These experiments were undertaken by Hernandez and others (1976); Gordon (1977); Steen and Gordon (1980a and 1980b); Castle and others (1980); Laird and others (1981); Holter and others (1982 and 1984); Mayne and Gordon (1984); Phipps and others (1984a, 1987a and 1988a); Moisey and Leaver (1985); Taylor and Leaver (1986); Thomas and others (1986); Coulon and others (1987 and 1996); Sabri and Roberts (1988); Fitzgerald and Murphy (1990); Rijpkema and others (1990); Weiss and Shockey (1991) and Aston and others (1994a and 1995).

The D-value of the silages used in these experiments ranged from 59 to 67% with a mean value of 63%. In this case, on average over 15 experiments, increasing concentrate intake from 4.0 to 7.3 kg/cow/day increased milk yield by 3.5 kg/cow/day or 1.07 kg/kg increase in concentrate intake, and reduced fat content slightly and increased protein content by 0.08%. This response in milk yield and composition is worth over $1\frac{1}{2}$ times the cost of the extra feed required to produce it, and so is a very economical response, which increased profitability by over £40/cow over a 160 day winter period.

The effects of further increasing the concentrate intake

TABLE 8 THE EFFECT OF GIVING DAIRY COWS OF MEDIUM GENETIC MERIT MODERATE OR HIGH LEVELS OF CONCENTRAT FEEDING DURING EARLY TO MID LACTATION WHEN THEY WERE GIVEN HIGH DIGESTIBILITY SILAGE. (AVERAGE RESULTS OF 12 EXPERIMENTS; THE D-VALUES OF THE SILAGES USED IN THESE EXPERIMENTS RANGED FROM 68 TO 76% WITH AN AVERAGE D-VALUE OF 71%)

	EFFECT OF INCREASING AVERAGE CONCENTRATE INTAKE FROM 7.1 TO 10.5KG/COW/DAY
Milk yield	Increased by 0.7 kg/cow/day
Milk yield	Increased by 0.21 kg/kg extra concentrates
Milk protein content	Increased by 0.10%
Milk fat content	Reduced by 0.08%

TABLE 9 THE EFFECT OF GIVING MEDIUM GENETIC MERIT COWS LOW OR MODERATE LEVELS OF CONCENTRATE FEEDING DURING EARLY TO MID LACTATION WHEN THEY WERE GIVEN MEDIUM DIGESTIBILITY SILAGE. (AVERAGE RESULTS OF 15 EXPERIMENTS; THE D-VALUE OF THE SILAGES USED IN THESE EXPERIMENTS RANGED FROM 60 TO 67% WITH AN AVERAGE D-VALUE OF 63%)

	EFFECT OF INCREASING AVERAGE CONCENTRATE INTAKE FROM 4.0 TO 7.3KG/COW/DAY
Milk yield	Increased by 3.5 kg/cow/day
Milk yield	Increased by 1.07 kg/kg extra concentrates
Milk protein content	Increased by 0.08%
Milk fat content	Reduced by 0.02%

TABLE 10 THE EFFECT OF GIVING MEDIUM GENETIC MERIT COWS MODERATE OR HIGH LEVELS OF CONCENTRATE FEEDING DURING EARLY TO MID LACTATION WHEN THEY WERE GIVEN MEDIUM DIGESTIBILITY SILAGE. (AVERAGE RESULTS OF 10 EXPERIMENTS; THE D-VALUE OF THE SILAGES USED IN THESE EXPERIMENTS RANGED FROM 59 TO 67% WITH AN AVERAGE D-VALUE OF 64%)

	EFFECT OF INCREASING AVERAGE CONCENTRATE INTAKE FROM 6.9 TO 10.3KG/COW/DAY
Milk yield	Increased by 2.6 kg/cow/day
Milk yield	Increased by 0.76 kg/kg extra concentrates
Milk protein content	Increased by 0.10%
Milk fat content	Reduced by 0.15%
	EFFECT OF INCREASING AVERAGE CONCENTRATE INTAKE FROM 9.7 TO 13.6G/COW/DAY
Milk yield	Increased by 0.4 kg/cow/day
Milk yield	Increased by 0.10 kg/kg extra concentrates
Milk protein content	Increased by 0.12%
Milk fat content	Reduced by 0.18%

of cows given medium to low quality silage are shown in Table 10. On average over 12 experiments, increasing concentrate intake from 6.9 to 10.3 kg/cow/day increased milk yield by 2.6 kg/cow/day or 0.76 kg/kg increase in concentrate intake and increased milk protein content by 0.10%, but reduced milk fat content by 0.15%.

In this case, the response in milk yield and protein content when concentrate intake was increased from 6.9 to 10.3 kg/cow/day was worth £75/cow over a 160 day winter period relative to a cost of £65 for the extra feed that was required to produce it.

On the other hand, in three of the experiments, the effect of further increasing concentrate intake from 9.7 to 13.6 kg/day was examined. In this case there was only a negligible increase in milk yield, while milk fat content was reduced by 0.18% and milk protein content was increased by 0.12%. Therefore in this case there was no increase in the value of the milk produced when concentrate intake was increased from 9.7 to 13.6 kg/cow/day and so the cost of the extra feed was almost entirely wasted.

Consequently, taken together, the results of the experiments which are summarised in Tables 9 and 10 would indicate that the optimum intake of concentrates for cows of medium genetic merit given medium to low quality silage was about 10 kg/cow/day. However as the value of the milk produced when concentrate intake was increased from 6.9 to 10.3 kg/cow/day was only slightly more than the cost of the feed required to produce it, if the price of milk were to fall and/or the price of concentrates were to increase substantially, then the optimum concentrate intake for cows given medium to low quality silage may decline slightly to 8 to 9 kg/cow/day.

The effects of feeding different amounts of concentrates on the health and reproductive performance of the cows were reported in only about one third of the experiments listed in Tables 7 to 10. It was reported that in two experiments cows given a high level of concentrate feeding had more mastitis than cows given a moderate input of concentrates, while in four of the experiments cows given high inputs of concentrates had more disease in general than cows given a moderate amount of concentrates.

In one experiment, feeding a low level (3 kg/cow/day) of concentrates with very high contents of protein and fat was associated with a high incidence of ketosis, while in two other experiments the level of concentrate feeding had no effect on the health of the cows. The level of concentrate feeding did not affect the reproductive performance of the cows in three of the experiments while no information was found on the effects of the level of concentrate feeding on reproductive performance in the other experiments.

On the basis of the overall results of the experiments listed in Tables 7 to 10, giving medium genetic merit cows a moderate level of concentrate feeding during early lactation, (i.e. 7 kg/cow/day with good quality silage and 10 kg/cow/day with medium to poor quality silage) maximised profitability, not only in terms of the value of the milk produced, but also in terms of the long-term health of the cows.

Effects of level of concentrate feeding for cows of high genetic merit

There is much less information available in the UK and

TABLE 11 THE EFFECT OF GIVING HIGH GENETIC MERIT COWS LOW, MODERATE OR HIGH LEVELS OF CONCENTRATE FEEDING WHEN THEY WERE GIVEN HIGH QUALITY SILAGE.(AVERAGE RESULTS OF SIX EXPERIMENTS; THE D-VALUES OF THE SILAGES USED IN THESE EXPERIMENTS RANGED FROM 70 TO 76% WITH AN AVERAGE D-VALUE OF 73%)

	EFFECT OF INCREASING AVERAGE CONCENTRATE INTAKE FROM 2.8 TO 8.2KG/COW/DAY
Milk yield	Increased by 6.0 kg/cow/day
Milk yield	Increased by 1.12 kg/kg extra concentrates
Milk protein content	Increased by 0.21%
Milk fat content	No Change
	EFFECT OF INCREASING AVERAGE CONCENTRATE INTAKE FROM 7.9 TO 13.0G/COW/DAY
Milk yield	Increased by 2.3 kg/cow/day
Milk yield	Increased by 0.45 kg/kg extra concentrates
Milk protein content	Increased by 0.13%
Milk fat content	Reduced by 0.07%

other European countries on the effects of concentrate feeding level for high yielding, high genetic merit cows than for cows of medium genetic merit. However a series of six experiments have been undertaken recently at Hillsborough by Ferris and others (1999a, 2001 and 2003); Keady and others (2002a and 2003) and Patterson and Carrick (2003), in which very high genetic merit Holstein cows were given different levels of concentrate feeding as supplements to silages of different quality. The results of eight comparisons involving high digestibility silages are summarised in Table 11. The D-value of the silages used in these experiments ranged from 70 to 76% with an average D-value of 73%, so these were very good quality silages. The cows involved in these experiments were also of very high genetic merit with a PIN2000 of around £45.

When concentrate intake in two of these experiments was increased from a very low level of under 3 kg/cow/day to 8.2 kg/cow/day the cows produced a very good response in milk yield of over one kg extra milk/kg of extra concentrates fed and there was also a major increase in milk protein content of 0.21%. On the basis of the costs given in Table 28, the value of the extra milk produced by the cows given the higher level of feeding was much greater than the cost of the extra feed required to produce it and so profitability was increased by over £100/cow over a 160 day winter period by feeding the higher level of concentrates.

When the concentrate intake of the cows given the high quality silage was further increased from 8 to 13 kg/cow/day, milk yield was increased by 0.47 kg for each extra kg of concentrates given to the cows and milk protein content was also increased by 0.13% as shown in Table 11. In this case the value of the extra milk produced when concentrate intake was increased from 8 to 13 kg/cow/day was £83/cow over a 160 day winter period, while the cost of the extra feed required to produce it was £96/cow (Table 27).

These findings would indicate that for these very high merit cows given high quality silage the most economical level of concentrate feeding was around 8 kg/cow/day. However as the value of the extra milk produced when the level of concentrate feeding was increased from 8 to 13 kg/cow/day was only 14% less than the cost of the extra feed required to produce it, if the price of milk increased substantially and/or the cost of concentrates was reduced significantly then the most economical level of concentrate feeding with this high quality silage may be somewhat higher at around 10 kg/cow/day, for very high genetic merit cows.

The results of five comparisons at Hillsborough in which very high genetic merit cows were given two levels of concentrate feeding in addition to medium quality silage are summarised in Table 12. These experiments were undertaken by Ferris and others (2001); Keady and others (2002a and 2003) and Keady and Mayne (2002). The D-value of the silages used in these experiments ranged from 65 to 68% with an average D-value of 66.5%. When the quantity of concentrates given with these silages was increased from 6.4 to 12.5 kg/cow/day, milk yield was increased by 0.85 kg/kg additional concentrates given, and milk protein content was also increased by 0.17%. In this case the value of the extra milk produced was over one and a half times the cost of the extra feed required to produce it. This increased profitability by about £60/cow

TABLE 12 THE EFFECT OF GIVING DAIRY COWS OF MEDIUM GENETIC MERIT MODERATE OR HIGH LEVELS OF CONCENTRATI FEEDING DURING EARLY TO MID LACTATION WHEN THEY WERE GIVEN HIGH DIGESTIBILITY SILAGE. (AVERAGE RESULTS OF 12 EXPERIMENTS; THE D-VALUES OF THE SILAGES USED IN THESE EXPERIMENTS RANGED FROM 68 TO 76% WITH AN AVERAGE D-VALUE OF 71%)

	EFFECT OF INCREASING AVERAGE CONCENTRATE INTAKE FROM 6.4 TO 12.5KG/COW/DAY
Milk yield	Increased by 5.2 kg/cow/day
Milk yield	Increased by 0.85 kg/kg extra concentrates
Milk protein content	Increased by 0.17%
Milk fat content	Reduced by 0.03%

over a 160 day winter feeding period and would indicate that the most profitable level of concentrate feeding for very high genetic merit cows given medium quality silage was at least 13 kg/cow/day.

There is little information on the effects of feeding more than 13 kg of concentrates/cow/day with medium quality silage. In the experiment carried out by Ferris and others (2001) cows consumed up to 21 kg of concentrates/cow/day. However when the cows were given 21 kg of concentrates, milk fat content was depressed by over 1.0 percent and milk protein content was also depressed slightly compared to the value obtained at a lower level of concentrate feeding. Consequently the cows which were given 21 kg of concentrates, actually produced a lower yield of milk fat plus protein than those given 16 kg of concentrates. Similarly when Ferris and others (2001) and Ferris and others (1999a) gave cows high quality silage supplemented with 18 to 19 kg of concentrates/cow/day, they produced a lower yield of fat plus protein than when they were given 13 to 15 kg of concentrates, because there was a major depression in milk fat content and a small depression in milk protein content at the highest level of concentrate feeding. In these experiments concentrates were fed as part of a complete diet and the input of 18 to 19 kg of concentrates represented 70% of the total dry matter intake.

The results of these experiments at Hillsborough and other research findings from the United States have shown that when the proportion of concentrates, especially concentrates with a high starch content, has been increased above 60 to 65% of total dry matter intake, there has been a major reduction in milk fat content and a slight reduction in protein content, and consequently the yield of fat plus protein has actually been reduced when the level of concentrate feeding was increased.

If it is assumed that high genetic merit cows given silage-based diets can consume about 20 to 22 kg of dry matter, then the upper limit of concentrate intake as part of a total mixed ration is around 15 to 16 kg/cow/day, if a major depression in milk fat content is to be avoided. From both a milk quality and a cow health perspective, the upper limit for concentrate intake is likely to be somewhat lower than this when the silage and concentrates are given separately.

Excessively high intakes of rapidly fermentable energy in concentrates, especially if the level of concentrate feeding is increased too rapidly after calving, can result in a high incidence of ketosis (acetonaemia) in dairy cows. There is also evidence that the over-rapid increase of concentrate intake plays a role in the development of sub-clinical laminitis in cows' feet (Howie, 1989). Leaver (1988) also reported from the findings of a number of experiments that high intakes of concentrates or high concentrate:silage ratios in the diet have been associated with lameness in dairy cows or have predisposed cows to an increased incidence of lameness.

There is little information on the effects of the level of concentrate feeding in the fertility of high genetic merit cows. In one study at Hillsborough, Ferris and others (2001b) found that high genetic merit cows given reasonable quality silage supplemented with 14 kg of concentrates/cow/day had a lower conception rate to first and second services than cows given a better quality silage supplemented with 5.5 kg concentrates/cow/day.

Consequently, until further research information is available, the information which is available to date, would indicate that the most profitable level of concentrate feeding for high genetic merit cows is likely to be 8 to 9 kg/cow/day for cows given high quality silage and 13 to 14 kg/cow/day for cows given medium quality silage.

SUMMARY OF THE MAIN POINTS FROM THE REVIEW OF RESEARCH ON THE OPTIMUM LEVELS OF CONCENTRATE FEEDING FOR DAIRY COWS

1. When medium genetic merit cows were given good quality silage with an average D-value of 71%, profitability was maximised when they were given 7 kg of concentrates /cow/day.
2. When medium genetic merit cows were given medium to poor quality silage with an average D-value of 63/64%, profitability was maximised when they were given 10 kg of concentrates/cow/day.
3. When very high genetic merit cows were given very good quality silage with a D-value of 74%, profitability was maximised when they were given 8 kg of concentrates/ cow/day.
4. When very high genetic merit cows were given medium quality silage with a D-value of 66%, profitability increased when concentrate intake was increased up to 13 kg/cow/day. The economic optimum input of concentrates was probably around 14 kg/cow/day.

TABLE 13 SUMMARY OF OPTIMUM LEVELS OF CONCENTRATE FEEDING FOR MEDIUM AND HIGH GENETIC MERIT COWS

	COW GENETIC MERIT			
	MEDIUM MERIT (PIN2000 £0-15)		HIGH MERIT (PIN2000 ABOVE £30)	
SILAGE QUALITY	LOW-MEDIUM	HIGH	MEDIUM	HIGH
D-value	63	71	66	73
Optimum level of concentrate feeding (kg/cow/day)	10	7	13-14	8

CHAPTER 4

THE EFFECT OF THE PROTEIN CONTENT IN CONCENTRATES FOR DAIRY COWS ON THE PROFITABILITY OF MILK PRODUCTION

Research has established that the protein in silage is not utilized by dairy cows as well as the protein in fresh grass or concentrates. Consequently even when cows in early lactation have been given silage with a relatively high protein content they have still responded to a relatively high protein content in concentrates.

A series of ten experiments have been carried out at Hillsborough by Gordon (1979); Gordon and McMurray (1979); Gordon (1980a and 1980b); Mayne and Gordon (1984 and 1985); Gordon and Peoples (1986); Gordon and Small (1990); Mayne (1989) and Peoples and Gordon (1989) and a further three experiments have been carried out in Great Britain by Fisher and others (1994) and Aston and others (1994b and 1998) to examine the effects of the protein content of concentrates given to dairy cows of medium genetic merit on milk yield and composition, and a further two experiments have been undertaken recently at Hillsborough by Patterson and Carrick (1995) using cows of high genetic merit.

On average over the 13 experiments with medium merit cows, the protein content of the lower protein concentrate was 13% while the protein content of the higher protein concentrate was 21%. The silages used in the 13 experiments ranged from a poor quality silage with a D-value of only 61% to a very high quality silage with a D-value of 77%. The average D-value of the silages used in the 13 experiments was 70% while the average protein content was 15.7%. These values are fairly close to the average values for silages made on dairy farms in Northern Ireland. The average level of concentrate feeding was 7.6 kg/cow/day which is close to the optimum level of feeding for medium merit cows, as discussed in the previous chapter.

On average over the 13 experiments, increasing the crude protein content of the concentrates from 13 to 21% increased milk yield by 1.6 kg/cow/day or 0.20 kg/percentage unit increase in concentrate crude protein content as shown in Table 14. Also milk fat content was reduced by 0.008% and milk protein content was increased by 0.014% for each percentage unit increase in concentrate crude protein content. Silage intake was also increased slightly by increasing the protein content of the concentrates.

Furthermore in three of the 13 experiments which involved four concentrates with a range of four protein contents between 10 and 21%, the response in milk yield for each percentage unit increase in protein content was fairly constant across the complete range from 10 to 21%. However in one of the experiments in which the protein content of the concentrates was increased above 21% there was little further increase in milk yield, and in fact when the protein content of the concentrates was increased above 24%, milk yield actually declined again.

For the purpose of calculating the economics of increasing concentrate protein content the price of milk is taken as 18 p/litre, the price of milled barley as £90/tonne and the price of soyabean meal as £162/tonne. Although dairy concentrates contain many other ingredients as well as barley and soyabean meal, a price of £90/tonne for a feedstuff containing 9 to 10% protein and £162/tonne for a feedstuff with a similar energy content and containing about 45% protein are a good guide to the relative costs of low and high protein concentrates. On the basis of these assumptions increasing the protein content of the concentrates in these experiments from 13 to 21%, would have cost £30/cow over a 160 day winter period while the value of the extra milk produced was £55/cow.

Therefore on the basis of the results of this extensive series of experiments, in terms of the costs of feed inputs and the value of the milk produced there was a significant economic advantage to be gained by feeding medium genetic merit cows a concentrate containing 21% protein rather than a concentrate with a lower protein content.

In one of the two experiments at Hillsborough involving high genetic merit Holstein cows, Patterson and Carrick (2003) offered the cows 11.5 kg of concentrates/cow/day containing six different protein contents ranging from 14 to 30% while in the second experiment they were again given 11.5 kg of concentrates/cow/day containing either 15 or 22% crude protein. The silage used in the first experiment contained 16% protein and was of reasonable quality with a D-value of 70%, while that used in the second experiment contained 17% protein and had a D-value of 68%.

On average over these two experiments increasing the protein content of the concentrates from 14 to 21% increased milk yield by 0.12 kg per percentage unit

TABLE 14 THE EFFECT OF INCREASING THE PROTEIN CONTENT OF CONCENTRATES GIVEN TO MEDIUM GENETIC MERIT DAIRY COWS ON MILK YIELD AND COMPOSITION. (AVERAGE RESULTS OF 13 EXPERIMENTS)

	RESPONSE TO INCREASING AVERAGE PROTEIN CONTENT OF CONCENTRATES FROM 13 TO 21%
Milk yield	Increased by 1.6kg/cow/day
Milk protein content	Increased by 0.11%
Milk fat content	Increased by 0.06%

increase in crude protein content but did not affect milk composition.

On the basis of the assumptions used above, increasing the crude protein content of the concentrates given to high genetic merit cows in these experiments from 14 to 21% increased feed costs over a 160 day winter period by £35/cow while the value of the extra milk produced was £24. As there was little response in milk yield in the first experiment when the protein content of the concentrates was increased above 21%, the optimum protein content, for the high genetic merit cows used in these experiments was in the lower part of the range 14 to 21%, probably around 16 to 17%. The fact that the high genetic merit cows used in these experiments gave a smaller response in milk yield per percentage unit increase in protein content as the medium genetic merit cows in the earlier series of experiments, while responses to additional nutrients are usually much greater with high merit cows, may have been due to the fact that the high genetic merit cows were given over 50% more concentrates (11.5 kg/cow/day compared to 7.6 kg for the medium genetic merit cows). This would have resulted in the high merit cows receiving a lot more total protein from the higher intake of concentrates and so this may have resulted in a lower response per unit of additional protein.

The two experiments with high merit cows also involved a source of protein which was protected against degradation in the rumen to examine if this would improve the value of the protein for dairy cows. In this study, concentrates containing protected soyabean meal and 15% protein sustained the same milk yield as concentrates containing conventional soyabean meal and 19% protein. The lower optimum protein content in concentrates containing protected soyabean meal would reduce nitrogen losses to the environment and may also be beneficial to the reproductive performance of the cows. However the economics of using a protected protein source would depend on its cost relative to the cost of other protein sources.

A further five experiments, two undertaken at Hillsborough by Mayne (1989 and 1992a) and three in Great Britain by Clements and others (1989); Reeve and others (1989) and Sutton and others (1994), examined the opportunity for using a low intake of a very high protein concentrate as a supplement to high or medium digestibility grass silages to sustain the same yield of milk as that produced by a higher intake of a conventional 18% protein concentrate. On average over these five studies, 4 kg/cow/day of a concentrate containing 34% protein sustained the same milk yield as 7 kg/cow/day of a conventional 18% protein concentrate. However the cows given the lower intake of the 34% protein concentrate ate about 1.3 kg/day more silage dry matter than those given the higher intake of the 18% protein concentrate. At current prices of feedstuffs, feed costs would be slightly lower for the cows given the lower intake of the high protein concentrates than for those given the higher intake of a conventional 18% protein concentrate.

However, the overall profitability of milk production can also be greatly influenced by the effects of different diets on the health and fertility of the cows as well as on feed costs and the value of the milk produced. When given a low intake of a very high protein concentrate, cows tend to mobilise more body fat reserves to sustain milk production due to the lower concentrate, and hence lower energy intake, and use these body fat reserves together with the high protein intake to produce milk. Consequently cows given a lower feed level of a high protein concentrate tend to lose more body condition during early lactation and this has been shown to reduce fertility (Butler and Smith, 1989; Senatore and others, 1996; Studer, 1998; Pryce and others, 2001).

Furthermore, a higher protein intake in itself may reduce the fertility of dairy cows. Research results on the effects of the protein content of the diet on the fertility of dairy cows have been reviewed by Ferguson and Chalupa (1989) and again more recently by Laven and Drew (1999). Ferguson and Chalupa (1989) found that in most, but not all of the studies reviewed, feeding diets with high crude protein contents decreased reproductive efficiency. Laven and Drew (1999) listed eight experiments for which the effects of increasing the protein content of the diet of dairy cows on conception rate to first service was reported and eight experiments for which the effects of protein intake on the number of services per conception were recorded.

The results of these experiments were quite variable. In four of the eight experiments for which conception rate to first service was reported, increasing the average protein content of the diet from 14.4 to 18.5% significantly reduced conception rate to first service while in the other four experiments increasing the protein content of the diet did not significantly affect conception rate to first service. Similarly in the eight experiments for which the number of services per conception are reported, increasing the protein content of the diet significantly increased the number of services per conception in four of the experiments but did not significantly affect it in the other four experiments.

Research in the United States has indicated that the variation in the effect of higher protein intakes on the fertility of dairy cows may be caused by high protein intakes reducing the fertility of cows which have been under nutritional stress or have experienced some form of disease after calving, albeit in some cases sub-clinical disease which may not have been apparent. On the other hand higher protein intakes appear not to have affected the fertility of cows which have experienced no disease or nutritional stress after calving. The findings of Ferguson (1996) and Barton and others (1996) support this view.

Consequently, as sub-clinical reproductive disorders or other health problems in dairy cows may not always be apparent, in herds in which maintaining a tight calving pattern or a calving interval as near as possible to 365 days is important, it would be prudent not to have a very high protein content in the diet. In particular, a high intake of protein which is highly degradable in the rumen should be avoided.

As the financial return from milk minus the cost of feed is likely to be maximised when concentrates contain 17 to 21% protein, but reproductive performance may be poorer as protein intake is increased, using concentrates with approximately 17% crude protein is likely to be a good compromise between maximising margin over feed in the short term and maintaining good reproductive performance in the longer term. However in situations in which maximising the return from milk over feed costs is more important then reproductive performance then it may be desirable to use concentrates containing up to 21% protein.

SUMMARY OF THE MAIN POINTS FROM THE REVIEW OF RESEARCH ON THE OPTIMUM LEVEL OF PROTEIN IN CONCENTRATES FOR DAIRY COWS

1. Increasing the crude protein content of concentrates given to medium merit cows receiving 7.6 kg of concentrates/cow/day from 13 to 21% produced an economic response in milk production.
2. High protein intakes have been associated with poorer reproductive performance in dairy cows in many experiments, although the effect has not been consistent.
3. Increasing the protein content of concentrates given to high genetic merit cows receiving 11.5 kg of concentrates/cow/day from 14 to 21% did not produce an economic response in milk production.
4. **When dairy cows are given average to high quality grass silage ad libitum, the optimum crude protein content in concentrates is likely to be around 17%.**
5. Using a source of soyabean meal which was protected against degradation in the rumen enabled the protein content of concentrates to be reduced substantially without affecting milk yield. However the economics of using a protected source of protein would depend on its cost relative to the cost of other sources of protein.

CHAPTER 5

CONCENTRATE FEEDING SYSTEMS

Systems of feeding concentrates vary from what is termed a flat-rate system which involves each cow in the herd or group receiving the same quantity of concentrates/day over the winter, to more complex systems which involve feeding different amounts of concentrates to each cow, either within the milking parlour or through electronically operated out-of-parlour feeders, to the inclusion of concentrates in total mixed rations.

Flat-rate feeding versus feeding according to yield

During the 1970s, Ostergaard (1979) working in Denmark, compared different systems of feeding the same total quantity of concentrates to dairy cows during the first half of the lactation. He found that feeding the same total quantity of concentrates by different methods produced the same milk yield. Since then, several experiments have been undertaken at Hillsborough, at Dumfries in Scotland and in the Netherlands to compare flat rate feeding and feeding cows concentrates according to milk yield. For example, Gordon (1982b), Mayne (1992c), Rijpkema and others (1990), Taylor and Leaver (1984a and 1984b), Moisey and Leaver (1985) and Taylor and Leaver (1986) carried out a total of 12 comparisons of flat rate feeding and feeding cows concentrates according to yield.

Eleven of the 12 comparisons involved autumn-calving cows which received concentrates for 20 to 25 weeks, with an average feeding period of 23 weeks while the twelfth comparison involved January calving cows which received concentrates for only 10 weeks. All of the cows were at pasture after the experimental period when the different systems of feeding concentrates were compared.

Each of the cows on the flat-rate system of feeding concentrates received the same quantity of concentrates and the daily intake of concentrates for each cow was kept constant throughout the total winter feeding period. When concentrates were fed according to yield, the higher yielding cows received more concentrates than the lower yielding cows in proportion to their milk yield and they also received more concentrates during the first half of the winter when they were in early lactation and their milk yield was higher, than during the second half of the winter when milk yield was lower. Two exceptions to this were in the studies carried out by Taylor and Leaver (1984a) and Moisey and Leaver (1985), in which the higher yielding cows on the feed-to-yield treatment received more concentrates than the lower yielding cows, but the level of concentrate feeding for each individual cow remained constant over the whole winter period.

However in all 12 comparisons, the cows on the flat-rate feeding and those on the feed-to-yield system of feeding received the same total quantity of concentrates over the whole winter period. Over the twelve comparisons concentrate intakes ranged from 6 to 12 kg/cow/day with an average intake of 8.9 kg/cow/day.

The average results for the 12 comparisons are summarised in Table 15. The results of these experiments clearly show that the simple flat-rate system of feeding concentrates produced as high a milk yield as the much more complicated system of feeding concentrates to individual cows according to milk yield, and that there was also little difference in milk composition between the two systems of feeding concentrates. One of the experiments at Hillsborough also included a comparison

TABLE 15 THE EFFECT OF FEEDING CONCENTRATES ON A FLAT-RATE BASIS OR ACCORDING TO MILK YIELD.
(AVERAGE RESULTS OF 12 COMPARISONS)

	FEEDING SYSTEM	
	FLAT RATE	FEED-TO-YIELD
Average concentrate intake (kg/cow/day)	8.9	8.9
Milk yield (kg/day)	25.1	24.8
Milk protein content (%)	3.96	3.97
Milk fat content (%)	3.24	3.27

TABLE 16 THE EFFECT OF FEEDING CONCENTRATES ON A FLAT-RATE BASIS OR ON A HIGH/LOW SYSTEM OF FEEDING.
(AVERAGE RESULTS OF TEN COMPARISONS)

	FEEDING SYSTEM	
	FLAT RATE	HIGH/LOW
Average concentrate intake (kg/cow/day)	7.9	7.9
Milk yield (kg/day)	22.8	23.0
Milk protein content (%)	4.10	4.08
Milk fat content (%)	3.27	3.28

of feeding concentrates on a flat-rate basis in the parlour and feeding concentrates according to yield through out-of-parlour feeders. In this case, milk yield was slightly higher for the flat-rate system while milk fat and protein contents were slightly higher for the feed-to-yield system.

A further seven experiments were carried out by Gordon (1982a); Taylor and Leaver (1984a); Poole (1987); Rijpkema and others (1990) and Aston and others (1995) to compare flat-rate feeding of concentrates with a high/low system. In these experiments autumn-calving cows on the flat-rate system all received the same quantity of concentrates each day throughout the winter as in the experiments described above. Each of the cows on the high/low system of feeding also received the same quantity of concentrates but they were all given a high input of concentrates during the first half of the winter when milk yield was high, followed by a lower input during the second half of the winter when milk yield was lower.

The results are summarised in Table 16. Again the results of these experiments clearly show that there was no advantage, in terms of milk yield or composition, of feeding a high input of concentrates during early lactation followed by a lower input during the second half of the winter, rather than feeding a flat rate during the entire winter.

In these experiments the cows given concentrates on a flat-rate basis consumed slightly more silage than those fed concentrates according to yield or on a high/low system of feeding, although the difference in intake was very small.

Complete diet feeding systems

Traditionally, dairy cows in Northern Ireland have been offered silage and concentrates separately. Silage has been offered ad libitum while concentrates have been offered in pre-determined quantities in the milking parlour or through out-of-parlour feeders. However the increase in the genetic merit of dairy cows in Northern Ireland and the consequent increase in concentrate levels has generated considerable interest in the use of diet mixer wagons to produce complete mixed rations for dairy cows.

The results of six experiments which have been carried out using medium genetic merit cows to examine the effects of offering the cows silage and concentrates separately or as a total mixed ration are summarised in Table 17. Two of these experiments were carried out at Hillsborough by Agnew (1992) and Agnew and others (1996), one was undertaken in Great Britain by Phipps and others (1984b), one in Scandinavia by Wiktorssen and Bergtsson (1973) and two in the United States by Holter and others (1977) and Nocek and others (1986).

On average over the six experiments, offering cows a complete diet rather than silage ad libitum and concentrates separately in two or three feeds/day, increased dry matter intake by 4% but did not affect milk yield or milk fat or protein contents.

A further three experiments have been carried out at Hillsborough to examine the effects of feeding silage ad libitum and feeding concentrates separately through an electronically operated out-of-parlour feeder or offering them a total mixed ration, on the feed intake and performance of high genetic merit dairy cows. Even

TABLE 17 THE EFFECTS OF OFFERING SILAGE AND CONCENTRATES SEPARATELY OR AS PART OF A COMPLETE DIET ON THE FEED INTAKE AND PERFORMANCE OF MEDIUM GENETIC MERIT DAIRY COWS. (AVERAGE RESULTS OF SIX EXPERIMENTS)

	METHOD OF FEEDING	
	SILAGE AND CONCENTRATE SEPERATRE	TOTAL MIXED RATION
Concentrate intake (kg/day)	8.5	8.5
Total dry matter intake (kg/cow/day)	15.9	16.6
Milk yield (kg/cow/day)	23.8	23.9
Milk fat content (%)	3.90	3.90
Milk protein content (%)	3.13	3.12

TABLE 18 THE EFFECTS OF OFFERING SILAGE AND CONCENTRATES SEPARATELY OR AS A TOTAL MIXED RATION ON THE FEED INTAKE AND PERFORMANCE OF HIGH GENETIC MERIT DAIRY COWS. (AVERAGE RESULTS OF THREE EXPERIMENTS)

	METHOD OF FEEDING	
	SILAGE AND CONCENTRATE SEPERATRE	TOTAL MIXED RATION
Concentrate intake (kg/day)	13.5	13.5
Total dry matter intake (kg/cow/day)	19.1	18.5
Milk yield (kg/cow/day)	31.1	33.0
Milk fat content (%)	4.05	3.91
Milk protein content (%)	3.42	3.41

though approximately half of the animals used in these three experiments were first lactation heifers, average concentrate intakes were high at 13.5 kg/cow/day and the milk yield of the animals given the complete diet averaged 33 kg/cow/day over the total 5 month experimental periods. In these experiments the concentrates given separately from the silage were offered four times per day through the out-of-parlour feeders.

The results are summarised in Table 18. On average over the three experiments, offering the cows a total mixed ration rather than silage and concentrates separately did not increase total dry matter intake but increased milk yield by 1.9 kg/cow/day and reduced milk fat content by 0.14% but had little effect on milk protein content. It would appear that in the absence of an increase in dry matter intake or the digestibility of the ration, the milk yield of the cows given the complete diet was higher than that of the cows fed silage and concentrates separately at the expense of a reduction in milk fat content. Nevertheless, the total yield of milk fat plus protein was slightly higher for the cows given the total mixed ration.

It is also important to consider that complete diet feeding provides additional potential benefits which are not available when silage and concentrates are fed separately. These include the opportunity to mix two or more forages, the incorporation of wet by-product feeds into the diet and facility to mix concentrate straights or other ration components on the farm which can provide opportunities for considerable savings in the cost of the ration.

However the use of total mixed rations may also require housing systems which enable cows to be housed and fed in groups according to milk yield to ensure that the lower yielding animals do not become too fat.

In conclusion, the use of total mixed rations did not affect the milk yield of medium genetic merit cows given around 9 kg of concentrates/cow/day. However it did produce a higher milk yield from high yielding, high genetic merit cows given 13.5 kg of concentrates/cow/day which represented over 60% of their total dry matter intake. Nevertheless, the use of complete diet feeding should be considered in terms of its potential impact on the overall costs and labour requirements of feeding the cows on the farm as these effects can often be more important than effects on milk yield.

CONCENTRATES TO DAIRY COWS

1. For autumn- and winter-calving cows, a flat-rate system of feeding concentrates across all cows in the herd and over the entire winter period has produced the same milk yield over the total lactation as more complex systems involving feeding different quantities of concentrates to individual cows and a high level of feeding in early lactation and a lower level in mid lactation.
2. Offering silage and concentrates as a complete diet rather than separately did not affect the yield or composition of milk produced by medium genetic merit cows which were given around 7 to 10 kg of concentrates/cow/day.
3. Offering silage and concentrates as a complete diet rather than separately with concentrates given through an out-of-parlour electronic feeder, increased milk yield by 2 kg/cow/day but reduced milk fat content by 0.14%.
4. Complete diet feeding can offer additional options such as the opportunity to mix two or more forages, the incorporation of wet by-products into the diet and a facility to mix concentrate straights or other ration components on the farm which can enable considerable savings to be made in the cost of the ration.
5. Complete diet feeding can require additional investment in buildings and can affect labour costs.
6. The effect of complete diet feeding on costs as discussed under (4) and (5) above may well be more important than its effect on milk yield.

A wide range of concentrate straights are available in Northern Ireland, and are currently being fed to both very high yielding and moderate yielding dairy cows on commercial farms. However most of the research which has been carried out to examine the feeding value of different feedstuffs for dairy cows has involved a comparison of cereal-based concentrates with a high starch content and by-product feeds with high contents of digestible fibre and low starch contents, such as sugarbeet pulp, citrus pulp, maize gluten feed and maize distillers grains.

Comparison of high-starch and high-fibre concentrates for dairy cows

The results of a total of 30 comparisons of high-starch, cereal-based concentrates and concentrates with a high content of digestible fibre and a low starch content, which have been carried out by Castle and others (1981); Mayne and Gordon (1984); Chamberlain and others (1984); Phipps and others (1987b); Huhtanen (1987); Sporndly (1991); Huhtanen (1993); Sutton and others (1993); Aston and others (1994b); Gordon and others (1995); Huhtanen and others (1995); Doherty and Mayne (1996); Keady and others (1998); Dewhurst and others (1999) and Keady and others (2002b) are summarised in Table 19. The cereal-based concentrates were based mainly on barley with some wheat included in some of the experiments, while the low starch, by-product-based concentrates nearly all contained sugar-beet pulp and some of them also contained citrus pulp, maize gluten feed and wheat bran.

On average over the 30 comparisons, offering cows a high fibre/low starch, by-product-based concentrate rather than a high starch, cereal-based concentrate, resulted in a slightly higher silage intake, increased milk fat content by 0.09% and reduced milk protein content by 0.07%, but did not affect milk yield. The high-fibre concentrates had a lower energy content than the high starch, cereal-based concentrates, but this was offset by the fact that the cows ate slightly more silage when they were given the high-fibre concentrates, and so there was no difference in milk yield between the two types of concentrates.

Obviously the main effects of the two types of concentrates were on milk composition. In a situation in which low milk protein content is a problem, increasing the starch content of the concentrate has improved milk protein content but has also reduced milk fat content. Conversely, if a low milk fat content is a problem, feeding a concentrate with a high content of digestible fibre should help to improve fat content but is likely to reduce protein content.

High intakes of high-starch concentrates, especially two large intakes in two feeds per day, separate from the silage, can predispose cows to digestive upsets particularly soon after calving and to laminitis in their feet as a result of the production of large quantities of acid in the rumen from the fermentation of the starch. For this reason, concentrates containing a mixture of cereals and by-products with a high content of digestible fibre may well be the most appropriate option for dairy cows in many cases.

Research data on the relative value of other feedstuffs from experiments with dairy cows is limited. However extensive research has been carried out at Hillsborough and other research centres to evaluate different feedstuffs for beef cattle and the results of these can provide some indication of the relative value of feedstuffs

TABLE 19 COMPARISONS OF HIGH-STARCH, CEREAL-BASED CONCENTRATES AND BY-PRODUCT-BASED CONCENTRATES WITH A HIGH CONTENT OF DIGESTIBLE FIBRE AND A LOW STARCH CONTENT FOR DAIRY COWS. (Average results of 30 comparisons)

	THE EFFECTS OF OFFERING DAIRY COWS HIGH FIBRE/ LOW STARCH CONCENTRATES INSTEAD OF CEREAL-BASED CONCENTRATES
Silage dry matter intake	Increased by 0.3 kg/cow/day
Milk yield	No effect
Milk fat content	Increased by 0.09%
Milk protein content	Reduced by 0.07%

for dairy cows.

Wheat

Even though the chemical composition of wheat and the results of digestibility studies indicate that the feeding value of wheat should be about 6% higher than that of barley, in beef cattle feeding experiments, wheat has had only the same feeding value as barley when given as part of a silage-based diet.

Maize meal

Conversely, in four feeding experiments with beef cattle at Hillsborough, maize meal has had a feeding value 16% higher than that of barley, as a component of grass silage-based diets, even though the results of digestibility studies have generally indicated that it has a feeding value only about 7% higher than that of barley. The higher feeding value of maize meal compared to barley may be related to the fact that the starch in maize is digested more slowly in the rumen than starch in barley or wheat. This reduces the rate of acid production from the fermentation of starch after the animal consumes concentrates, which in turn may result in more effective digestion of the fibre from the silage component of the ration than when barley or wheat are fed.

By-product feedstuffs

- It is important to note that the composition of by-product feedstuffs can vary considerably and so it is advisable to have a representative sample of the feedstuff analysed before feeding it.
- **It is vitally important that by-product feedstuffs or other straights are supplemented with appropriate minerals and vitamins.**
- The physical nature of by-product feedstuffs can vary considerably and this can result in slower rates of consumption and in some situations can cause difficulty in achieving the required level of intake. The use of a complete diet mixer wagon can minimise this potential problem.

Maize gluten feed

Maize gluten feed is one of the most commonly used cereal by-products in Northern Ireland. The use of maize gluten feed plus minerals and vitamins as the only source of concentrates for dairy cows was investigated at Hillsborough by Gordon (1987b). In this experiment maize gluten feed was compared with a barley/soyabean meal mix and a commercial dairy concentrate. The cows were given medium quality silage ad libitum. The results are summarised in Table 20.

These results show that for the medium genetic merit cows used in this experiment, milk yield and milk composition were similar for the three sources of concentrates. However a different result may be obtained at higher levels of concentrate feeding. Nevertheless, under the conditions of this experiment it was calculated that maize gluten feed had a feeding value equivalent to 95% of that of an 18% protein barley/soyabean meal mix or a 17% protein dairy concentrate. This result is in close agreement with the results of six feeding experiments with beef cattle at Hillsborough.

Maize gluten feed has been found to be more acidic

TABLE 20 A COMPARISON OF CONCENTRATE SOURCES FOR DAIRY COWS (GORDON, 1987B)

	CONCENTRATE SOURCE		
	COMMERCIAL DAIRY CONCENTRATE	MAIZE GLUTEN FEED FEED	BARLEY/SOYABEAN MEAL
Concentrate level (kg/day)	6.0	6.0	6.0
Silage intake (kg DM/day)	8.8	8.4	8.5
Milk yield (kg/cow/day)	22.0	21.7	22.0
Milk fat content (%)	3.72	3.68	3.80
Milk protein content (%)	2.85	2.85	2.85

than other feedstuffs. Consequently there has been some concern about effects of feeding maize gluten feed with acidic silages. However in experiments at Hillsborough with beef cattle, feeding maize gluten feed did not result in as low a pH in the rumen as feeding cereals. This may be attributable to the fact that the high starch content in cereals is rapidly fermented in the rumen and this produces large quantities of acid, while maize gluten feed has a lower starch content and consequently produces less acid.

Maize distillers dark grains

In experiments with beef cattle, maize distillers dark grains have had an effective energy content similar to that of barley, but their relatively high protein content (around 26%), has given them a monetary value somewhat higher than barley, depending on the cost of other sources of protein. However including substantial amounts of maize distillers dark grains in the diet has reduced milk protein content (Owen and Larson, 1991), and this has been attributed to its high oil content (Murphy and O'Mara, 1993).

Sugarbeet pulp and citrus pulp

In several experiments with dairy cows and beef cattle, sugarbeet pulp has had a feeding value equivalent to around 96% of that of barley, while citrus pulp has had an effective energy content equivalent to around 93% of that of barley. However citrus pulp had a protein content of only 6%, so that its monetary value has been about 90% of that of barley. Nevertheless, as mentioned above, silage intake has been slightly higher when sugarbeet and citrus pulp have been fed rather than cereals, and so they have resulted in similar milk yields to those produced by barley.

Sugarbeet and citrus pulp have been found to be very palatable feeds for cattle and so can be very useful components of concentrates in situations in which a high intake of concentrates is needed. The inclusion of sugarbeet or citrus pulp in cereal-based concentrates for dairy cows can also reduce the rate of acid production in the rumen and thereby reduce the risk of laminitis in their feet.

However other high-fibre by-product feedstuffs such as sunflower meal and rice bran have been found to have very low effective energy contents when included in rations for cattle, and consequently are generally not suitable for inclusion in silage-based rations for dairy cows.

Molasses

The feeding value of molasses in the diet of beef cattle and heifers has been examined in a series of 13 experiments at Grange and Moorepark Research Centres (Drennan, undated). From the results of these experiments, the effective energy content of molasses was calculated to be equivalent to around 70% of that of barley which combined with the very low protein content of molasses, gave it a calculated monetary value equivalent to two thirds of that of barley when included in diets at up to 2.5 kg/head/day. However, the feeding value of molasses has been found to decline as the quantity consumed per animal/day increased. At levels of intake above 2.5 kg/head/day molasses had a calculated monetary value equivalent to 60% of that of barley.

Fats and oils

Fats and oils have very high energy contents, their metabolisable energy content usually being more than double that of cereals (Garnsworthy, 2002). Consequently fats and oils can be a useful source of energy, especially for high yielding cows when they have difficulty consuming sufficient feed relative to their level of milk production. However when natural fats and oils have been included in the diet of dairy cows, the digestibility of the diet and silage dry matter intake have been reduced slightly which has tended to offset the potential benefits of their high energy content.

For example, in five experiments at Moorepark Research Centre and in the United States, including full-fat soyabeans, full-fat rapeseed or full-fat cottonseed in the diet of dairy cows, on average did not affect milk yield and reduced milk protein content slightly (Murphy and others, 1990 and 1995; Schauff and others, 1992; Wu and others, 1994). It also reduced dry matter intake and the digestibility of the diet, presumably as a result of the fibre particles becoming coated with oil in the rumen as described by Garnsworthy (2002).

Consequently a number of products have been developed which are referred to as "protected fats" or "bypass fats", the aim being to protect the digestion of the rest of the diet in the rumen against any detrimental effects of the fat.

From a review of the effects of the use of fats in dairy cow diets, Garnsworthy (2002) concluded that the response by dairy cows to supplementary fat is complex and not always predictable. Possible responses which have been reported include increased milk yield, decreased milk protein content and increased live-weight gain or a reduction in live-weight loss. For example, Garnsworthy and Huggett (1992) found that when fat was included in the diet of cows with a high body condition score they responded by reducing the rate at which they mobilised body fat to support milk production. On the other hand, when fat was included in the diet of cows which had a low body condition score they responded by producing more milk but milk protein content was reduced.

In conclusion, the results of research on the effect of including protected fat in the diet of dairy cows indicate that it can be a useful source of energy for high yielding cows in early lactation, but its use requires careful nutritional management as the effects of including protected fat in the diet can be unpredictable.

OF FEEDSTUFFS

1. Relative to using a cereal-based concentrate with a high starch content, using a concentrate with a high content of digestible fibre and a low starch content did not affect milk yield but increased milk fat content and reduced milk protein content.
2. High-fibre concentrates generally have a lower energy content than cereal-based concentrates, but this is offset by a slightly higher silage intake with high-fibre concentrates, so that there has been no difference in milk yield.
3. The inclusion of "protected fats" in the diet of high yielding cows can increase energy intake but responses can be rather unpredictable.

As discussed in Chapter 9, the cost of grass silage per unit of metabolisable energy utilized by dairy cows is currently about double the cost of efficiently utilized grazed grass. Consequently, the production and utilization of silage should be used to complement the efficient use of grazed grass if the costs of producing milk are to be minimised, and in most situations the quantity of silage made should be sufficient to feed cows only during the period when pasture grazing is not feasible, due to inadequate availability of grass for grazing and/or ground conditions which do not permit grazing. Production of silage should also be timed to remove surplus herbage during periods of rapid grass growth, in a manner which ensures efficient utilization of grass by grazing cows, while at the same time ensuring that the performance of cows at pasture is not prejudiced by lack of available grass.

The feeding value of grass silage for dairy cows is determined largely by its digestibility and intake potential, or how much of the silage the cows will eat. The digestibility of silage is determined mainly by the stage of maturity at which the grass is harvested. Several experiments at Hillsborough have shown that under Northern Ireland climatic conditions the D-value of silage declines by about 3 percentage units for each week that harvesting is delayed beyond mid-May (e.g. Steen, 1992; Steen and others, 2002; Ferris, 2002).

The effect of increasing the digestibility of grass silage by harvesting the grass at an earlier stage of growth has been examined in six experiments carried out at Hillsborough by Gordon and Murdoch (1978); Steen and Gordon (1980b); Gordon (1980c); Ferris and others (2001) and Keady and others (2002a and 2003) and a further seven experiments carried out in Great Britain (Castle and others, 1980; Thomas and others, 1981; Moisey and Leaver, 1984; Taylor and Leaver, 1984b; Phipps and others, 1987a and Aston and others, 1994a).

On average over these 13 experiments the lower digestibility silages had a D-value of 63% while the higher digestibility silages had a D-value of 70%. Increasing the digestibility of the silage produced an average increase in milk yield over the thirteen experiments of 2.6 kg/cow/day, or 0.38 kg of milk/percentage unit increase in D-value when the cows were given 7.5 kg of concentrates/cow/day as shown in Table 21. Increasing silage digestibility also increased milk protein content by 0.09%.

The response of 0.38 kg of milk/percentage unit increase in silage D-value is in close agreement with the findings of Gordon (1989c) who reviewed the results of several early experiments which examined the effects of the digestibility of grass silage on milk yield and reported a response of 0.37 kg of milk/percentage unit increase in D-value.

While the first 10 of the 13 experiments listed above involved medium genetic merit cows, the three most recent experiments, all of which were undertaken at Hillsborough, involved cows of very high genetic merit. These experiments involved different levels of concentrate feeding as well as silages of medium and high digestibility.

TABLE 21 THE EFFECT OF INCREASING THE DIGESTIBILITY OF GRASS SILAGE ON THE SILAGE INTAKE AND PERFORMANCE OF DAIRY COWS.(AVERAGE RESULTS OF 13 EXPERIMENTS)

	SILAGE D-VALUE (%)	
	63	70
Concentrate intake (kg/day)	7.5	7.5
Silage dry matter intake (kg/day)	8.7	10.4
* Milk yield (kg/day)	22.6	25.2
Milk fat content (%)	4.02	3.96
Milk protein content (%)	3.20	3.29

* Milk yield was increased by 0.38 kg/percentage unit increase in silage D-value.

This enables the response in the milk yield of medium and high genetic merit cows to be compared at the same level of concentrate feeding.

When both the medium and high genetic merit cows were given 7 kg concentrates/cow/day, the response in milk yield to increasing the digestibility of the silage given to the cows was 0.45 kg of milk/percentage unit increase in silage D-value for the high genetic merit cows, compared to 0.37 kg of milk/percentage unit increase in silage D-value for the medium merit cows. These results indicate that high genetic merit cows produce a greater response in milk yield to an improvement in silage quality than medium merit cows, in the same way that they produce a greater response to higher inputs of concentrates as discussed in Chapter 3.

In eight of the thirteen experiments listed above, the cows were given two, three or four levels of concentrate feeding with the higher and lower digestibility silages (Gordon and Murdoch, 1978; Steen and Gordon, 1980; Castle and others, 1980; Phipps and others, 1987a; Aston and others, 1994a; Ferris and others, 2001; Keady and others, 2002a and 2003). On average over these eight experiments, cows given silages with a D-value of 72% and supplemented with 5.6 kg of concentrates/cow/day produced the same amount of milk as cows given silages with a D-value of 65% and 9.6 kg of concentrates as shown in Table 22. Thus for each unit increase in silage D-value, concentrate intake could be reduced by 0.6 kg/cow/day without affecting milk yield.

However the cows given the higher digestibility silages supplemented with 5.6 kg of concentrates produced milk with higher protein (0.09%) and higher fat (0.10%) contents than the cows given the lower digestibility silage supplemented with 9.6 kg of concentrates/cow/day.

Two of these eight experiments did not begin until the cows were past peak milk yield and continued through mid lactation while a third experiment involved only heifers, and so the average milk yield of the cows and the levels of concentrate feeding are lower than would be expected for cows in early lactation. However as many early autumn-calving cows are in mid-lactation during the second half of the winter the results are applicable to many commercial farms. Furthermore, the cows used in the last three experiments produced an average milk yield of over 30 kg/cow/day during the entire winter period and the results of these experiments are very much in line with the results of the earlier experiments involving lower yielding cows.

TABLE 22 THE EFFECT OF THE DIGESTIBILITY OF GRASS SILAGE ON THE QUANTITY OF CONCENTRATES REQUIRED TO SUSTAIN A CONSTANT MILK YIELD. (AVERAGE RESULTS OF 8 EXPERIMENTS)

	SILAGE D-VALUE (%)	
	65	72
Concentrate intake (kg/cow/day)	9.6	5.6
Silage dry matter intake (kg/cow/day)	8.3	11.6
Milk yield (kg/cow/day)	24.6	24.6
Milk fat content (%)	3.96	4.06
Milk protein content (%)	3.17	3.26
Total feed costs including labour for feeding etc (£/cow over a 160 day winter)	364	333
Value of milk produced (£/cow over a 160-day winter) Margin over feed costs	705	723
(£/cow over a 160-day winter)	341	390

The digestibility of the medium and high digestibility silages used in these eight experiments (D-values of 65 and 72%) are close to the digestibility of the silages made in typical 2-cut and 3-cut systems at Hillsborough over many years, as shown in Table 28 in Chapter 9. Therefore, it is considered to be appropriate to use the costings per megajoule (MJ) of metabolisable energy (ME) for the 2-cut and 3-cut silages and concentrates given in Table 28, to estimate the costs of feeding cows silage with a D-value of 72% and 5.6 kg concentrates or silage with a D-value of 65% plus 9.6 kg concentrates in the eight experiments listed above. The cows given the higher digestibility silage and 5.6 kg of concentrates consumed 11.6 kg of silage dry matter/day and the total cost of the diet was £333/cow for a 160 day winter, while the cows given medium digestibility silage and 9.6 kg of concentrates consumed 8.3 kg of silage dry matter/day and the total cost of the diet was £364/cow for a 160 day winter. The value of the milk produced by the cows given the high digestibility silage was also higher than that produced by the cows given the lower digestibility silage due to its higher fat and protein contents. Consequently the margin over feed costs including all labour for feeding etc as shown in Table 28, was approximately £50/cow higher over a 160 day winter feeding period for the cows given the high digestibility silage and a lower input of concentrates compared to the cows given the lower digestibility silage and a higher input of concentrates, when a charge of £100/acre is assumed for the land required to produce the silage. However it is recognised that circumstances and hence the costs of different feeds are very different on different farms.

For example, in the eight experiments listed above the cows given higher digestibility silage and a lower input of concentrates required 40% more silage than the cows given lower quality silage and a higher input of concentrates. In situations in which land availability or silo capacity are major limiting factors on the farm, the use of high quality silage may restrict the number of cows which can be kept on the farm and hence the overall profitability of the farm business. However if large areas of Northern Ireland are classified as a Nitrate Vulnerable Zone in the future, this would be likely to limit the opportunity to use high stocking rates on dairy farms. An enforced limit on stocking rates in this situation may well further increase the economic advantage of using high digestibility silage and a lower input of concentrates rather than using a high stocking rate system based on lower digestibility silage and a higher concentrate input.

In any case, on farms on which the availability of labour or capital is a major factor limiting the number of cows which can be kept, the use of high quality silage should enable profitability per cow and hence the overall profitability of the farm business to be maximised.

Also on farms where good open clamp silos are used and any silage effluent produced is channelled into tanks which are required to store slurry during the winter, the costs of storing silage would be much lower than those used in the costings given in Table 28. Conversely, in situations in which a walled and roofed silo, complete with tanks specifically to collect and store silage effluent (and which are not used for other purposes) are required on a farm, then the costs of storing silage would be much greater than those given in Table 28.

The costings used above include a charge of £100/acre for the land which is required to produce the silage. However as discussed in Chapter 9, if legislation is introduced in the European Union and by the UK government over the next few years to totally decouple subsidy payments from production so that there are no longer any subsidy payments for keeping suckler cows or breeding ewes or growing cereals, the number of suckler cows, and hence the total number of beef cattle in Northern Ireland is projected to decline substantially. It is possible that in this situation the cost of grass for cutting or grazing could also decline substantially. To examine the effects of a major reduction in the cost of renting grassland, costs have been calculated using a value of £74/ha. In this situation, if no change in the price of concentrates or other costs is assumed, the calculated margin over feed costs for a 160 day winter period would be £60/cow higher for high digestibility silage and a lower input of concentrates than for the lower digestibility silage and a higher concentrate input.

While five of the eight experiments listed above involved cows of medium genetic merit, the three most recent experiments undertaken at Hillsborough by Ferris and others (2001) and Keady and others (2002a and 2003) involved cows of very high genetic merit. In these experiments the response in milk production to higher quality silage was greater than the responses obtained in the other five experiments involving medium genetic merit cows.

On average in experiments at Hillsborough involving high genetic merit animals, cows given high digestibility silage (average D-value 75%) supplemented with 7.0 kg of concentrates/cow/day produced the same milk yield as cows given medium digestibility silage (D-value 66%) supplemented with 12.1 kg of concentrates/cow/day. Therefore, for each percentage unit increase in the digestibility of the silage, concentrate intake was reduced by 0.6 kg/day without affecting milk yield, although milk fat and protein contents were 0.04 and 0.06% higher for the cows given the high digestibility silage and the lower input of concentrates.

This is exactly the same saving in concentrate intake as a result of feeding higher digestibility silage as that obtained with medium genetic merit cows, because the high genetic merit cows gave a greater response in milk yield to both an increase in the digestibility of the silage and to feeding more concentrates than the medium genetic merit cows.

Consequently the results of this extensive series of experiments would indicate that the feed intake of high genetic merit cows can be increased either by feeding higher digestibility silage or by feeding more concentrates, in the same way that the feed intake of medium genetic merit cows can be increased, except that the overall level of feeding should be higher for high genetic merit cows.

On the basis of the costings presented in Table 28, the margin over feed costs, including the labour associated with feeding etc, for the cows given high digestibility silage and 7.0 kg of concentrates/day would be £27 to £43/cow higher for a 160 day winter period than the margin for the cows given medium digestibility silage and 12.1 kg of concentrates/cow/day, depending on the rental value of grassland as discussed above.

Opting for medium digestibility silage for high merit cows is also a high risk strategy. On a number of occasions at Hillsborough, when grass has been harvested during the first week of June with the aim of making medium digestibility silage, the quality of the silage has been either better or worse than anticipated. For example, in recent years the quality of silages made during the first week of June has varied from as high as a well preserved silage with an ME content of 11.3 MJ/kg dry matter to as low as a badly preserved silage with an ME content of 9.0 MJ/kg dry matter. As discussed previously, the maximum amount of concentrates which can be fed is normally 60 to 65% of total dry matter intake, if a major depression in milk composition is to be avoided. Consequently in a situation in which a badly preserved silage with an ME content of only 9 MJ/kg dry matter (i.e. a D-value of only 56%) is the only forage available to high yielding, high merit cows, total feed intake is likely to be limited, milk yield and composition reduced, and the cows predisposed to an increased risk of metabolic diseases.

Furthermore, as was clearly demonstrated in the year 2002, if the aim is to make medium digestibility silage by harvesting grass during the first week of June, and harvesting has to be delayed by two or three weeks due to wet weather, then a very poor quality silage will be made. However if the aim is to make high digestibility silage by harvesting grass in mid May, and harvesting is delayed by two to three weeks because of bad weather, then it is still possible to make a medium quality silage, feed more concentrates and achieve a reasonable level of profitability from winter milk production. Also, feeding high levels of concentrates in addition to poorer quality silage in order to achieve high energy intakes, rather than achieving a high intake of high quality silage and offering a more moderate input of concentrate can often lead to considerable health problems in cows on commercial farms as outlined by Howie (1989), a practicing veterinarian from Cheshire.

Similar conclusions have been drawn from research with high yielding cows on commercial farms in the United States. Chase (2002) reviewed research for cows producing around 13,000 kg of milk/cow in 305 days and concluded that "a forage source with high digestibility and intake is still the key to development of rations to support high levels of milk production".

The value of additives for grass silage

Many experiments have been undertaken to examine the effects of different silage additives on the performance of dairy cows. Formic acid has generally been found to be the most effective additive for improving the fermentation quality of silage and the performance of dairy cows given silage made under difficult conditions when the untreated silage was poorly preserved.

The results of 25 comparisons of untreated and formic acid-treated silages which have been identified in the scientific literature are summarised in Table 23. Seven of these were undertaken at Hillsborough by Gordon (1989a and 1989b); Mayne (1990a, 1992b and 1993) and Patterson and others (1997). The other 18 comparisons were carried out at Moorepark Research Centre by Butler (1977); Murphy (1981); Murphy and Gleeson (1984) and Keady and Murphy (1996 and 1997), in Great Britain by Castle and Watson (1970a, 1970b and 1973); Chamberlain and others (1987 and 1990); Davies (1990) and Smith and others (1993) and in Sweden by Martinsson (1992).

In eight comparisons of untreated and formic acid-treated silages in which the untreated silages were poorly preserved, formic acid treatment increased milk yield by 1.0 kg/cow/day with a slight increase in milk protein content and a slight reduction in milk fat content as shown in Table 23. However in a further 17 comparisons in which the untreated silages were well preserved, treatment with formic acid did not affect milk yield, but increased milk fat content by 0.25% and milk protein content by 0.07% as shown in Table 23.

There has also been considerable interest in the use of sulphuric acid as a silage additive for dairy cows as a cheaper alternative to formic acid (Gordon, 1989d). However, on average over a series of five experiments carried out at Hillsborough and Moorepark Research Centres by Mayne (1990b and 1993) and Murphy (1989 and 1990), the use of sulphuric acid as a silage additive increased silage dry matter intake by 0.5 kg/cow/day, but did not increase milk yield or milk fat plus protein yield. On the basis of these findings, it is concluded that sulphuric acid was not an effective silage additive and its use as an additive for silage for dairy cows in these experiments would have reduced the profitability of milk production.

The use of bacterial inoculants as silage additives has increased greatly over the past 10 years, largely due to the fact that they are safer to handle and less corrosive to machinery than acids. However, responses in the performance of dairy cows to the use of bacterial

TABLE 23 THE EFFECT OF USING FORMIC ACID AS A SILAGE ADDITIVE ON THE SILAGE INTAKE AND PERFORMANCE OF DAIRY COWS

1. AVERAGE RESULTS FOR EIGHT COMPARISONS IN WHICH THE UNTREATED SILAGES WERE POORLY PRESERVED	RESPONSE TO FORMIC ACID
Silage dry matter intake	Increased by 0.9 kg/cow/day
Milk yield	Increased by 1.0 kg/cow/day
Milk fat content	Reduced by 0.02%
Milk protein content	Increased by 0.07%
2. AVERAGE RESULTS FOR 16 COMPARISONS IN WHICH THE UNTREATED SILAGES WERE REASONABLY WELL PRESERVED	
Silage dry matter intake	Increased by 0.8 kg/cow/day
Milk yield	No response
Milk fat content	Increased by 0.25%
Milk protein content	Increased by 0.07%

inoculants as silage additives have been quite variable. The results of 26 comparisons of untreated and inoculant-treated silages have been identified in the scientific literature and are summarised in Table 24.

Fifteen of these comparisons were undertaken at Hillsborough by Gordon (1989a and 1989b); Mayne (1990a, 1992 and 1993) and Patterson and others (1996, 1997 and 1998), while the other 10 comparisons were undertaken at Moorepark Research Centre by Murphy (1981 and 1989) and Keady and Murphy (1996 and 1997), in Great Britain by Chamberlain and others (1987); Leaver (1991); Davies (1990) and Smith and others (1993) and in Sweden by Martinsson (1992).

On average over the 26 comparisons, treatment of grass with a bacterial inoculant prior to ensiling resulted in an increase in the silage dry matter intake of dairy cows of 0.3 kg/cow/day, an increase in milk yield by 0.2 kg/cow/day and a slight increase in both milk fat and protein contents as shown in Table 24. On average over the 18 comparisons for which the live-weight change of the cows was reported, inoculant treatment had little effect on live-weight gain or loss.

The average response in milk yield to treatment of silage with an inoculant was very similar in the 17 comparisons in which the untreated silages were well preserved (i.e. ammonia nitrogen content less than 10% of total nitrogen) and in the nine comparisons in which the untreated silages were not well preserved.

In 21 of the 26 comparisons of untreated and inoculant-treated silages, the grass was not wilted sufficiently prior to ensiling to produce an effective increase in dry matter content. However, Patterson and colleagues (1996 and 1998) carried out a series of four experiments at Hillsborough involving a total of 11 crops of grass to examine the effects of treating both unwilted and wilted grass with an inoculant prior to ensiling. One of the comparisons made by Martinsson (1992) also involved wilted grass. The results for the unwilted or very slightly wilted silages and for the wilted silages are also summarised separately in Table 24.On average over 21 comparisons of untreated and inoculant-treated silages made from unwilted or only slightly wilted grass, in which the average dry matter content of the grass at ensiling was approximately 17%, treatment with the additives resulted in an increase in silage dry matter intake of 0.4 kg/cow/day, an increase in milk yield of 0.2 kg/cow/day and increases in milk fat and protein contents of 0.05%.

However in the five comparisons involving wilted silages with an average dry matter content of approximately 30%, treatment with inoculants did not affect milk yield and the protein and fat contents of the milk produced from the inoculant-treated silages were slightly lower than for the untreated silages as shown in Table 24.

The effect of using bacterial inoculants on profitability

For the purpose of calculating the effect of inoculant use on the profitability of milk production the following assumptions have been made:

A price of 18 p/litre for milk, an increase in milk price of 0.18 p/litre/0.1% increase in fat content and an increase of 0.32 p/litre/0.1% increase in protein content, a cost

TABLE 24 A COMPARISON OF FEEDING CONCENTRATES ONCE/DAY AND COMPLETE DIET FEEDING FOR FINISHING BEEF CATTLE (DRENNAN, 1990)

	CONCENTRATE FEED LEVEL			
	LOW		HIGH	
METHOD OF FEEDING CONCENTRATES	ONCE/DAY	COMPLETE DIET	ONCE/DAY	COMPLETE DIET
Concentrate intake (kg/day)	2.7	2.7	5.2	5.2
Total feed intake (kg DM/day)	8.9	8.8	9.4	9.3
Carcass gain (kg/day)	0.44	0.46	0.52	0.60

of £1.20/tonne to treat grass with an inoculant and the other costs of silage as given in Table 28 in Chapter 9.

On the basis of these assumptions, the cost of treating grass with an inoculant to provide sufficient silage to feed a cow for a 160 day winter period plus the cost of the increase in silage intake due to inoculation in the 21 comparisons involving unwilted or very slightly wilted grass as shown in Table 24, was £20/cow, while the total value of the extra milk produced plus the improvement in milk composition as a result of treatment with the inoculants was £13/cow.

In the case of the five comparisons involving wilted silage, the cost of the additive plus the increase in silage intake was £8/cow while the response in milk yield and composition was equivalent to a reduction in value of £3/cow.

Consequently, on the basis of these costings the use of an additive tended to reduce the profitability of milk production by £7 to 11/cow over the winter. Furthermore, on average over the 21 comparisons of untreated and inoculant-treated silages involving unwilted or only very slightly wilted grass and which have been listed above, the cows were given approximately 6 kg of concentrates/cow/day. On the basis of the responses in milk yield to additional concentrates at this level of concentrate feeding, as discussed in Chapter 3, the average response in milk yield to treatment with an inoculant additive in the 21 comparisons is equivalent to the response which would be expected from feeding an extra 0.25 kg of concentrates/cow/day. If a price of £153/tonne is assumed for concentrates, including the costs of storage and feeding as outlined in Table 28, the cost of producing this response by feeding more concentrates would be £5/cow over a 160 day period, compared to a cost of £21/cow to produce the same response using inoculant-based silage additives.

However it is important to note that the results discussed above relate to the average response in 26 comparisons of untreated and inoculant-treated silages, and so an individual inoculant may give an economic response in milk yield and composition. Nevertheless, before an additive is used commercially it is important to ascertain whether or not all the independent research information is available and has shown that the additive has not only been effective in increasing the performance of dairy cows, but also that the responses in milk yield and composition have been sufficiently large to cover the cost of applying the additive and the cost of the extra silage which the cows have eaten as a result of additive treatment, or indeed have been as great as the response which would be expected from spending the same amount of money on extra concentrates.

Effects of wilting grass for silage

The effects of field wilting of grass prior to ensiling on the performance of dairy cows was examined in an extensive series of experiments at Hillsborough during the 1980s. Gordon (1980a and 1980c); Gordon (1981); Gordon and Peoples (1986); Small and Gordon (1988) and Peoples and Gordon (1989) undertook a series of eight comparisons of precision-chopped unwilted and wilted silages, while Gordon (1986 and 1987a) carried out two further experiments to compare unwilted silage made with a flail forage harvester and wilted silage made with a precision-chop harvester. On average over these 10 comparisons the dry matter intake of the wilted silages was 0.8 kg/cow/day (or 9%) higher than that of the unwilted silages. However the cows given the wilted silage produced 0.8 kg/cow/day less milk than the cows given the unwilted silage, although the milk produced from the wilted silage contained 0.03% more fat and 0.02% more protein than the milk produced from the unwilted silages. From the results of these experiments Gordon (1989d) concluded that the yield of milk produced per hectare of grass harvested for wilted silage was about 10% lower than for unwilted silage made with a precision chop harvester and about 20% lower than for unwilted silage made with a flail harvester.

However in these experiments, the unwilted and wilted silages were treated with formic acid as an additive and consequently both silages were well preserved. The unwilted silages had an average ammonia nitrogen content of 7% of total nitrogen. Also in several of the experiments, wilting took place under difficult weather conditions and consequently the grass remained in the field for prolonged periods to achieve dry matter contents of 25 to 50%. The average period of wilting over all of the comparisons was 3 to 4 days. In this situation, the lack of any positive effect of the higher dry matter intake on milk yield, or indeed, on average, a lower milk yield, from wilted silage is likely to have resulted from nutrient losses from the grass while it was lying in the swathe and a lower digestibility for the wilted than for the unwilted silage.

More recent research has examined the opportunities to increase the rate of drying of crops of grass in the field by conditioning, spreading and tedding the grass (Wright, 1997). Wright and others (2000) undertook a detailed analysis of the factors which affect the response in the performance of dairy cows to field wilting using data from 38 experimental comparisons of unwilted and wilted silages from a wide range of research centres. The response in milk energy output to field wilting, which reflects the combined effects of the volume of milk produced and its fat and protein contents, was closely related to the rate at which the grass dried in the field and the fermentation quality of the unwilted silage, as indicated by its ammonia content.

The faster the grass dried in the field the more positive was the response in milk yield to wilting.

Also if the unwilted silage was poorly preserved then there was a better response in milk yield to wilting. The response to wilting was also related to the dry matter content of the wilted silage, in that if the silage was wilted to a dry matter content of 30%, there was a better response in milk yield than if it was wilted to only a dry matter content of 25%.

However it should be emphasized that the rate of drying in the field was more important than the final dry matter content of the grass at ensiling. This would indicate that a short, fast wilt, to say, 25% dry matter is better than a long, slow wilt to 30% dry matter.

As the rate of drying in the field has been shown to be closely related to the weight of mown crop lying per unit area of ground (Wright, 1997), spreading grass during, or immediately after mowing should greatly improve the speed of drying and hence maximise milk yield from wilted silage.

During the 1990s a series of experiments were carried out at Hillsborough to examine the effects of rapid wilting in the field on the silage intake and performance of dairy cows (Patterson and others 1996 and 1998). These experiments involved a total of 4 comparisons of unwilted and wilted silages made from 11 crops of grass. The wilted grass was conditioned at mowing, spread immediately after mowing and tedded during the wilting period, which on average was 35 hours. On average, over the four comparisons, wilting increased the dry matter content of the silage from 19 to 32%. The silages were either treated with a bacterial inoculant as an additive prior to ensiling or received no additive, although the unwilted silages were generally reasonably well preserved, with an average ammonia nitrogen content of 9% of total nitrogen.

In this situation, wilting increased silage dry matter intake by 11%, increased milk yield by 0.5 kg/cow/day and increased milk fat content by 0.17% and protein content by 0.17% as shown in Table 25. In earlier experiments at Moorepark, Butler (1977) and Murphy and Gleeson (1984) obtained similar responses in performance when wilting took place under good conditions. Although the response in milk volume to wilting was modest, the overall response in fat plus protein yield was 7% which was equivalent to an increase of 1.4 kg of milk/cow/day at constant fat and protein contents. The results of these experiments show that wilting can produce positive effects on milk yield and composition, albeit the effects on milk yield have been fairly modest.

However, it is important to consider the benefits of wilting, other than its effect on animal performance, as these may well justify its use. For example, achieving a significant increase in the dry matter content of grass prior to ensiling reduces or even eliminates effluent production and hence the risk of pollution of waterways which is of paramount importance in any silage-making system. Wilting also reduces the erosion of concrete in silos and reduces the weight of material to be chopped and transported to the silo per tonne of dry matter ensiled. For example if grass is mown at a dry matter content of 15% and is wilted to 30% dry matter, this reduces the weight of fresh crop by 50%.

Wilting can also be an effective substitute for a silage additive. On average over the 4 comparisons, the results of which are summarised in Table 25, cows given wilted silage made with no additive produced 0.3 kg more milk/cow/day than the cows which received unwilted

TABLE 25 THE EFFECTS OF RAPID WILTING ON SILAGE INTAKE AND THE PERFORMANCE OF DAIRY COWS.
(AVERAGE RESULTS OF 4 COMPARISONS INVOLVING 11 CROPS OF GRASS)

	SILAGE	
	UNWILTED	WILTED
Composition of silage		
Dry matter (%)	19	32
Ammonia-N (% total N)	9	9
PERFORMANCE OF DAIRY COWS	RESPONSE TO WILTING	
Silage dry matter intake	Increased by 1.1 kg/cow/day or 11%	
Milk yield	Increased by 0.5 kg/cow/day	
Fat content	Increased by 0.17%	
Protein content	Increased by 0.17%	

silage made with an additive. The milk produced by the cows given the wilted silage made with no additive also contained 0.19% more fat and 0.20% more protein than the milk produced by the cows given unwilted silage made with an additive.

As discussed in the previous section, applying an additive to unwilted grass has been estimated to cost about £20/cow over a 160 day winter with an estimated return from increased production of only £13/cow. The results of the experiments undertaken by Patterson and others would indicate that rapid effective wilting of grass prior to ensiling can produce a greater response in milk yield and composition than applying an additive. In addition, applying an additive represents about 10% of the total cost of making silage and therefore producing wilted silage without an additive can considerably reduce the costs of silage making in comparison to producing unwilted, additive-treated silage.

The benefits of having silage effluent production reduced or totally eliminated, less erosion of concrete in the silo, less material to be transported to the silo and also a possible reduction in the costs of silage making by eliminating the use of an additive can justify the use of wilting whenever possible. However if a positive response in milk yield and composition can also be achieved through rapid drying in the field, as demonstrated at Hillsborough by Patterson and colleagues, this will contribute to a further reduction in the costs of producing milk from wilted silage.

SILAGE

1. Increasing the digestibility of grass silage by 7 percentage units increased milk yield by 2.6 kg/cow/day and increased milk protein content.
2. Cows which were given grass silage with a D-value of 72% plus 5.6 kg of concentrates/cow/day produced the same yield of milk as cows given silage with a D-value of 63% plus 9.6 kg concentrates/cow/day, but the cows which were given the high digestibility silage produced milk with higher fat and protein contents.
3. On the basis of the costings given in Table 28, the cows given the higher digestibility silage and lower input of concentrates produced a higher profit margin over feed costs.
4. On average over 26 comparisons, applying an inoculant additive to grass before ensiling did not improve the margin over feed costs as calculated in this review. However, an individual additive could produce an economic response, but it is important to ensure that all of the independent research information available for the additive supports the likelihood of this.
5. Prolonged wilting of grass under difficult conditions prior to ensiling has reduced the performance of dairy cows.
6. Rapid wilting under good conditions has produced a small positive response in milk yield and substantially increased milk fat and protein contents.
7. Wilting of grass prior to ensiling can be justified for reasons other than its effect on milk yield and composition, but if a positive response in milk yield and composition can also be obtained by using a good wilting technique, this will contribute to a reduction in the costs of producing milk from wilted silage.

The intake of grass silage has generally been found to be lower than that of fresh grass, especially high quality grazed grass. Consequently over the past few years there has been increasing interest in the use of silage made from whole-crop maize or wheat as a means of increasing the dry matter intake and milk production of high yielding dairy cows given grass silage-based diets.

Maize silage

The effect of including maize silage in the diet of cows given grass silage-based diets depends very much on the quality of both the maize silage and the grass silage which it replaces. While the digestibility of grass silage and hence its feeding value declines as the crop matures, the feeding value of maize silage has been found to increase as the crop matures up to a dry matter content of 30 to 35%, and up to a starch content of about 30%. For example, in two early experiments in the United States, Huber and others (1965) found that when cows were given maize silage with a dry matter content of 33%, silage dry matter intake was 15% higher and milk yield was 2 kg/cow/day higher than when they were given maize silage with a dry matter content of 25%.

Later research in Great Britain has shown similar effects. For example, Phipps and others (1979) found that cows given maize silage with a dry matter content of 30% produced 1.0 kg more milk/cow/day than cows given silage with a dry matter content of 25%. In a recent experiment, Phipps and others (2000) offered cows grass and maize silages at a ratio of 1:3 on a dry matter basis (i.e. 75% maize and 25% grass silage) and supplemented with 10 kg of concentrates/cow/day. Milk yields were 29.4, 33.0 and 30.8 kg/cow/day for cows given maize silages with dry matter contents of 23, 30 and 39% respectively.

Researchers in France also found that as the dry matter content of maize silage increased progressively from 20 to 35%, dry matter intake by dairy cows increased by over 40% (Demarquilly, 1988).

However in two recent experiments undertaken at Hillsborough in which cows were given mixtures of silages containing 60% grass silage and 40% maize silage on a dry matter basis, Keady and others (2002a) found that when the dry matter content of the maize silage was increased from 20 to 29%, there was no increase in dry matter intake, and milk yield was increased by only 0.5 kg/cow/day. Similarly, in a second experiment undertaken by Keady and others (2003) in which cows were also offered grass and maize silages in a ratio of 60:40 on a dry matter basis, increasing the dry matter content of the maize silage from 19 to 36% again increased milk yield by only 0.5 kg/cow/day.

Furthermore, in these two experiments further increases in the dry matter content of the maize silage from 29 to 38% in the first experiment and from 36 to 43% in the second experiment did not affect milk yield or the yield of fat plus protein.

Overall the results of experiments carried out in the United States, Continental Europe and in the UK indicate that the feeding value of maize silage increases as dry matter and starch contents increase up to 30% and then declines again slightly at higher dry matter contents.

In a series of six experiments undertaken in Great Britain, Weller and Phipps (1985) and Phipps and others (1988, 1991, 1992, 1995 and 2000) and in two experiments at Hillsborough, Keady and others (2002a and 2003) examined the effects of including a proportion of maize silage in diets for dairy cows based on medium to poor quality grass silage.

In six comparisons in which the silage offered to the cows contained either 100% medium quality grass silage with an average D-value of 66% or 66% grass silage and 34% good quality maize silage with a dry matter content of 31%, including maize silage in the diet increased milk yield by 1.6 kg/cow/day and increased milk protein content by 0.10% as shown in Table 26. The average concentrate intake in these studies was 7.3 kg/cow/day.

In seven comparisons in which the silage offered to the cows contained either 100% medium to poor quality grass silage with an average D-value of 64% or 25% grass silage and 75% good quality maize silage with an average dry matter content of 30%, including maize silage in the diet increased silage dry matter intake by 29% and increased milk yield by 2.8 kg/cow/day and increased milk protein content by 0.11% but reduced milk fat content by 0.09% (Table 26).

In the two recent experiments at Hillsborough, two

TABLE 26 THE EFFECT OF INCLUDING MAIZE SILAGE IN DIETS BASED ON MEDIUM QUALITY GRASS SILAGE

1. THE EFFECT OF FEEDING SILAGE CONTAINING 34% MAIZE SILAGE (31% DRY MATTER) AND 66% MEDIUM QUALITY GRASS SILAGE RATHER THAN 100% MEDIUM QUALITY GRASS SILAGE (D-VALUE 66%)	
	RESPONSE TO INCLUDING MAIZE SILAGE IN THE DIET
Silage dry matter intake	Increased by 16%
Milk yield	Increased by 1.6 kg/cow/day
Milk protein content	Increased by 0.09%
Milk fat content	Increased by 0.03%
2. THE EFFECT OF FEEDING SILAGE CONTAINING 75% MAIZE SILAGE AND 25% MEDIUM QUALITY GRASS SILAGE RATHER THAN 100% MEDIUM QUALITY GRASS SILAGE (D-VALUE 64%)	
	RESPONSE TO INCLUDING MAIZE SILAGE IN THE DIET
Silage dry matter intake	Increased by 29%
Milk yield	Increased by 2.8 kg/cow/day
Milk protein content	Increased by 0.10%
Milk fat content	Reduced by 0.09%

experiments at Moorepark (Fitzgerald and others, 1994; O'Mara and others, 1998) and one at Dumfries in Scotland (Hameleers, 1998) cows were given silage containing either 100% high digestibility grass silage with an average D-value of 72%, or 60% of these grass silages and 40% good quality maize silage with an average dry matter content of 30%. The average level of concentrate feeding was 7.0 kg/cow/day, which for cows of relatively high genetic merit, was a moderate level of feeding and would have enabled the cows to respond to a higher nutrient intake from maize silage. However in these experiments including maize silage in the diet did not affect milk yield and produced only a small increase in milk protein content of 0.04%, even though silage intake was increased by 7%, as shown in Table 27.

Similarly, in a series of four experiments undertaken by Cabon and Riviere (1990) in France cows were given either 100% good quality grass silage or 100% good quality maize silage. The grass silage had an average D-value of around 70% and the maize silage had an average dry matter content of 32% and contained 47% grain in the dry matter.

On average over the four experiments giving the cows maize silage rather than grass silage increased silage dry matter intake by 18% but did not affect milk yield, although it increased milk fat content by 0.18% and milk protein content by 0.11%.

In the two experiments at Hillsborough and one carried out at Moorepark by Fitzgerald and others (1994), including maize silage with a low dry matter content (21%) in a diet based on good quality grass silage reduced milk yield by 0.7 kg/cow/day but increased milk fat content by 0.27% and milk protein content by 0.06% as shown in Table 27.

Overall the results of research which has been undertaken to examine the effects of including maize silage in grass silage-based diets for dairy cows, have shown that the feeding value of maize silage increases with increasing dry matter content up to 30% dry matter and a starch content of 30%, and then declines slightly at higher dry matter contents.

Replacing a small proportion (34%) of low to medium quality grass silage in the diet with good quality maize silage has increased milk yield by 1.6 kg/cow/day and

TABLE 27 THE EFFECT OF INCLUDING GOOD AND POOR QUALITY MAIZE SILAGES IN DIETS BASED ON HIGH QUALITY GRASS SILAGE

1. THE EFFECT OF FEEDING SILAGE CONTAINING 40% MAIZE SILAGE (DRY MATTER CONTENT OF 30%) AND 60% HIGH QUALITY GRASS SILAGE RATHER THAN 100% HIGH QUALITY GRASS SILAGE (D-VALUE 72%)	
	RESPONSE TO INCLUDING MAIZE SILAGE IN THE DIET
Silage dry matter intake	Increased by 7%
Milk yield	No effect
Milk protein content	Increased by 0.04%
Milk fat content	Increased by 0.03%
2. THE EFFECT OF FEEDING SILAGE CONTAINING 40% MAIZE SILAGE (DRY MATTER CONTENT OF 21%) AND 60% HIGH QUALITY GRASS SILAGE RATHER THAN 100% HIGH QUALITY GRASS SILAGE (D-VALUE 73%)	
	RESPONSE TO INCLUDING MAIZE SILAGE IN THE DIET
Silage dry matter intake	Increased by 2%
Milk yield	Reduced by 0.7 kg/cow/day
Milk protein content	Increased by 0.06%
Milk fat content	Increased by 0.27%

increased milk protein content by 0.09%, while replacing a large proportion (75%) of medium to poor quality grass silage with good quality maize silage produced a much larger response in milk yield of 2.8 kg/cow/day and in protein content of 0.10% but reduced fat content by 0.09%.

When 40% of good quality grass silage was replaced by good quality maize silage, milk yield was not affected but there was a slight increase and in milk protein content (0.04%). However when 40% of good quality grass silage was replaced by poor quality maize silage (21% dry matter), milk yield was reduced by 0.7 kg/cow/day but milk fat content was increased by 0.27% and milk protein content by 0.06%.

It should also be noted that because of the low protein content in maize silage a concentrate with a high protein content was used with the maize silage in several of the experiments to enable the potential of the maize silage to be realised.

While the results of the experiments reviewed in this section have shown that the inclusion of maize silage in diets based on medium to poor quality grass silage significantly improved milk yield and composition, they have also shown that when maize silage is included in diets based on high quality grass silage the improvement in milk output has been confined largely to an improvement in milk quality. Consequently the financial benefits of using maize silage must be based largely on achieving a lower cost of production for maize silage than for good quality grass silage.

At present the cost of producing maize silage can compare favourably with those for grass silage in areas that are suitable for growing maize when arable area aid payments are available (Kilpatrick and others, 2001). However if direct payments from the EU are decoupled from production over the next few years, so that there are no subsidies available for growing maize silage, then a reappraisal of the relative costs of producing maize and grass silages should be undertaken at that time as current information would indicate that the costs of producing maize silage may then be greater than those for grass silage (Kilpatrick and others, 2001).

Whole-crop wheat

There is less research information available on the use of whole-crop wheat silage for dairy cows than on the use of maize silage. This may be at least partly because the results of experiments with whole-crop wheat have been less encouraging than those with maize silage.

In three experiments in Great Britain, Leaver and Hill (1995) and Phipps and others (1995) offered cows silage-based diets containing either 100% grass silage or 65% grass silage and 35% ensiled whole-crop wheat. The grass silages were slightly above average quality with an average D-value of around 68%, while the whole-crop wheat silages were of good quality with an average dry matter content of 35%.

On average over the three experiments, including ensiled whole-crop wheat in the diet increased silage dry matter intake by 12%, but had very little effect on milk yield or milk protein or fat contents and did not affect the yield of fat plus protein. The absence of a response in milk production despite the higher silage intake when whole-crop wheat was included in the diet is likely to have resulted from the lower digestibility and feeding value of the whole-crop wheat silage than the grass silage.

As the grass silages used in these experiments were only slightly better than average quality and there was no response in milk yield or milk composition to the inclusion of whole-crop wheat in the diet, extrapolation of these results would indicate that the inclusion of whole-crop wheat silage in a diet based on high quality grass silage may actually reduce milk yield.

Consequently on the basis of the limited amount of research information available, the substantially higher intake of whole-crop wheat silage than grass silage, combined with a lack of response in milk yield when whole-crop wheat silage is included in the diet, would indicate that the cost of producing whole-crop wheat silage would need to be less than 70% of the cost of producing reasonable quality grass silage per tonne of dry matter for it to be beneficial to include whole-crop wheat silage in the diet of dairy cows if arable aid payments are not available in the future. However the costings produced by Kilpatrick and others (2001) would indicate that this is unlikely to be the case.

Fodder beet

A further alternative approach towards achieving high dry matter intakes by high yielding dairy cows has been to include fodder beet in the diet. A series of six experiments have been carried out at Dumfries in Scotland by Roberts (1987), Sabri and Roberts (1988) and Fisher and others (1994), at Reading by Phipps and others (1995) and at Hillsborough by Ferris and others (2003). On average over these six experiments, cows were given reasonable quality grass silage with an average D-value of 69%, although some of the silages were not well preserved. The silages were supplemented with either 6.4 kg of concentrates/cow/day or with the same quantity of concentrates plus approximately 24 kg of fresh chopped fodder beet which provided about 4 kg of fodder beet dry matter/cow/day.

On average over the six experiments, including fodder beet in the diet reduced silage dry matter intake by 1.8 kg/cow/day and increased milk yield by 1.3 kg/cow/day, milk fat content by 0.13%, milk protein content by 0.15%, and either reduced live-weight loss or increased live-weight gain by 0.33 kg/day. Two of the experiments also included more than one level of concentrate feeding. In these experiments about 15 kg of fodder beet was required to produce the same response in milk yield as one kg of additional concentrates.

The cows which were given fodder beet ate about one kg less silage dry matter, so that to sustain a given milk yield, 15 kg of fresh fodder beet were equivalent to one kg of concentrates plus one kg of silage dry matter. However this does not take into consideration that feeding 15 kg of fodder beet/cow/day, produced much larger increases in milk fat and protein content and either a greater live-weight gain or a lower live-weight loss in the cows than feeding an extra kg of concentrates.

On the basis of the results which are summarised in Tables 7 to 12, increasing concentrate intake by one kg would be expected to reduce milk fat content by 0.01% and increase milk protein content by 0.03%, while on the basis of the results presented above feeding 15 kg of fodder beet would be expected to increase milk fat content by 0.08% and increase protein content by 0.09%.

It is also difficult to put a monetary value on the reduction in live-weight loss or increase in live-weight gain of cows which have been recorded when fodder beet has been fed, as this will vary depending on the circumstances on individual farms.

In situations in which excessive loss of body condition during early lactation, especially in high yielding cows, is a problem, on the basis of the results presented above, feeding fodder beet should be a more effective method of solving this problem than other methods of increasing the feed intake of cows such as improving silage quality or feeding more concentrates. However, in situations in which excessive weight loss is not a problem, feeding a large quantity of fodder beet may result in overfat cows.

Overall, the research results presented in this section, indicate that giving cows fodder beet, produced a smaller response in milk yield than that produced by the same increase in the energy intake of the cows in the form of additional concentrates. However, feeding fodder beet produced larger increases in milk fat and protein contents and in live-weight gain of the cows than what would normally be expected from a similar increase in energy intake in the form of concentrates.

Consequently the greatest value of fodder beet as a component of dairy cow rations is likely to be its potential to increase milk fat and protein contents and reduce the loss of body condition in high yielding cows during early lactation. However, washing and chopping fodder beet prior to feeding can be quite labour intensive and this should be taken into account when estimating the monetary value of fodder beet.

SUMMARY OF THE MAIN POINTS FROM THE REVIEW OF RESEARCH ON THE USE OF ALTERNATIVE FORAGES FOR DAIRY COWS

1. The effects of including maize silage in grass silage-based diets depends on the quality of the maize silage and the grass silage which it replaces.
2. Including good quality maize silage in diets based on medium quality grass silage increased milk yield by 1.6 kg/day and milk protein content by 0.09%.
3. Including maize silage in diets based on good quality grass silage has either not affected milk yield or reduced yield slightly depending on the quality of the maize silage, but still improved milk composition.
4. Including whole-crop wheat silage in the diet of dairy cows which were given average to good quality grass silage increased silage intake, but did not affect milk yield or milk composition.
5. Including fodder beet in the diet of dairy cows which were given reasonable quality grass silage, produced a smaller response in milk yield than what would normally be expected from a similar increase in energy intake by feeding extra concentrates. However feeding fodder beet increased milk fat content and produced a very large increase in milk protein content and either reduced the rate of live-weight loss or increased the rate of live-weight gain in the cows.

CHAPTER 9

MINIMISING THE COST OF MILK PRODUCTION THROUGH THE EFFICIENT USE OF GRAZED GRASS

Research carried out over several years and in several countries has shown that pasture-based systems of milk production have a more positive image with consumers, in that they are considered to be more environmentally friendly and provide better animal welfare and health with less dependence on antibiotics and other drugs. Hence systems involving grazing are socially more acceptable than intensive systems in which cows are kept and fed indoors throughout the year (Cheeke, 1999; Meyer and Mullinax, 1999; Subak, 1999; White and others, 2002).

Grazed grass is also the cheapest source of feed for dairy cows in Northern Ireland. The relative costs of grazed grass, grass silage and concentrates have been calculated and are presented in Table 28.

For the purpose of calculating these costs the following assumptions have been made:

1. Swards used for 2-cut and 3-cut silage systems, and grazed swards which were utilized efficiently and poorly were reseeded every 5, 8, 15 and 15 years respectively and costs of reseeding are based on those given by Kilpatrick and others (2001).
2. The 2-cut silage sward received 240 kg N; 25 kg P2O5 and 62 kg K2O fertilizer/ha, the 3-cut silage sward received 300 kg N; 25 kg P2O5 and 62 kg K2O fertilizer/ha, the efficiently grazed sward received 350 kg N; 25 kg P2O5 and 37 kg K2O fertilizer/ha and the poorly utilized sward received 300 kg N; 25 kg P2O5 and 37 kg K2O fertilizer/ha. All slurry was returned to the area which was harvested for silage.
3. The yields of grass for silage are based on yields obtained at Hillsborough, while yields under grazing are based on research results from several centres as discussed below. As there was a roadway or cow track through the cut and grazed swards, losses due to this are assumed to be the same for cutting and grazing. The cost of roadways through the grazing area are based on those given by Kilpatrick and others (2001) and assuming an optimal paddock layout. No costs are included for the roadway through the silage area as depreciation of this is considered to be minimal.
4. Harvesting costs per tonne of grass harvested, based on current contractor quoted prices, were 25% higher for the 3-cut system than for the 2-cut system, because even though the total weight of grass to be harvested, transported to the silo and ensiled per acre was slightly greater for the 2-cut system than for the 3-cut system, the swards had to be mown three times in the 3-cut system compared to only twice for the 2-cut system.
5. Labour for bringing the cows to and from the milking parlour, and for feeding, bedding and removing slurry from housed cows is charged at £6/hour. Labour costs for bringing cows to and from the parlour are much greater for cows which are at grass than for cows which are housed and fed silage and concentrates. On the other hand, cows which are housed and fed silage and concentrates incur substantial costs for labour and machinery for feeding, bedding and removing slurry which do not apply in the grazing situation. Consequently, it is important that these costs are included in any comparison of the costs of grazed grass, grass silage and concentrates.
6. Silage storage costs vary greatly depending on the type of silo involved. For example, costs per tonne of silage, are much greater for a roofed silo with purpose built tanks to collect the effluent, than if the effluent is collected in tanks which are used to collect slurry during the winter within the dairy buildings, or for an open clamp silo from which the effluent is collected in slurry tanks. The values used in Table 28 are around the middle of the range of costs. A cost of £1/tonne for storing concentrates has been included.
7. Land charges of £247/ha for grazing and £259 for cutting for silage are included in the costs [with an adjustment for the loss of production when the swards are being reseeded]. The grass harvested in two or three cuts of silage represented 80% of the total production from the sward for the year, except in the years when the swards were reseeded when it represented 94% of total production.
8. If it is assumed that land rental values of £247-259/ha are supported by the current system of direct payment subsidies within the beef, sheep and cereal sectors, then an adjustment to land rental values will be appropriate if decoupling of subsidy payments is introduced within the next few years. It is extremely difficult to predict what land rental values are likely to be if decoupling of subsidy payments takes place. However to examine what the impact of a major reduction in land rental values would be, the costs of grazed grass and silage when a land charge of £74/ha is assumed, have been included in Table 28.
9. A cost of £140/tonne is assumed for purchased concentrates. It is assumed that cows which are housed and fed silage are also fed concentrates and so a proportion of the costs of feeding, bedding and removing slurry are allocated to the concentrate part of the ration. However when cows are fed concentrates at pasture, most of these costs do not apply to them. This would give a total cost of £143/tonne for concentrates fed at grass and £153/tonne for concentrates fed to housed cows.

TABLE 28 RELATIVE COSTS OF GRAZED GRASS, GRASS SILAGE AND CONCENTRATES

	GRAZED GRASS EFFICIENTLY UTILIZED	GRAZED GRASS POORLY UTILIZED	GRASS SILAGE 2-CUT	GRASS SILAGE 3-CUT	CONCENTRATES
Herbage yield (tonnes DM/ha)	–	–	12.6	12.1	
Utilized yield (tonnes DM/ha)	10.5	7.5	9.8	9.4	
D-value (%)	74	70	63	71	
ME (MJ/kg DM)	11.8	11.2	10.1	11.4	
Costs (£/ha for forage, £/tonne for concentrates)					
Reseeding	24	24	71	45	
Fertilizer/lime/herbicide	175	146	126	151	
Fertilizer application	42	42	15	22	
Harvesting			247	296	
Polythene			5	5	
Storage			67	65	1
Fencing, roadways and water	60	60			
Topping		24			
Rolling			12	12	
Slurry application			29	27	
Labour for bringing cows to and from parlour	33	33	12	12	
Feeding, bedding and removing slurry					
(Labour, material and machinery)	–	–	142	136	12
Purchase	–	–	–	–	140
TOTAL COSTS	334	329	726	771	153
TOTAL COSTS INCLUDING LAND CHARGE					
£247/ha	584	579	941	983	153
£74/ha	408	403	787	831	153
Cost (pence/MJ ME)					
£247/ha land charge	0.47	0.69	0.95	0.92	1.37
£74/ha land charge	0.33	0.48	0.80	0.78	1.37

10. Other costs were generally based on those given by Kilpatrick and others (2001) and allowing for changes in prices since then.

On the basis of these assumptions, inefficiently utilized grazed grass costs almost 50% more per megajoule of metabolisable energy (ME) consumed by the cow than efficiently utilized grazed grass. The cost of silage, per megajoule of ME, is double the cost of efficiently utilized grazed grass, and the cost of concentrates is approximately three times that of grazed grass. However the cost of silage would be only 1.3 times the cost of inefficiently utilized grazed grass, while the cost of concentrates would be only double the cost of inefficiently utilized grass. Clearly, the economic benefits for milk production of Northern Ireland being a good grass-growing area are highly dependent on achieving efficient utilization of the grass by grazing cows. If a land charge of only £74/ha is applied in a post-decoupling scenario, then on the basis of the costings given in Table 28, silage would cost two and a quarter to two and a half times as much as efficiently utilized grass, while concentrates would cost over four times as much as efficiently utilized grass, assuming no major change in the price of concentrates post-decoupling.

Harvesting high yields of grass by grazing cows

There is a substantial amount of research information available on the yields of grass harvested per ha by silage harvesting equipment. For example, in a series of experiments carried out at Hillsborough, the yields of grass produced in two-cut and three-cut silage systems until late August were 12.6 and 12.1 tonnes of dry matter per ha respectively (Steen, 1996) and these values are used in Table 28.

However it is much more difficult to estimate the yields of grass harvested by grazing cows. In early work at Hillsborough, Steen (1978) estimated the yield of grass harvested by cows which were stocked tightly enough to achieve reasonably efficient utilization of grass, by estimating the yields of grass on the paddocks before and after they were grazed. The estimated yield harvested by the cows was 12.6 tonnes of dry matter per ha on average over two years. A similar yield (12.4 tonnes of dry matter/ha) was calculated from the energy requirements of the cows. In these experiments, at each grazing the cows consumed 45% of the total grass on the paddock measured to ground level. This is equivalent to about 75% of the grass available above 4 cm. In an experiment in which the cows were very laxly grazed so that they were consuming only about 30% of the grass above ground level in the paddock at each grazing, the quantity of grass consumed by the cows was estimated to be 10.1 tonnes of dry matter/ha. Similarly, in a farm scale study undertaken over three years in Wales, Evans (1981) recorded an average grass yield of 11.1 tonnes of dry matter/ha for grazed swards compared to a yield of 12.1 tonnes of dry matter/ha for swards which were cut for silage two or three times and grazed in the autumn. Also, in an extensive series of experiments which were carried out in the Netherlands using perennial ryegrass-based swards, Schils and others (1999) recorded an average yield of 13.3 tonnes of dry matter/ha when the grass was harvested by grazing dairy cows compared to 12.8 tonnes of dry matter when the grass was harvested mechanically after similar growth intervals. Schils and others (1999) also found that when perennial ryegrass-based swards were harvested for silage in early to mid May and after a six week growth interval and were grazed for the remainder of the season, the total yield of grass was 13.3 tonnes of dry matter/ha compared to a yield of 13.1 tonnes of dry matter/ha when the swards were harvested mechanically once after a 5 week growth interval and then grazed by dairy cows for the remainder of the season.

In early work undertaken at Moorepark, Co Cork, McFeely and others (1975) and McFeely (1978) found that when grass swards were harvested mechanically at very frequent intervals, yield was depressed compared to less frequent harvesting, while frequent grazing by dairy cows did not depress output compared to less frequent grazing. For example, when swards were grazed at two week or four week intervals throughout three grazing seasons, average milk yield over the three years was 1% higher for the two week grazing interval than for the four week grazing interval. On the other hand, when the swards were harvested mechanically at two or four week intervals, throughout the growing seasons, yield was 33% lower for the two week than for the four week harvesting interval.

Alternatively, for a recent estimate of the relative costs of grazed grass and silage in Northern Ireland, Kilpatrick and others (2001) estimated the yield of grass utilized by grazing cows by taking the yield which has been produced by swards harvested mechanically at similar intervals, and then assuming that grazing cows harvest 75% of this yield, and that the other 25% is lost. However the results of the research which has actually involved grazing dairy cows, and which are discussed above would very much question the validity of this method of estimating the yield of grass harvested by grazing dairy cows. Although there is some death and decay of herbage within swards which are grazed, there is also death and decay of herbage in the base of silage swards. Also, although cows may consume only 75% or less of the grass in a paddock at any one grazing, the stubble which is left does not necessarily "disappear" before the next grazing so that cows can harvest as much grass over the total growing season as would be harvested by mechanical equipment.

From the research findings discussed above it can be concluded that, under good grazing management, yields of grass harvested by grazing dairy cows have been similar to those harvested mechanically, and that frequent harvesting of grass swards by grazing cows produced a very different effect on output than frequent harvesting with mechanical equipment.

Herbage intake by grazing dairy cows

While the information discussed above clearly shows that high yields of grass can be harvested by grazing dairy cows, it is also important that this is efficiently converted to milk which requires a reasonably high intake of grass/cow/day. Intakes of grass by grazing dairy cows have been estimated in many experiments carried out in several countries. The results of some of these which are likely to be relevant to grazing conditions in Northern Ireland are summarised in Tables 29 and 30.

Higher yielding cows have a greater drive to consume more feed than lower yielding cows, and so usually have higher grass intakes than lower yielders. Consequently the research information on grass intakes of cows has been divided into that which relates to cows producing more than 25 kg of milk/day and that which relates to cows producing less than 25 kg/day. As well as estimated dry matter intakes and milk yields, information on concentrate supplementation and the gain or losses of body condition are also shown. This is important, as high yielding cows can produce very high yields of milk at grass in the short term by rapidly mobilising body reserves to sustain a level of milk production substantially above what their intake of grass can produce. However this is not sustainable in the longer term and so when considering the potential yields of milk which can be produced from grass, it is important that the cows are either maintaining or gaining body condition or have only a slight loss of body condition which is normally acceptable during early lactation from a cow health perspective.

In the experiments listed in Tables 29 and 30 the availability of grass to the cows was restricted slightly to ensure reasonably efficient utilization of grass, but was not restricted severely enough to cause a major depression in grass intake and milk yield. To quantify the extent of this restriction, in most of the experiments the cows were given a liberal allowance of grass as well as the slightly restricted allowance and grass dry matter intake was just over one kg/cow/day lower with the restricted allowance than with the liberal allowance.

In the seven experiments which are summarised in Table 29, cows were producing over 25 kg of milk/cow/day. These were undertaken at Moorepark by Dillon and Buckley (1998), in England by Arriaja-Jordon and Holmes (1986), in France by Peyraud and others (1996) and in Australia by Dalley and others (1999) and Stockdale (2000). On average over the seven experiments the cows consumed 18.5 kg of grass dry matter/cow/day and produced an average yield of 29 kg of milk/cow/day. In four of the experiments, the cows received no concentrates, while in the two experiments undertaken at Moorepark, and the one undertaken in England, they received 1.0 kg of concentrates/cow/day.

In six of the seven experiments, the cows were either maintaining body condition or had a slight increase in body condition, while in one experiment they experienced a slight loss of condition. However, on average over the seven experiments the cows had a slight increase in body condition, even though they were producing 29 kg milk/cow/day from pasture with a concentrate intake of only 0.4 kg of concentrates/cow/day. These results would indicate that when ground conditions are satisfactory and the weather is reasonable, grass

TABLE 29 GRASS DRY MATTER INTAKES AND MILK YIELDS IN EXPERIMENTS IN WHICH GRASS AVAILABILITY WAS SLIGHTLY RESTRICTED TO ACHIEVE EFFICIENT UTILIZATION OF GRASS. (AVERAGE RESULTS FOR 7 EXPERIMENTS IN WHICH THE COWS WERE PRODUCING MORE THAN 25 KG MILK/COW/DAY)

Herbage dry matter intake	18.5 kg/cow/day
Concentrate intake	0.4 kg/cow/day
Milk yield	29 kg/cow/day
Change in body condition score	Slight increase in condition score

produced during the spring and early summer can sustain milk yields of around 30 kg/cow/day without the cows losing body condition.

Dry matter intakes can also be estimated from the energy requirements of the cows. For example, a typical Holstein cow producing 30 kg of milk/day and maintaining body condition would require approximately 215 MJ of ME/day or about 18 kg of good quality grass dry matter during the spring and early summer. The fact that the cows in the experiments listed in Table 29 were producing 29 kg of milk/cow/day, and had a slight increase in body condition would indicate that the estimated intake of 18.5 of grass dry matter/cow/day was a reasonably accurate estimate of their intake.

While the information presented above would indicate that grass can sustain a milk yield of around 30 kg/cow/day under reasonably good grazing conditions, when ground conditions and/or the weather are poor, substantially lower milk yields are likely to be sustained by grazed grass, as discussed later in this chapter. Also the nutritive value of grass has been found to decline during the latter part of the grazing season, and so milk yields of around 25 kg/cow/day in mid to late summer and 20 kg/cow/day in autumn are likely to be realistic targets for yields sustainable from grass.

Grass dry matter intakes and milk yields for cows which were producing less than 25 kg of milk/cow/day are presented in Table 30. These experiments were undertaken at Moorepark by Stakelum (1986a, 1986b and 1986c); Stakelum and others (1995); Dillon and others (1995) and Dillon and Buckley (1998); in France and the Netherlands by Peyraud and others (1996); Delagarde and others (1997) and Meijs and Hoekstra (1984) and in Australia by Grainger and Matthews (1989).

In these experiments grass availability was restricted slightly to achieve reasonably efficient grass utilization but was not severely restricted. The cows used by Grainger and Matthews were Jersey crosses of only 454 kg live weight and so an intake has been estimated for this experiment for a typical 600 kg Holstein cow. The two experiments which were undertaken by Dillon and others (1997) at Moorepark were carried out during very wet weather with poor ground conditions. Rainfall was 40 to 76% above normal. The data for the last three experiments listed relate exclusively to heifers in their first lactation while the other data relate mainly to cows in their second or later lactation, with only about 10% heifers in the experiments.

Average grass dry matter intakes in the experiments which were carried out under reasonable grazing conditions were 17 kg dry matter/cow/day for cows and 15 kg of dry matter/day for heifers. In the two experiments undertaken during bad weather with poor ground conditions, the dry matter intake of cows was 14.6 kg/cow/day. The results of these experiments indicate that under reasonable grazing conditions cows producing less than 25 kg of milk/cow/day can consume about 17 kg of grass dry matter/cow/day, which should enable cows in mid or late lactation to gain body condition and so offset losses in body condition which may have occurred during early lactation. These results also indicate that grass intakes may be about 15 to 20% lower for heifers in their first lactation than for mature cows. The results of the experiments undertaken by Dillon and others also emphasize the point that grass dry matter intakes during bad weather with difficult ground conditions, were about 20% lower than those generally recorded under more favourable grazing conditions.

TABLE 30 GRASS DRY MATTER INTAKES AND MILK YIELDS IN EXPERIMENTS IN WHICH THE AVAILABILITY OF GRASS WAS SLIGHTLY RESTRICTED TO ACHIEVE EFFICIENT UTILIZATION OF GRASS. (Data for cows producing less than 25 kg milk/cow/day)

(1) AVERAGE RESULTS FOR 8 EXPERIMENTS DURING WHICH GRAZING CONDITIONS WERE SATISFACTORY	
Grass dry matter intake	17 kg/cow/day
Milk yield	19 kg/cow/day
Concentrate intake	0.2 kg/cow/day
Change in body condition	Slight increase in body condition
(2) AVERAGE RESULTS FOR TWO EXPERIMENTS DURING WHICH GRAZING CONDITIONS WERE POOR	
Grass dry matter intake	14.6 kg/cow/day
Milk yield	24 kg/cow/day
Concentrate intake	Zero
Change in body condition	Cows losing condition
(3) AVERAGE RESULTS OF THREE EXPERIMENTS INVOLVING ONLY HEIFERS	
Grass dry matter intake	15 kg/cow/day
Milk yield	21 kg/cow/day
Concentrate intake	0.5 kg/cow/day
Change in body condition	Slight increase in body condition

Grazing management

The main objectives of good grazing management are to manage the grass and the cows to ensure that the cows have adequate high quality grass throughout the grazing season so that a high grass intake and a high level of animal performance are sustained, while at the same time avoiding under-utilization of the sward and wastage of grass. These objectives are best achieved by ensuring that the cows are turned out as early in the spring as is practicable and that the correct stocking rate is used throughout the grazing season, so that the feed requirements of the cows are closely matched to the rate of grass growth.

However achieving efficient utilization of pasture while at the same time maintaining high levels of individual animal performance necessitates a high standard of skill and grazing management. The results of several experiments have shown that an inadequate supply of grass can reduce the milk yield of cows, especially high yielding cows by 2 to 5 kg/cow/day (Grainger and Matthews, 1989; Peyraud and others, 1996; Stockdale, 2000). On the other hand, having an excessive quantity of grass on the paddocks before grazing so that the sward is becoming stemmy at the base, or under-grazing due to too low a stocking rate resulting in stemmy low digestibility grass on the paddocks for subsequent grazing has also been shown to reduce milk yield. For example, Stockdale (1999) found that when the digestibility of the sward was reduced by 4 percentage units, milk yield was reduced by about 2 kg/cow/day, while Fisher and others found that when the digestibility of the sward was reduced by about 9 percentage units, milk yield was reduced by 2 to 3 kg/cow/day, even though the cows were given 5 kg of concentrates/cow/day. Similarly in work at Hillsborough, Christie and others (2000) found that increasing the height of swards before grazing from 25 to 40 cm, increased the yield of grass on the sward by 123%, but reduced milk yield by 5 kg/cow/day, even though the sward with the higher yield of grass before grazing was not grazed off as closely as the sward with the lower yield. These results emphasize the importance of having good dense swards of high quality grass about 15 to 25 cm high before grazing, and of avoiding very high yields of grass which are difficult to utilize, or alternatively of having too little grass so that intake is severely restricted.

Research findings have generally shown that the aim should be to have a post-grazing stubble height of approximately 7 cm in the spring and early summer, and 8 to 9 cm in the later summer and autumn to achieve efficient utilization of grass, while at the same time avoiding a severe restriction of grass intake by the cow.

Research at Hillsborough has clearly shown that achieving efficient utilization of high quality grass, while at the same time avoiding having a shortage of grass requires careful planning and budgeting of grass supply. Decisions to increase the grazing area or take paddocks out of the grazing cycle and harvest them for silage need to be taken early, otherwise the action will not be as effective in correcting the supply of grass. Also when a decision is taken to remove paddocks from the grazing cycle they should be cut for silage as soon as possible, as delaying cutting until there is a greater yield of grass, has often resulted in a shortage of grass later, because the regrowth on the paddocks is slower following the harvesting of a heavier crop of grass.

Alternatively when there is a shortage of grass, either the grazing area should be extended by using silage aftermaths, or if these are not available, the cows should be given concentrates, or if the shortage is severe, silage and concentrates. Speeding up the rate of the rotation around the paddocks when there is a shortage of grass has been found to exacerbate the shortage of grass, because this further reduces the overall rate of grass growth (Mayne and others, 1997). Instead, it has been found that increasing the length of the rotation (i.e. slowing down the rotation), by feeding concentrates and silage has been the most effective method of increasing the supply of grass in the longer term.

SUMMARY OF THE MAIN POINTS FROM THE REVIEW OF RESEARCH ON THE EFFICIENT USE OF GRAZED GRASS

1. Efficiently utilized grazed grass has been estimated to cost only half as much as grass silage and only a third of the cost of concentrates per megajoule of ME utilized by dairy cows.
2. With good grazing management, the yields of grass harvested by grazing dairy cows have been similar to those harvested by silage harvesting machinery.
3. Under satisfactory grazing conditions in spring and summer, high yielding cows have consumed 18 to 19 kg of grass dry matter/day which can sustain a milk yield of around 30 kg/day without cows losing body condition.
4. Lower yielding cows have consumed around 17 kg of grass dry matter/cow/day under reasonable grazing conditions, which has enabled the cows to produce around 20 kg of milk/cow/day and gain body condition.
5. Grass dry matter intakes have been substantially lower during wet weather with poor ground conditions.
6. Achieving a high intake of grass dry matter/cow/day, while at the same time achieving efficient utilization of the pasture requires a high standard of grazing management.
7. Under-utilization of grass during the early grazing season has reduced grass quality and milk yield during the later grazing season.

As discussed earlier in this chapter, milk production from good quality grazed grass is normally limited to around 30 kg/cow/day in spring and early summer, 25 kg in mid to late summer and around 20 kg in autumn, if a significant loss in the body condition of the cows is to be avoided. Furthermore, during bad weather with difficult ground conditions, milk yields sustained by grazed grass may be considerably less than these. There may also be periods when the quantity of grass available for grazing is severely limited by factors such as cold weather or drought, which result in very slow rates of grass growth.

In several experiments, the response in milk yield to concentrate supplementation has been substantially greater when the intake of grass has been severely restricted than when the intake of grass has been only slightly restricted to achieve fairly efficient utilization of grass. Therefore these two situations will be dealt with separately.

Supplementation of pasture when there is adequate grass available

Responses in milk yield to concentrate supplementation at pasture have also been found to depend on the potential milk yield of the cow. Responses to concentrate supplementation in 10 experiments in which the milk yield of the cows was less than 25 kg/cow/day are summarised in Table 31. These were undertaken at Moorepark by Stakelum (1986a, 1986b and 1986c) and Murphy and others (1995) in the UK by Jennings and Holmes (1984) and in Australia, France and Finland by Grainger and Matthews (1989); King and others (1990); Opatpatanakit and others (1993); Hoden and others (1991) and Khalili and Sairanen (2000).

On average over the 10 experiments, feeding four kg of concentrates/cow/day increased milk yield by 1.5 kg/cow/day or 0.37 kg of milk/kg of concentrates, and increased milk protein content by 0.07% but reduced milk fat content by 0.16%. In these experiments feeding concentrates reduced estimated grass intake by about 0.4 kg of dry matter/kg of concentrates fed. On the basis of the costings given in Table 28, the cost of concentrates minus the saving in the amount of grass eaten is equivalent to 12 p/kg of concentrates fed. If the price of milk is taken as 18 p/litre, then a response of 0.67 kg of milk is normally required to cover the cost of feeding one kg of concentrates. However if the cows are in very poor body condition for some reason, and extra feed is required to improve body condition in preparation for the next lactation, then the value of the extra body condition produced by feeding concentrates needs to be taken into account and so in this situation it may be economical to feed concentrates even if the response in milk yield is less than 0.67 kg/kg of concentrates. Nevertheless, as the value of the extra milk produced in the experiments summarised in Table 31, was equivalent to less than half of the cost of the concentrates required to produce it, it is highly unlikely that it would have been economical to feed concentrates to the cows used in these experiments when they had an adequate supply of grass, unless in exceptional circumstances.

Responses to concentrate supplementation in 16 experiments in which the cows were producing more than 25 kg of milk/cow/day are summarised in Table 32. These experiments were carried out in the UK and Ireland

TABLE 31 RESPONSES TO CONCENTRATE SUPPLEMENTATION OF PASTURE IN COWS PRODUCING LESS THAN 25 KG MILK/COW/DAY. (AVERAGE RESULTS OF TEN EXPERIMENTS)

	CONCENTRATE INTAKE (KG/COW/DAY)	
	0.1	4.1
Milk yield (kg/cow/day)*	17.0	18.5
Milk fat content (%)	4.02	3.86
Milk protein content (%)	3.30	3.37

* Milk yield was increased by 0.37 kg/kg concentrate fed

TABLE 32 RESPONSES TO CONCENTRATE SUPPLEMENTATION OF PASTURE IN COWS PRODUCING MORE THAN 25 KG MILK/COW/DAY. (AVERAGE RESULTS OF 16 EXPERIMENTS)

	CONCENTRATE INTAKE (KG/COW/DAY)	
	1.1	6.3
Milk yield (kg/cow/day)*	25.4	29.0
Milk fat content (%)	3.79	3.60
Milk protein content (%)	3.10	3.18

* Milk yield was increased by 0.69 kg/kg additional concentrates

by Sayers and others (2001); Jennings and Holmes (1983 and 1984); Wilkins and others (1994 and 1995); Arriaja-Jordan and Holmes (1986); Dillon and others (1997) and Dillon and Buckley (1998) and in France, the United States and Australia by Delaby and others (2001); Hoden and others (1991); Reis and Combs (2000); Bargo and others (2002) and Stockdale (2000).

The magnitude of the responses obtained in these experiments has been very variable, ranging from a very uneconomical response of 0.23 kg of milk/kg of concentrates fed, to a very economical response of 1.12 kg of milk/kg of concentrates fed. Responses to concentrates given at pasture may vary depending on several factors including the potential milk yield of the cows, prevailing weather conditions and the quality of the grass available. For example, Hoden and others (1991) obtained responses in milk yield of 0.50, 0.70 and 0.75 kg/kg of concentrates fed to cows producing 25, 30 and 35 kg of milk/cow/day respectively at the beginning of the grazing period.

In the experiments carried out by Dillon and others (1997); Dillon and Buckley (1998); Delaby and others (2001) and Stockdale (2000) the cows were producing 27 to 35 kg of milk/cow/day at the start of the experiments, while those used by Sayers and others (2001) at Hillsborough and by Reis and Combs (2000) and Bargo and others (2002) were high genetic merit cows producing 40 to 46 kg of milk/cow/day at the start of the experiments. Those undertaken by Reis and Combs (2000) and Bargo and others (2002) in the United States involved cows which produced 10,500 to 11,500 kg of milk/lactation, although the swards used in these experiments would not have been of as high a quality as those normally available to dairy cows in Northern Ireland. On average over the 16 experiments, the response in milk yield and composition was approximately equal to the cost of the feed required to produce it. Therefore in this situation the economics of feeding concentrates at grass are likely to be determined by the need to maintain the body condition of high yielding cows, and the impact of this on the health and fertility of the cows and on production in the long term. For example, Dillon and others (1997) found that feeding 4 kg of concentrates/cow/day for two months during bad weather improved the reproductive performance of the cows, while Dillon and Buckley (1998) found that feeding concentrates to high genetic merit cows during better grazing conditions did not affect fertility.

On the basis of the energy requirements of the cows and the grass dry mater intakes recorded in recent experiments, Mayne and others (2000) suggested the concentrate inputs shown in Table 33 for high yielding cows at pasture.

However, it should be noted that these are likely to apply to cows in their second or later lactation under reasonable grazing conditions. As discussed earlier, first lactation heifers have had lower grass intakes than mature cows and they also have an additional energy requirement for growth. Consequently concentrate requirements of heifers are likely to be substantially higher than those of mature cows with the same milk yield. Alternatively the concentrate requirements of heifers may be similar to those of the mature cows in the herd, even though they are producing substantially less milk. Furthermore, as discussed earlier, grass dry matter

TABLE 33 SUGGESTED CONCENTRATE FEED LEVELS FOR HIGH YIELDING COWS WHEN GRASS AVAILABILITY IS SLIGHTLY RESTRICTED TO ACHIEVE REASONABLY EFFICIENT UTILIZATION OF GRASS, BUT NOT SEVERELY RESTRICTED

	EARLY SEASON			LATE SEASON	
Milk yield (kg/day)	25	35	40	25	35
Suggested concentrate feed level (kg/day)	0	4.5	7.0	4.0	8.5

(From Mayne and others, 2000)

intakes can be substantially lower when the weather is bad and/or ground conditions are poor. Consequently, concentrate requirements are likely to be higher during periods of bad weather.

The effects of feeding silage as a supplement to pasture have also been examined in a number of experiments in which the cows had an adequate supply of grass. However, offering silage to cows as a supplement to an adequate supply of grazed grass has generally not increased milk yield. In fact, offering cows at pasture either grass or maize silage has resulted in a slight reduction in milk yield on average over several experiments (Phillips, 1988; Holden and others, 1995 and O'Brien and others, 1996).

A further alternative approach to achieving high feed intakes in high yielding cows which has been examined in a number of experiments is to offer the cows very liberal quantities of grass. However, in the majority of experiments in which this approach has been examined, the responses in milk yield to grazing cows very laxly rather than with a slightly restricted supply of grass have been relatively low compared to those which have been obtained from feeding a modest input of concentrates. In two experiments undertaken at Moorepark by Stakelum and Dillon (1990 and 1991), a 22% reduction in stocking rate increased milk yield/cow by only 1.0 kg/day, but reduced milk yield/ha of pasture grazed by 18%. Similarly, in a series of three experiments at Moorepark, Stakelum (1986a, 1986b and 1986c) offered cows either a slightly restricted supply of grass or an ad libitum supply. Increasing the allowance of grass increased milk yield by only 0.5 kg/cow/day while giving the cows about 4 kg of concentrates/cow/day increased milk yield by 1.4 kg/cow/day. In two experiments in France, Delaby and others (2001) found that offering grass ad libitum rather than a slightly restricted supply increased milk yield by 0.6 kg/day, while in this case offering the cows 6 kg of concentrates/cow/day increased milk yield by 5.7 kg/cow/day.

Furthermore, Stakelum (1993) found that when cows were grazed laxly during the early grazing season, milk yield/cow increased slightly at this stage, but the lax grazing during the early season reduced the digestibility of the grass available later in the season. As a result of this, milk yield was reduced during the later grazing season, so that on average over five grazing seasons, lax grazing during the early season actually reduced total milk yield/cow over the total grazing season. These results again emphasize the importance of maintaining high quality, leafy swards throughout the grazing season.

However in other experiments more severe restrictions in herbage intake have produced major depressions in milk yield. For example, Peyraud and others (1996) found that reducing the quantity of grass available to cows by about 30% reduced milk yield by over 3 kg/cow/day, while Stockdale (2000) obtained a similar reduction in milk yield when herbage allowance was reduced. Also when Maher and others (1997) restricted the grass availability fairly severely to 16 kg of dry matter/cow/day above 3.5 cm, milk yield was reduced by 2.3 kg/cow/day and milk protein content was reduced by 0.11%.

Supplementation of pasture when there is a very restricted supply of grass available

Several experiments have shown that the response in milk yield to concentrate supplementation of pasture is considerably greater when herbage supply is severely restricted than when adequate grass is available. For example, on average over five experiments undertaken by Mayne (1991); Grainger and Matthews (1989); Robaina and others (1998); Delaby and others (2001) and Bargo and others (2002) the response in milk yield to concentrate supplementation was approximately 50% greater when grass availability was severely restricted than when the cows had adequate grass. Furthermore in the study undertaken at Hillsborough by Mayne (1991), the response to concentrate supplementation was almost five times greater when the availability of grass was severely restricted than when the cows had a very liberal supply of grass. When the supply of grass is severely restricted cows may require supplementation with silage as well as higher levels of concentrate supplementation, depending on the severity of the shortage of grass. Feeding high levels of concentrates as supplements to grazed grass without the inclusion of silage in the diet can result in very low milk fat contents.

The effect of the type of concentrate offered as a supplement to grazed grass

Several experiments have been carried out to compare cereal-based concentrates with a high starch content and concentrates with a high content of digestible fibre based on ingredients such as sugarbeet pulp for dairy cows at pasture. The results of seven comparisons of high starch, cereal-based concentrates and concentrates with a high content of digestible fibre and a low starch content are summarised in Table 34. These experiments were carried out at Hillsborough by Sayers, Mayne and Barthram (2000); in Great Britain by Garnsworthy (1990) and Fisher and others (1996) and in Finland by Khalili and Sairanen (2000). On average over the seven comparisons, the type of concentrate had little effect on milk yield, but the high fibre concentrates produced a higher milk fat content while the high-starch concentrates produced a slightly higher milk protein content. In the two comparisons at Hillsborough, grass intake was higher when the cows were given the high-fibre concentrate, which would appear to have offset the lower energy content of this concentrate in comparison with the high-starch concentrate, and so milk yields were similar for the two concentrates. However it is important to note that a high intake (11.4 kg/cow/day) of the high-starch concentrate resulted in a severe depression in milk fat content. In view of this, it is considered to be prudent to use a good quality concentrate containing both cereals and ingredients with a high content of digestible fibre depending on the price of the various ingredients, but avoiding low energy ingredients such as rice bran and sunflower meal.

In contrast to the results of the experiments discussed above, in which the high-starch concentrates were based mainly on barley, in a series of three experiments undertaken in Germany, Schwarz and others (1995) offered zero grazed dairy cows supplements based on sugarbeet pulp or maize meal. In this case the response in milk yield to supplementation with maize meal was almost double the response to sugarbeet pulp. While the results of these experiments may not be directly applicable to dairy cows grazing in Northern Ireland, they do merit further investigation into the value of maize meal as a supplement for grazing dairy cows, especially in view of the very positive results which have been obtained at Hillsborough when maize meal has been offered as a supplement to grass silage for beef cattle instead of other feedstuffs such as barley, wheat and high-fibre by-product feedstuffs.

The effect of the protein content of concentrates given

TABLE 34 THE EFFECTS OF OFFERING DAIRY COWS AT PASTURE CONCENTRATES WITH EITHER A HIGH STARCH CONTENT OR A HIGH CONTENT OF DIGESTIBLE FIBRE. (Average results of five comparisons)

	CONCENTRATE TYPE	
	HIGH STARCH	HIGH FIBRE
Concentrate intake (kg/cow/day)	5.6	5.6
Milk yield (kg/cow/day)	25.6	25.5
Milk fat content (%)	3.76	4.03
Milk protein content (%)	3.30	3.25

TABLE 35 THE EFFECT OF THE PROTEIN CONTENT OF CONCENTRATES OFFERED TO DAIRY COWS AT PASTURE ON MILK YIELD AND COMPOSITION (AVERAGE RESULTS OF 15 COMPARISONS)

	PROTEIN CONTENT OF CONCENTRATES (%)	
	11	25
Concentrate intake (kg/cow/day)	5.2	5.2
Milk yield (kg/cow/day)	24.6	24.8
Milk fat content (%)	3.64	3.58
Milk protein content (%)	3.15	3.15

to dairy cows at pasture or zero grazed has also been examined in a number of experiments. The results of 15 comparisons of low and high protein concentrates are summarised in Table 35. These experiments were undertaken at Hillsborough by Sayers and Mayne (1998); at Moorepark by Dillon and Stakelum (1990); in Great Britain by Castle and others (1979) and Jennings and Holmes (1983 and 1984) in France by Delaby and others (1996) and in the United States by McCormick and others (2001) and Jones-Endsley (1997). On average over the 15 comparisons, increasing the protein content of the concentrates offered with grass from 10 to 24% increased milk yield by only 0.2 kg/cow/day and reduced milk fat content. The average response in milk yield was less than the cost of the extra feed required to produce it. High protein intakes have also been found to reduce the fertility of dairy cows in several experiments as discussed in Chapters 4 and 14. However, the protein content of the high protein concentrates used in some of these comparisons was very high and there was a positive response to protein in some of the experiments. In view of this, it may be prudent to use concentrates with a protein content of about 15%, rather than lower protein concentrates for dairy cows at pasture.

SUMMARY OF THE MAIN POINTS FROM THE REVIEW OF RESEARCH ON FEEDING CONCENTRATES AND OTHER FEEDSTUFFS TO COWS AT PASTURE

1. Cows which were producing less than 25 kg of milk/cow/day and which had an adequate supply of grass did not produce an economic response to concentrate supplementation.
2. Cows which were producing more than 25 kg of milk/cow/day and which had an adequate supply of grass produced an economic response to feeding about 6 kg of concentrates/cow/day in some experiments but not in others, the magnitude of responses having been very variable.
3. Feeding grass or maize silage as a supplement to an adequate supply of grass has not increased milk yield.
4. Offering cows very liberal allowances of grass rather than a slightly restricted allowance as a means of increasing feed intake has produced a small increase in milk yield relative to that achieved from feeding 4 to 6 kg of concentrates/cow/day, and has also resulted in considerable difficulty in managing grass swards in some situations.
5. A severe restriction of the availability of grass has resulted in major reductions in milk yield.
6. Offering high yielding cows a slightly restricted allowance of grass to achieve reasonably efficient utilization of the pasture, and supplementing with the quantities of concentrates which are shown in Table 33 has been most appropriate during reasonable grazing conditions.
7. Grass intakes have been lower during bad weather and so higher levels of concentrate supplementation than those shown in Table 33 are likely to be most economical.
8. The most appropriate approach to supplementation of pasture for high yielding cows may be to provide sufficient concentrates to prevent a major loss of body condition, as this is likely to result in optimum health and production in the long term.
9. First lactation heifers have had lower grass intakes than mature cows, and so, are likely to require more concentrates than mature cows with the same milk yield.
10. Supplementing grass with concentrates containing high contents of starch or digestible fibre has produced similar milk yields, but high-starch concentrates have resulted in a higher milk protein content and a lower milk fat content.
11. Supplementing pasture with high-protein concentrates rather than with low-protein concentrates produced only a small response in milk yield. As high protein intakes can also reduce the fertility of dairy cows, as discussed in Chapter 4, concentrates with a relatively low protein content (up to 15%) are likely to be most appropriate for cows grazing good quality pasture.

CHAPTER 11

EXTENDING THE GRAZING SEASON

As grazed grass is the cheapest source of feed for dairy cows in Northern Ireland (Table 28) a number of experiments have been undertaken at Hillsborough and Moorepark to examine the effects of turning cows out to pasture earlier in the spring or keeping them out later in the autumn on milk yield and composition. The results of six experiments carried out at Hillsborough by Mayne and Laidlaw (1995); Mayne and others (1997) and Sayers and Mayne (2001) and at Moorepark by Dillon and Crosse (1994) are summarised in Table 36. Four of these involved turning cows out early in the spring for a few hours/day, while the other two involved allowing them out to pasture for 3 hours/day for an extra four weeks in the autumn. Some of the cows were in early lactation while others were in late lactation, just prior to drying off.

The results of the six experiments are very consistent in that allowing cows access to spring or autumn pasture for an average of 3 hours/day, increased milk yield by 2 to 3 kg/cow/day and milk protein content by 0.16%, although the effect on milk fat was more variable, but overall it was increased by 0.18%. However in a further experiment, Ferris, Gordon and Patterson (2001) obtained no response in milk yield or composition to allowing cows access to pasture during late winter. However the management of the cows in this experiment was very different from the management in the other six experiments. In the five experiments undertaken at Hillsborough by Mayne and Laidlaw (1995); Mayne and others (1997) and Sayers and Mayne (2001) the cows varied from cows in early lactation which received good quality silage and 6 kg

TABLE 36 THE EFFECTS OF ALLOWING COWS ACCESS TO PASTURE FOR A FEW HOURS EACH DAY IN EARLY SPRING OR LATE AUTUMN ON MILK YIELD AND COMPOSITION

(1) EFFECT OF ALLOWING COWS ACCESS TO PASTURE FOR 3 HOURS/DAY IN EARLY SPRING. (AVERAGE RESULTS OF FOUR EXPERIMENTS)		
	ACCESS TO PASTURE	
	NO ACCESS	AT PASTURE 3 HOURS/DAY
Concentrate intake (kg/cow/day)	5	5
Silage dry matter intake (kg/cow/day)	10.1	7.2
Milk yield (kg/cow/day)	21.2	23.7
Milk fat content (%)	3.90	4.10
Milk protein content (%)	2.85	3.00
(2) EFFECTS OF ALLOWING COWS ACCESS TO PASTURE FOR 3 HOURS/DAY IN LATE AUTUMN. (AVERAGE RESULTS OF TWO EXPERIMENTS)		
	ACCESS TO PASTURE	
	NO ACCESS	AT PASTURE 3 HOURS/DAY
Concentrate intake (kg/cow/day)	4	4
Silage dry matter intake (kg/cow/day)	10.9	6.8
Milk yield (kg/cow/day)	17.7	19.9
Milk fat content (%)	4.15	4.29
Milk protein content (%)	3.18	3.37

concentrates/cow/day indoors to cows in mid lactation which received silage plus 4 kg concentrates and cows in late lactation which received silage plus 2 kg concentrates/cow/day just prior to drying off. In the experiments undertaken by Mayne and Laidlaw (1995); Mayne and others (1997); Sayers and Mayne (2001) and Dillon and Crosse (1994) early spring grazing commenced during the last week of February or the first week of March and continued for 6 to 8 weeks until mid April, the conventional time for turning cows out to grass in Northern Ireland. In these experiments, cows which were allowed access to grass for 3 hours/day consumed 4 kg of grass dry matter/cow/day while those which were allowed out to pasture for 6 hours consumed 6.6 kg of grass dry matter/cow/day.

On the other hand, in the experiment carried out by Ferris, Gordon and Patterson (2001) the cows were allowed access to pasture from late February but the experiment was terminated on 24 March, well before the conventional time for turning cows out to pasture in Northern Ireland. The cows had to be rehoused on two occasions during the four week experiment because of adverse weather and ground conditions. Furthermore, in this experiment the cows were allowed access to pasture for 2 to 3 hours/day in February but this was increased to 8 to 9 hours/day in March, while in the previous studies the access time to pasture was maintained at 2 to 3 hours/day through March and into early April. However despite the fact that Ferris, Gordon and Patterson (2001) kept the cows out at pasture for up to 9 hours/day, they consumed only 3.5 kg of grass dry matter/cow/day compared to an intake of over 4 kg of grass dry matter/cow/day in previous experiments at Hillsborough when cows had access to pasture for only 2 to 3 hours/day. This would indicate that in this experiment the cows may have been kept out at pasture too long each day in bad weather with only a very limited supply of grass, as authors have stated that they were forced to graze down to low residual sward heights.

As the cows which were kept indoors in this latest experiment were on a similar plane of nutrition relative to their milk yield as those used in the earlier experiments at Hillsborough it would appear that the major difference in the effects of allowing cows access to pasture in these experiments were likely to have resulted from differences in how the cows were managed at pasture, and in particular the availability of grass relative to the time that they were kept out each day. The results of these experiments emphasize that the potential benefits in milk yield and composition of allowing cows access to grass for a few hours/day in early spring are likely to be obtained only when the cows are appropriately managed at pasture. Without appropriate management there may well be no benefit in milk yield or composition from turning cows out early.

As well as the immediate benefits in terms of milk yield and composition, turning cows out early in the spring has resulted in other longer term benefits in terms of the management of pastures and the cows. For example with mild winters, turning cows out late in the spring has resulted in high yields of grass on the grazing area especially towards the end of the first grazing cycle. This has necessitated the use of high stocking rates to get these high yields of grass utilized. This in turn can lead to severe poaching of swards if there is wet weather in late April or May. The high stocking rates needed in May to utilize the high yields of grass resulting from late turnout reduces the size of the area needed for grazing which, combined with poaching if there is wet weather, has often resulted in a severe shortage of grass in early June if silage aftermaths are not yet available for grazing. This situation was very apparent when cows were turned out late in the year 2002.

On the other hand, when cows have been turned out early when the weather and ground conditions in March have facilitated this, the early grass has been grazed off without poaching which has kept the grass well under control during the remainder of the spring. Then when bad weather has occurred later in the spring, as in 2002, the cows have been rehoused at night and fed the silage which was saved by having them out by day in March. This, combined with the fact that a lower stocking rate could be used because the cows were out early and so avoiding a build up of a very high yield of grass on the grazing area, resulted in much less poaching of the pasture than occurred when cows were turned out late and had to be kept out during the bad weather because the late turnout had resulted in all the silage having been eaten before they were turned out.

In view of the erratic weather patterns in Northern Ireland and the results of recent research, it would seem that when the weather and ground conditions are good in early spring it is prudent to get cows out and utilize the grass, because the weather and ground conditions later may be such that it is not possible to utilize it until it is past the stage for grazing. Furthermore recent research undertaken by Washburn and others (2002) in the United States has indicated that the health of dairy cows is better when they have access to pasture than when they are kept indoors continually. Also Offer and others (2002) concluded that extended grazing in the spring and autumn was a major factor contributing to a lower incidence of lameness in cows which had been involved in extended grazing than in those which had not.

While research has shown that there can be substantial benefits from allowing cows out to pasture in early spring in terms of both milk yield and composition and the overall management of the cows and the sward, keeping cows out late in the autumn can be more problematic. For example, keeping cows out in late autumn necessitates retaining a supply of grass to be grazed at this stage. This has been achieved by deferring grazing grass produced in August/September (Mayne and others, 2000). However if the weather and ground conditions are good in September, and grass which could have been grazed or made into silage at this stage is retained for grazing in November, the weather conditions could be very bad at that time, as was the case in 2002, which would make it extremely difficult to get the grass utilized. This is in contrast to the situation with early turnout in the spring, because if it is planned to turn cows out in March and this is not possible, then the situation is no worse than if the plan in the first place had been to keep them inside until April.

Furthermore from research undertaken at Moorepark, Dillon and Crosse (1994) reported that when grazing of swards in the autumn was delayed by six weeks, the reduction in the amount of grass available for grazing in early spring was more than the amount of extra grass which was harvested in the autumn.

SUMMARY OF THE MAIN POINTS FROM THE REVIEW OF RESEARCH ON EXTENDING THE GRAZING SEASON

1. Overall, the results of research on turning cows out to grass for a few hours/day in early spring would indicate that this can produce substantial benefits in terms of improvements in milk yield and composition and in the ease of management of both the cows and the grass swards.
2. Consequently, early grazing in spring can make a significant contribution towards reducing the cost of producing milk at this time of year.
3. However appropriate management of the cows at pasture is needed if these benefits are to be realised.
4. Keeping cows out for a few hours/day in late autumn can produce similar benefits in terms of milk yield and composition as allowing them out early in the spring.
5. However utilizing grass during the late autumn can be difficult if the weather is poor, and so retaining substantial quantities of grass for grazing in late autumn can be a high risk strategy.

Milk protein and fat contents can both be increased through breeding and nutrition. While breeding for

CHAPTER 12

IMPROVING THE PROFITABILITY OF MILK PRODUCTION THROUGH BETTER MILK COMPOSITION

improved milk composition is a slow and long term process, the improvements can be permanent if the breeding strategy to improve milk composition is maintained. On the other hand, nutrition can provide an immediate response in milk protein content and can also be used to increase or decrease milk fat content, or change the composition of the fat according to the requirements of individual milk processors.

The nutritional factors which affect milk composition have already been discussed in the preceding chapters and so this chapter summarises the information on the wide range of factors which affect milk composition.

Pre-calving feeding

- When cows have been given high-concentrate diets during early lactation, calving them with a high body condition score (3.5) rather than with a condition score of 2 to 2.5, reduced dry matter intake after calving and consequently reduced milk protein content by 0.08% and increased fat content by 0.13%, as shown in Table 1.
- When cows are given high-forage diets during early lactation, having a low body condition score at calving can reduce milk protein content during early lactation.
- Inadequate protein in the diet before calving can reduce milk protein content during early lactation.

Silage quality

Improving the quality of the silage part of rations given during the winter months has been a very effective method of improving milk composition.

- Increasing the digestibility of grass silage by 7 percentage units (i.e. from 63 to 70%) increased milk protein content by 0.09%, as shown in Table 21.
- Even when the concentrate intake of cows given medium quality silage (D-value 65%) was increased by 4 kg/day compared to the quantity of concentrates given with high quality silage (D-value 72%) so that milk yields were the same, **the cows given high digestibility silage and 5.6 kg of concentrates/cow/day produced milk with a 0.09% higher protein content and a 0.10% higher fat content than the milk produced by cows given medium digestibility silage and 9.6 kg concentrates/cow/day,** as shown in Table 22.
- Rapid wilting of grass prior to ensiling increased milk protein content by 0.06% and milk fat content by 0.19% as shown in Table 25.
- Treating grass with a bacterial inoculant prior to ensiling had small and variable effects on milk composition, as shown in Table 24.
- Replacing 35 to 40% of the grass silage in dairy cow diets with maize silage increased milk protein content by 0.04 to 0.11%, the effect being greater when the grass silage was of medium quality than when it was of high quality, as shown in Tables 26 and 27.
- Including maize silage in the diet also increased milk fat content in some experiments but not in others.
- Including whole-crop wheat in the diet did not affect milk composition, as discussed in Chapter 8.
- Including 20 to 25 kg of fodder beet in the diet of dairy cows was very effective for increasing milk protein and fat contents. This increased milk protein content by 0.15% and milk fat content by 0.13%, as discussed in Chapter 8.

Concentrate intake

Increasing concentrate intake increased energy intake and so has increased milk protein content.

- With medium genetic merit cows increasing concentrate intake from 3.5 to 10.5 kg/cow/day increased milk protein content by 0.21%, which is equivalent to 0.03% per kg increase in concentrate intake.
- Increasing concentrate intake from 3.5 to 10.5 kg/cow/day reduced milk fat content by 0.14% which is equivalent to 0.02% per kg increase in concentrate intake.
- When concentrate intake has been increased from about 10 to 13.6 kg/cow/day, milk protein content continued to increase by 0.03%/kg increase in concentrate intake, but milk fat content was reduced by 0.05%/kg increase in concentrate.
- With high genetic merit dairy cows, increasing concentrate intake from around 7 to 13 kg/cow/day increased protein content by 0.16%, or 0.027% per kg increase in concentrate intake and reduced fat content by 0.11%, or 0.018% per kg increase in concentrate intake.
- When the intake of concentrates was increased above 65% of the total diet dry matter (i.e. about 15 to 16 kg/cow/day) there was a major depression in fat content. For example, when concentrate intake, given in a total mixed ration was increased from 16 to 21 kg/cow/day, milk fat content was reduced by 0.96% and milk protein content was also reduced

by 0.12%.

- Within the normal range of concentrate intake (i.e. up to 60% of total dry matter intake), the system of feeding concentrates to cows has had little effect on milk composition. For example, there was no major or consistent effect of flat rate feeding, feeding-to-yield, a high/low system of concentrate allocation or of feeding concentrates separate from the silage or as part of a total mixed ration on milk composition as shown in Tables 15 to 18, with the exception that complete diet feeding of high genetic merit cows reduced milk fat content.

Type of concentrate

- Replacing a cereal-based concentrate in the diet with a concentrate containing little starch and a high content of digestible fibre (e.g. sugarbeet pulp or citrus pulp) reduced milk protein content by 0.15% and increased milk fat content by 0.10%.
- Including ingredients with a high oil or fat content such as full fat soyabean or rapeseed, maize distillers grains or tallow in concentrates reduced milk protein content, and either increased or decreased milk fat content. Including "protected fats" in the diet has produced variable responses including a reduction in milk protein content and either an increase or a decrease in milk fat content.

Grazed grass

- Turning cows out to grass in the spring has generally increased milk protein content and reduced milk fat content.
- However an increase in milk protein content when cows are turned out to pasture is normally dependent on an increase in energy intake. Consequently the response to turnout depends on the level of feeding before turnout in relation to milk yield and the availability of grass after turnout.
- In most experiments when cows in early lactation have been experiencing the normal slight loss of body condition prior to turnout, turning them out to an adequate supply of pasture has increased milk protein content by 0.10 to 0.40%.
- However when cows have been on a very high plane of nutrition prior to turnout or grass availability has been severely restricted, milk protein content has not been increased.

Extending the grazing season

- As with full turnout to pasture, the effects of turning cows out early in the spring or keeping them out late in the autumn for a few hours per day on milk composition depend on the plane of nutrition in relation to milk yield prior to turnout and the availability of grass.
- In most studies allowing cows out to pasture for a few hours/day increased milk protein content by about 0.15% and milk fat content by zero to 0.48%.
- However inappropriate management of the cows at pasture can eliminate these benefits.
- When cows are on a very high plane of nutrition prior to turnout there may be no improvement in milk composition after turnout.

Profitability

It is important to note that improving milk composition does not always improve profitability. For example, if the quantity of concentrates given to cows is below the economic optimum as discussed in Chapter 2, increasing concentrate intake should improve milk composition in addition to milk yield and increase profitability. However if cows are already being given the economic optimum input of concentrates, increasing concentrate intake further to achieve a further improvement in milk composition is likely to reduce profitability.

Within the dairy industry high genetic merit cows are normally defined as those which have the genetic potential or genetic ability to produce very high yields of milk because they have been genetically selected as being the superior cows for this purpose. Research at Hillsborough and Moorepark Research Centres over the past few years has confirmed that high genetic merit cows in terms of their Predicted Transmitting Ability (PTA) and Profit Index (PIN) have in fact produced substantially higher yields of milk than cows of medium genetic merit with lower PTA and PIN values. For example, in an experiment undertaken at Hillsborough by Ferris and others (1999) which involved both high and medium genetic merit cows, the high merit cows, which had a PTA2000 for milk of 255 kg and for fat plus protein of 24.7 kg produced 4 kg more milk/cow/day over a 182 day period than medium merit cows with a PTA2000 for milk of minus 303 kg and for fat plus protein of minus 17.6 kg. Similarly in an experiment at Moorepark, Dillon and Buckley (1998) found that high genetic merit cows with an average RBI95 of 134 produced 3 kg more milk/cow/day over the total lactation than medium genetic merit cows with an average RBI95 of 117.

In the comparison at Hillsborough, the high merit cows produced milk with slightly higher fat and protein contents than that produced by the medium merit cows, while at Moorepark the high merit cows produced milk with a lower fat content and slightly lower protein content than that produced by the medium merit cows. However the composition of the milk produced by high and medium genetic cows will depend on their PTA for fat and protein percentage. Consequently cows which are of high genetic merit in terms of milk yield can produce milk with either higher or lower fat and protein contents than that produced by medium genetic merit cows, depending on their PTA for fat and protein percentage.

In a major experiment undertaken at Hillsborough by Ferris and others (1999), high genetic merit cows produced 12% more milk and 18% more fat and protein than medium merit cows given the same diet, even though the high genetic merit cows consumed only 6% more feed than the medium merit cows. Consequently, for each 100 units of energy consumed by the cows, the high merit cows produced 6% more milk and 12% more fat and protein than the medium merit cows. This may suggest at first sight that the high merit cows converted food into milk more efficiently than the lower yielding medium merit cows. However energy metabolism studies undertaken by Grainger and others (1985) in Australia and by Ferris and others (1999b) at Hillsborough have shown that high and medium merit cows convert food into milk with the same efficiency. Therefore the high merit cow does not have a more efficient “internal body mechanism” for converting feed into milk. Instead the extra milk produced by the high merit cows was produced by either mobilizing more body reserves to support milk production than the medium merit cows, or by partitioning more feed to milk production and less to gaining body condition than in the medium merit cows. However, when high merit cows produce higher yields of milk than lower yielding cows partly by mobilizing body reserves to support milk production, these body reserves must be replenished again before the next lactation, if the higher milk yields are to be sustained in the long term.

Also if higher and lower yielding cows are the same size, the higher yielding cows produce more milk/tonne of feed consumed because a higher proportion of the food is used for milk production and a lower proportion for maintenance requirements because fewer cows are required to produce the same volume of milk. For example, if higher yielding cows produce 20% more milk/cow, then 20% more of the lower yielding cows are required to produce 100,000 litres of milk. Consequently even though both types of cow convert feed into milk with the same biological efficiency, the lower yielding cows require slightly more feed because there are 20% more of them to be maintained throughout the year.

In the studies at Hillsborough, high genetic merit cows were bigger than the medium merit cows and consequently they had a higher maintenance requirement than the medium merit cows as well as producing higher yields of milk, and so when the feed which was required to replenish the body reserves is taken into consideration, there was no difference in the quantity of milk produced per tonne of feed consumed by the two types of cows.

Size, body condition and maintenance energy requirements

In studies at Hillsborough, high merit cows have been bigger and heavier than traditional medium merit cows when both have had the same body condition score (Gordon and others, 1995). This is in line with the fact that a positive genetic correlation has been found between milk yield and body size of dairy cows (Ahlborn and Dempfle, 1992). Consequently, when dairy cows have been selected for higher milk yield, they have also been selected simultaneously for larger body size. However, because of their tendency to mobilize body reserves to support milk production, high merit cows have tended to have lower body condition scores than medium merit cows. Nevertheless, in an extensive series of energy metabolism studies at Hillsborough, Birnie (1999) found that the maintenance energy requirements of dairy cows are proportional to their size, rather than to their body weight as influenced by their body condition. In other words, if a big thin cow and a small fat cow are the same weight, the big thin cow still has a larger maintenance energy requirement than the small fat cow in proportion to her body size rather than in proportion to her weight.

Feed intake

In experiments carried out at Hillsborough by Gordon and others (1995); Ferris and others (1999) and Patterson and Carrick (2003); high genetic merit cows consumed 4 to 6% more feed than medium merit cows when both were given the same diet. Although this higher intake has been sufficient to provide some of the extra nutrients which were required to sustain the higher yield of milk produced by these cows, it was insufficient to provide all the extra nutrients required. Consequently high merit cows require a higher quality diet than lower yielding medium merit cows and they may also require more feed during late lactation and the dry period than medium merit cows to enable the body reserves which have been lost during early lactation to be replenished in preparation for the next lactation.

TABLE 37 PROJECTED BIOLOGICAL EFFICIENCY AND FEED COSTS FOR MEDIUM GENETIC MERIT COWS GIVEN A HIGH-FORAGE DIET AND HIGH GENETIC MERIT COWS GIVEN A HIGHER INPUT OF CONCENTRATES

	COW GENOTYPE	
	MEDIUM MERIT	HIGH MERIT
Milk yield in 305 days (kg)	6,000	9,000
Concentrate input (tonnes)	0.75	2.0
Grass intake (tonnes DM)	2.4	2.5
Silage intake (tonnes DM)	1.2	1.4
ME intake/year (MJ)	51,000	68,200
Milk yield/1000 MJ of ME (kg)	118	132
Total feed costs		
(based on values given in Table 28)		
Assuming a land charge of £247/ha		
Feed costs/cow/year	£373	£591
Cost/1000 kg of milk	£62	£66
Assuming a land charge of £74/ha		
Feed costs/cow/year	£314	£528
Cost/1000 kg of milk	£52	£59

High genetic merit cows have also been found to produce a substantially greater response in milk yield to higher inputs of concentrates than medium merit cows as discussed in Chapter 3. This would indicate that medium genetic merit cows are more suited to a grass-based/high-forage system of production, while high genetic merit cows are more suited to a high-concentrate system of production. Projected biological efficiencies of milk production and projected costs of production have therefore been calculated for a traditional/New Zealand type Friesian cow given 750 kg concentrates/year and producing 6000 kg of milk and a high genetic merit Holstein cow given two tonnes of concentrates/year and producing 9000 kg of milk. The results are summarised in Table 37. Energy requirements are based on UK feeding standards for dairy cows (Agricultural and Food Research Council, 1993) and feed costs are based on the values given in Table 28. On the basis of these assumptions the high merit cows were 12% more efficient in terms of milk output/unit of energy consumed. However, because the high merit cows had a high proportion of concentrates in the ration, total feed costs/1000 kg of milk are 6% higher for the high merit, than for the medium merit cows, when a land charge of £247/ha is assumed.If direct payments are decoupled from production in the future and land rental values fall, then total projected feed costs per 1000 kg of milk would be 13% higher for the high merit cows than for the medium merit cows.

These calculations are based on the same herd replacement rate for the medium and high yielding cows. However data from the United States and New Zealand indicate that the replacement rate is much higher for high yielding Holstein cows on a high-input system than for lower yielding New Zealand type cows on a forage-based system. A higher replacement rate can have a major effect on both the biological efficiency and the cost of milk production. For example, Gordon (1996) found that increasing herd replacement rates from 15 to 40%/year, which are typical replacement rates for herds in New Zealand and many high-yielding herds in the United States respectively, would reduce the efficiency of milk production by 17%. Consequently a high yielding herd with a replacement rate of 40% could actually be less efficient at producing milk than a lower yielding herd with a 20% replacement rate.

At current costs of rearing dairy herd replacements, as estimated by Carson and others (2002b), an increase in the replacement rate from 20 to 40% would increase herd costs by £70/cow/year for all of the cows in the herd.

Furthermore, costs relating to infertility and disease are also likely to be higher for high-yielding, high genetic merit cows, as discussed in the next section. However, overhead costs for buildings would be lower for high-yielding, high merit cows because fewer cows would be required to produce a given output of milk, while overhead costs for machinery and equipment would generally be higher for high-yielding cows, due to the more complex feeding and management systems which are generally used with high-yielding cows. Total labour costs for high and medium cows would depend on the extent to which the lower labour costs for high merit cows, because fewer cows are required to produce, say 100,000 litres of milk, are offset by higher labour costs associated with greater problems with infertility and disease and the higher standard of management required by high merit cows as discussed in the next section, and with the more complex feeding systems which have been found to be beneficial with high-yielding cows.

However widespread analysis for high-yielding cows kept on high input systems of dairying and for lower yielding cows on high-forage/pasture-based systems across the world have shown that when the price of milk paid to producers is lower, the proportion of grazed grass in the diet is increased. For example, Mayne (1998) reported the results of an analysis which showed that when milk price was about 40% lower, the proportion of grazed grass in the cows diet increased from 35 to 90%. This analysis indicated that milk producers tend to operate to an income margin, in that when incomes are high, surplus income is reinvested back into the farm, whereas when milk price and incomes are low, producers reduce costs by increasing the proportion of grazed grass in the cows diet. However investment in more complex and higher cost systems when incomes are high can create major difficulty in the longer term when milk price and incomes come under pressure.

However within a Northern Ireland context, the use of high yielding, high genetic merit cows, with a high input of purchased feed, can enable milk output/ha to be increased substantially compared to a grass-based system with lower yielding cows. Consequently high input systems with high-yielding, high genetic merit cows can generate a higher profit/ha in a situation in which the availability of land is the major factor limiting the size of the farm business, even though costs/litre of milk produced are higher and hence profit/litre is lower than with a grass-based system.

However this again emphasizes the urgent need for new opportunities to be opened up in Northern Ireland for enthusiastic young people who want to enter the dairy industry to be able to lease land on a long-term basis rather than on a conacre basis. This would create opportunities for them to produce milk at a lower cost per litre, on a low-cost, grass-based system, rather than in a higher cost, high input system. This is very important for the long-term viability of the dairy industry in Northern Ireland, as higher cost, high input systems are likely to be less competitive than either low input systems in other countries in which larger grassland farms are available, or high input systems in other countries which are better suited climatically for these systems and where concentrate feedstuffs are much cheaper.

Effects of genetic selection for higher milk yield on the health and fertility of dairy cows

The effects of selecting dairy cows for higher milk yield on their overall health and fertility has been examined in many studies in Europe, North America, New Zealand and Australia.

In several studies selection for higher milk yield has been associated with a higher incidence of disease in dairy cows or with an increase in overall health costs. For example, in three studies undertaken in the United States and in Scotland, Shanks and others (1978); Rogers and others (1999) and Pryce and others (1997) found that either genetic selection for high milk yield or having higher yielding cows were associated with a higher incidence of disease in the cows. However, Rogers and others found that while higher daily or total lactation yields were associated with poorer cow health, selecting cows for higher total production over their entire life was associated with a lower incidence of disease. Presumably, cows with better health, tend to have longer productive lives, and consequently even though they tend to have lower milk yields in an individual lactation, their longer productive life can result in a higher lifetime production of milk.

In two studies undertaken in the United States by Shanks and others (1978) and Short and others (1990a), genetic selection for higher milk yields was associated with higher health costs. Heringstad and others (1999) found that selection for higher yield in Norwegian dairy cattle was associated with a higher incidence of mastitis in subsequent generations, while Grohn and others (1995) found that higher milk yield was associated with a higher incidence of mastitis in over 8000 dairy cows in commercial herds in New York State, USA, but did not detect a significant relationship between milk yield and the incidence of other diseases.

Selection for higher milk yield or having higher yielding cows have also been associated with poorer fertility in many studies undertaken across the world. For example, as long ago as 1975, Spalding and others (1975) found that high yielding cows in herds in New York State, had an average conception rate to first service which was over 20 percentage units lower than that for lower yielding cows. More recently, in studies undertaken in the UK and Ireland, Dillon and Buckley (1998); Buckley and others (2001); Taylor and others (2001); Snijders and others (2001); Mayne (1999) and Horan and others (2003) have all found that higher yielding, high genetic merit Holstein cows have had poorer fertility (or reproductive performance) than lower yielding medium genetic merit cows. Similarly in several other studies undertaken in the United States by Seykora and McDaniel (1983); Legates and others (1988); Harrison and others (1990); Hageman and others (1991); Bonczek and others (1992) and Lucy and Crooker (2001), in Scotland by Pryce and others (1997) and Pryce and Veerkamp (2001) and in New Zealand by Grosshans and others (1997), selection for higher yield has also been associated with poorer fertility in dairy cows. In further studies in the United States and in Great Britain, Laben and others (1982); Badinga and others (1985); Hillers and others (1984); Hermas and others (1987); Faust and others (1988); Butler and Cranfield (1989); Butler and Smith (1989); Short and others (1990b); Nebel and McGilliard (1993); Ferguson (1996); Loeffler and others (2001) and Wathes (2001) all found that fertility was poorer in higher yielding than in lower yielding cows, while in Scandinavia, Poso and Mantysaari (1996) found that as milk yield increased the incidence of reproductive disorders also increased.

However in other studies undertaken by Barnes and others (1990) and Morton (2001) poorer fertility in higher yielding or higher genetic merit cows was less apparent. Also in a recent study of fertility in 19 commercial dairy herds in Northern Ireland, Mayne and others (2002) found that the cows in the six herds with the lowest conception rate to first service had a lower milk yield than the six herds with the highest conception rate. However, the herds with the longest calving interval and the lowest heat detection rate were also higher yielding herds than those with the shortest calving interval and the best heat detection rates. These results would suggest that the higher conception rate in the higher yielding herds may have been due to a longer interval after calving before the cows were inseminated, as the herds with the longest calving interval were also higher yielding herds. Furthermore as there were only six herds in each group, differences in conception rate may have been due to differences in the standard of management on the farms. This view is supported by the fact that the cows in the herds with the lowest and highest conception rates had the same genetic merit (i.e. PIN2000 value of 7) and yet the herds with the highest conception rates were higher yielding.

The results of the studies undertaken at Moorepark and Hillsborough by Dillon and Buckley (1998); Mayne (1999) and Horan and others (2003) provide a more accurate assessment of the effects of factors within the cows on fertility, because they examined fertility within herds, rather than between herds, and so the major effect of differences between herd managers and their standard of management on fertility have been eliminated. The results of these three studies are summarised in Table 38.

The medium merit cows used in the studies undertaken by Mayne (1999) and Horan and others (2003) were bred by New Zealand sires. On average over the three sets of data, pregnancy or conception rate to first and second services was about 25 percentage units lower for the high genetic merit Holstein cows than for the medium merit New Zealand type cows.

There has been considerable debate about whether the poorer fertility in high genetic merit cows is a direct result of their higher milk yield on their physiology or nutritional stress, or if higher genetic merit cows have genetically related poorer fertility independent of the direct effects of their milk yield on fertility. There is relatively little information on this, but results of two studies appear to indicate that high genetic merit cows have genetically related poorer fertility, independent of their milk yield or nutritional status. For example, Oltenacu and others (1991) found that higher milk yields in the first lactation were associated with poorer fertility in the animals when they were maiden heifers as well as when they were lactating, while Mee and others (2000) found that high genetic merit cows at Moorepark had poorer fertility than medium merit animals when both had the same milk yield. On the other hand, other findings from the United States would suggest that the decline in fertility may be related more to the higher milk yield of high merit cows than to a genetic effect per se (Butler and Smith, 1989). More recent evidence presented by Pryce and Veerkamp (2001) would indicate that the poorer fertility in high genetic merit cows is related to both their higher milk yield and to their genetics per se.

Other studies have shown that the health and fertility of dairy cows can also be related to their body size. For example, Mahoney and others (1986) found that within the Holstein breed, cows which had been selected for larger size required significantly more health care than smaller cows, while Hansen and others (1999) also found that within the Holstein breed, smaller cows had longer productive lives than bigger cows.

Larger body size has also been associated with poorer fertility in dairy cows. For example, Hansen and others (1998) reported that after 30 years of selection for larger and smaller body size in dairy cows, the larger cows required more services per conception than the smaller cows. Similarly, in studies in the United States, Israel, New Zealand and Ireland, Badinga and others (1985); Markusfeld and Ezra (1993); Laborde and others (1998) and Berry and others (2003) also found that larger body size in dairy cows was associated with poorer fertility.

The mounting cost of infertility and disease in dairy herds is becoming a major issue in many countries. Nash and

TABLE 38 THE EFFECT OF THE GENETIC MERIT OF DAIRY COWS ON FERTILITY

	COW TYPE	
	HIGH MERIT	MEDIUM MERIT
Pregnancy rate to 1st service (%)	41	53
Pregnancy rate to 2nd service (%)	37	58
No of services/conception	2.08	1.79
Infertility rate (% of cows)	23	6
(Source: Dillon and Buckley, 1998)		
	HIGH MERIT HOLSTEIN	NEW ZEALAND FRIESIAN
PIN	71	4
305 day milk yield (kg)	7329	6540
Conception rate to 1st service (%)	34	64
Conception rate to 1st and 2nd services (%)	60	84
No of services/conception	2.1	1.7
Calving interval (Days)	384	371
(Source: Mayne, 1999)		
	HIGH MERIT AMERICAN HOLSTEIN	NEW ZEALAND HOLSTEIN FRIESIAN
EBI (Breeding Index)	57	34
Milk yield (kg/cow in 2002)	6512	5650
Milk protein (%)	3.43	3.57
Milk fat (%)	4.01	4.44
No of services per conception	2.23	1.54
Pregnancy rate to 1st service (%)	36	62
Pregnancy rate to 1st and 2nd services (%)	54	87
Overall pregnancy rate (%)	69	92
(Source: Horan and others, 2003)		

others (2000) recently reported that the National Mastitis Council (1996) had estimated the cost of mastitis in dairy cows in the United States to be equivalent to 10% of the value of milk sales from US dairy farms. This very high cost of mastitis to the US dairy industry may be related to the fact that dairy cows in the US are very high yielding, as higher yields have been associated with a higher incidence of mastitis as discussed above, and also to the fact that the majority of dairy cows in the US are fed intensively indoors.

In a recent study undertaken in the US by Washburn and others (2002) cows which were kept indoors had an 80% higher incidence of mastitis and about four times as many cows were either culled or died as a result of mastitis than was the case in cows which were out at pasture.

Meanwhile, Lamming and others (1998) have reported the estimated cost of infertility in dairy cows in the UK to be over £500 million/annum, which is equivalent to over £150/cow/year. Also according to a report in The Veterinary Record (6 March 1999), a survey undertaken by the National Milk Recording organisation revealed that lameness had affected 25% of the cows surveyed and cost £40/cow in average herds.

However the results of many of the studies which have been carried out to examine the effects of selecting dairy cows for higher milk yields have indicated that the heritabilities of health traits and fertility are very low (e.g. Hansen and others, 1983; Oltenacu and others, 1991; Pryce and others, 1997 and Heringstad and others, 1999). Consequently genetic selection for improved health and fertility within a cattle population or breed is likely to result in a slow rate of improvement.

At the same time there is rapidly increasing concern about the recent increase in the number of strains of bacteria which are capable of causing serious illness in humans and which are also now resistant to antibiotics. This deteriorating situation has already led to a ban on the use of several antibiotics in feeds for farm livestock and may well lead to further restrictions on the use of antibiotics in farm animals in the future, and consequently increase the need to breed cattle which are less susceptible to disease. There is also increasing concern within society about the welfare of farm animals including dairy cows. Within this scenario, there has been increasing interest recently in possible differences between breeds of dairy cattle in terms of their susceptibility to disease and level of fertility.

A major experiment has been carried out over several years in the United States by White and others (2002) and Washburn and others (2002) to compare Holstein and Jersey cows. The results of this study are summarised in Table 39. These results show that milk yield of Holstein cows was much higher than that of the smaller Jersey cows although milk composition would have been higher for the Jerseys. However fertility was much better in Jersey cows and the incidence of mastitis and culling and

TABLE 39 A COMPARISON OF HOLSTEIN AND JERSEY COWS IN THE UNITED STATES

	BREED	
	HOLSTEIN	JERSEY
Milk yield (kg/lactation)	7513	5754
Conception rate to 1st service (%)	45	60
Cows pregnant in 75 days (%)	58	78
Cows infected by mastitis (%)	41	26
Average number of infections per cow over all cows	0.81	0.41
Mastitic cows culled or died (%)	5.6	1.7

death losses attributed to mastitis were much lower in the Jerseys. In another study in New Zealand, Grosshans and others (1997) also found that reproductive performance was better in Jersey than in Friesian cows.

Another major breed comparison study has been undertaken by researchers from Moorepark Research Centre, Co Cork (Crosse and others, 1998; Buckley and others, 2003). In this study, four breeds/strains of cows were compared. These were Holstein Friesians imported from Holland, native Irish Friesians from the Castlelyons Research Farm herd, and Normande and Montbeliard cows which had been imported from France. Of the two dual purpose breeds, the Montbeliard cows produced about 10% more milk and had better fertility than the Normande cows, while the imported Holsteins produced about 13% more milk than the native Friesians. On average, the Montbeliard cows produced 14% less milk than the Holstein cows, but fertility was better for the Montbeliards, with a pregnancy rate to first service of 50% for Montbeliards compared to only 37% for Holsteins. Also only 9% of Montbeliard cows were infertile compared to 26% of Holsteins (Buckley and others, 2003). In an economical analysis of milk production from the various breeds, farm profit tended to be higher for the Montbeliard cows than for the Holsteins (Crosse and others, 1998).

In a further interesting development of this research programme, Dillon and others (2003) are comparing Holstein Friesian cows with Montbeliard, Normande, Holstein cross Montbeliard and Holstein cross Normande cows in a high-forage system with a total input of 900 kg concentrates/cow/year. Preliminary results of this comparison are shown in Table 40.

As in the previous study Montbeliard and Normande cows produced less milk than the Holsteins. In this case the Montbeliards produced 633 kg, or 11% less milk than the Holsteins, while the Normandes produced 1414 kg or 24% less milk than the Holsteins. However the Holstein cross Montbeliard and Holstein cross Normande cows, instead of producing a milk yield half way between the Holstein and the Montbeliard/Normande cows, actually produced a yield which was similar to the yield of the pure Holstein cows. Presumably this was a result of the hybrid vigour in the crossbred cows. Also, despite the fact that their milk yield was similar to that of the pure Holsteins, the crossbred cows retained the better fertility of the Montbeliard and Normande cows compared to the Holsteins, as only 7% of the crossbred cows were not in-calf at the end of the breeding season, compared to 20% of the Holsteins not being in-calf.

Further studies are in progress at Hillsborough and Moorepark Research Centres and on farms in Northern Ireland to compare Holstein cows with Norwegian Red cows. There has been much interest in animal health in Scandinavia for many years and the use of antibiotics in farm animals is very tightly controlled. Consequently for about the past 30 years Norwegian cows have been selected for better health and fertility as well as for higher production.

Initial results from the study at Hillsborough have shown that the high genetic merit Holstein cows produced about 2000 kg more milk/cow than the Norwegian cows when both were on a high-input system in which they were given about three tonnes of concentrates/cow/year. However when they were given only about one tonne of concentrates/cow/year, the Holstein cows produced only about 500 kg more milk/cow than the Norwegian cows (Keady and Mayne, 2002).

The results of other studies which have been reported by Oldenbroek (1986 and 1988) and Holmes (1995) have also shown that when the energy intake of cows is reduced the reduction in milk yield is greater in Holstein/Friesians than in smaller breeds, or conversely when energy intake is increased the increase in milk yield is greater in Holsteins. Furthermore, Wang and others (1992) found that cows which were bred by some bulls produced substantially more milk than cows sired by other bulls when both were given high inputs of concentrates, but they actually produced slightly less milk when both were given high-forage diets with a low input of concentrates. L'Huillier and others (1988) and Mao and Burnside (1969) also found a significant interaction between different genetic lines of cows and level of feeding, while Lamb and others (1977) found a significant interaction between milk production and level of feeding for cows sired by New Zealand and North American Holstein bulls, but not between different American Holstein bulls.

This interaction between the genotype of the cow and the

TABLE 40 A COMPARISON OF HOLSTEIN, MONTBELIARD, NORMANDE, HOLSTEIN CROSS MONTBELIARD AND HOLSTEIN CROSS NORMANDE COWS (DILLON AND OTHERS, 1003)

	COW TYPE		
	HOLSTEIN FRIESIAN	MONTBELIARD AND NORMANDE	HOLSTEIN CROSS MONTBELIARD AND HOLSTEIN CROSS NORMANDE
milk yield (kg/cow)	5897	4873	5831
milk fat (%)	3.70	3.71	3.76
milk protein (%)	3.40	3.48	3.39
no of services/conception	2.03	1.94	1.83
conception rate to 1st service (%)	53	46	55
conception rate to 1st and 2nd services (%)	73	74	82
percent of cows not in calf	20	8	7

intensity of feeding would indicate that cows which are genetically superior for milk production under a high-concentrate system of feeding may not be the best animals in a high-forage, grass-based system and vice-versa.

Only very preliminary results are available to date from the comparison of Holstein Friesian and Norwegian cows on commercial dairy farms across Northern Ireland (Ferris, 2003). These preliminary results should be treated with caution, because to date they relate to only about 60% of the cows on the farms, and so the differences between the breeds may change slightly when all the results are available.

However, to date the Holsteins have had higher feed intakes and have produced more milk than the Norwegians, average 305-day yields for the first lactation heifers being approximately 5950 kg for the Holsteins compared to 5700 kg for the Norwegians, although fat and protein contents were slightly higher for the Norwegian animals. Yields for the second lactation, which is nearly complete, are projected to be around 7000 kg for the Holsteins in comparison to 6500 kg for the Norwegian cows. Holstein heifers have also been slightly easier to settle in the milking parlour after their first calving than the Norwegian heifers.

On the other hand, the Norwegian cows have had better health than the Holsteins. For example, a lower proportion of the Norwegian heifers required assistance at their first calving compared to the Holstein heifers. Also the calves born to Norwegian heifers had greater vitality than those born to the Holsteins, calf mortality amongst the Norwegians having been only about one third of the level amongst the Holsteins. In preliminary observations, the somatic cell count has been about 50% higher in milk from Holstein cows than in milk from Norwegian cows, while by the time they reached their second lactation the Norwegian cows have tended to be better on their feet than the Holsteins. However udder health and feet problems are likely to become more important issues as the cows get older.

The Norwegian cows also have had better fertility than the Holstein cows. Conception rate to first service in first lactation cows was 50% for Norwegians compared to only 39% for the Holsteins. Consequently, 17% of the Holstein animals have had to be culled due to infertility, compared to only 6% of the Norwegian animals. The overall culling rate has also been much lower for the Norwegian cows, being only about half of that for the Holsteins.

Preliminary results from the ongoing research at Moorepark Research Centre to compare Holstein Friesian and Norwegian cows are in close agreement with the results being recorded in the Hillsborough project on Northern Ireland farms. Dillon and others (2003) recently reported preliminary results from the study at Moorepark. In 2002 the Norwegian cows produced about 350 kg less milk than the Holsteins. Conception rates to the first and second services and the number of services required per conception were only slightly better for the Norwegian than for the Holstein cows, but again as in the Northern Ireland study, the percentage of cows not in-calf was much lower for the Norwegian than for the Holstein cows.

Cross-breeding between two or more breeds has been an integral part of the beef and sheep industries in this country for many years. The aim of this is to produce animals which have better fertility and are less susceptible to disease, because they exhibit hybrid vigour which has been found to be an important characteristic of crossbred animals. Crossbreeding has also been used within the dairy industry in New Zealand. For example, Harris and others (2001) have recently reported that Jersey cross Holstein cows have about one year longer productive life in dairy herds than pure Jersey or pure Holstein cows. Also as discussed above, initial results from research at Moorepark Research Centre involving Holstein cross Montbeliard cows have been very encouraging. Consequently, a research project has recently been initiated on a number of Northern Ireland dairy farms, through the Institute at Hillsborough, to evaluate crossbred cows in terms of milk yield, health, fertility and other characteristics, and in terms of overall profitability.

SUMMARY OF THE MAIN POINTS FROM THE REVIEW OF RESEARCH ON IMPROVING THE GENETIC MERIT OF DAIRY COWS

- From the results of extensive research it is concluded that genetic selection in recent years has produced major increases in the genetic potential of dairy cows in Northern Ireland for milk production.

- High genetic merit cows have been found to be better suited to high-input systems of production, while lower genetic merit New Zealand-type cows and some other breeds and crosses have been more suited to high-forage, grass-based systems of production.
- High genetic merit cows have been found to produce more milk per tonne of feed consumed than medium merit cows if the same herd replacement rate is assumed.
- However within a Northern Ireland context, total feed costs per 1000 kg of milk have been projected to be higher for high merit cows on a high-input feeding system than for medium merit cows on a grass-based system.
- Also if high yielding cows have a higher herd replacement rate than lower yielding cows there may be little difference between them in overall milk output per tonne of feed consumed by the cows and the heifer replacements.
- Costs associated with infertility and disease are also likely to be higher for high merit cows.
- Overhead costs for buildings are likely to be lower for high merit cows while overhead costs for machinery and equipment are likely to be higher for high merit cows.
- Labour costs/1000 kg of milk produced by high and medium merit cows are likely to vary depending on the circumstances on individual farms.
- Total costs per litre of milk produced are likely to be lower for medium merit, New Zealand type cows on a grass-based system of production than for high merit Holstein cows on a high input system of production.
- However a smaller number of higher yielding cows on a high input system require less land than a larger number of lower yielding cows on a grass-based system which is a further important consideration in situations in which the availability of land is the major factor limiting the size of the farm business.
- **Infertility and disease are now sources of major financial loss to the Northern Ireland dairy industry.**
- **For this reason, and also because of the implications of disease in farm animals on animal welfare and human health, it is considered to be of paramount importance that much greater emphasis is placed on selecting dairy animals for better health and fertility in the future than has been the case in the past.**
- Results of recent and on-going research in Northern Ireland and elsewhere have indicated that a cautious introduction of a wider range of dairy breeds and crosses into dairy herds is likely to be the most rapid method of improving dairy cow health and fertility.
- Recent research findings have also indicated that this is likely to result in only a small reduction in milk yield compared to that produced by Holstein cows in herds in which most of the milk is produced from grass and forage with modest inputs of concentrates.
- However, in herds in which very high inputs of concentrates are used, Holstein cows are likely to have a major superiority in terms of milk yield.

Poor fertility has been identified as a major problem in dairy herds in the UK. For example, Lamming and others (1998) estimated its total cost to be over £500 million/year, while Esselmont, Kossaibati and Allcock

(2001) estimated the cost of delayed conception to be £1.73 to £4.08/cow/day that conception was delayed after 85 days from calving. Conception rate to first service has been estimated to have fallen by 1% per year over 20 years, from 55.6% between 1975 and 1982 to only 39.7% between 1995 and 1998 (Royal and others, 2000). Similarly in a recent study of fertility in 19 dairy herds in Northern Ireland, average conception rate to first service was only 37.1% and average calving interval was 407.2 days (Mayne and others, 2002).

If it is assumed that fertility in the 19 dairy herds which were studied by Mayne and others (2002) is representative of fertility in all dairy herds in Northern Ireland, and the costs estimated by Esselmont, Kossaibati and Allcock (2001) are used, **the cost of delayed calving and culling cows due to infertility in Northern Ireland are approximately £160/cow/year over all the cows in the Province.**

Factors affecting fertility

1. As discussed in Chapter 1, cows which are overfat or are too thin at calving have been found to have poorer subsequent fertility, than cows with the optimum body condition score at calving.
2. Cows with low feed intakes and high yielding, thin cows which lost a lot of body condition during early lactation have had poor fertility (Staples and others, 1990; Studer, 1998).
3. As low dry matter intakes have resulted in poor fertility it is important to ensure that all cows have ad libitum access to feed.
4. Within the normal range, level of concentrate feeding has generally not affected fertility, but very low inputs or very high inputs have been associated with poorer fertility.
5. The use of high quality forage and appropriate inputs of concentrates relative to the yield potential of the cows should optimise fertility.
6. A high protein content in the diet can significantly reduce dairy cow fertility, although this effect has not been consistent across all experiments.
7. Avoiding a deficiency of, or an imbalance in the intake of several minerals and vitamins, is of paramount importance in maintaining good fertility.
8. Poor fertility has also been associated with a high incidence of several other diseases during early lactation including milk fever, retained placenta, metritis and lameness. Therefore maintaining a high standard of overall herd health will also improve fertility (Studer, 1998).
9. Using sires which have been proven to improve the fertility of their daughters should improve herd fertility in the long term.
10. Crossing two dairy breeds to produce crossbred daughters should improve fertility as a result of hybrid vigour. This is likely to be a much faster way of improving fertility than selecting animals within a breed for higher fertility.
11. Good heat detection is a vital part of good fertility in cows bred by AI. In the study undertaken by Mayne and others (2002) on commercial farms in Northern Ireland, heat detection rates varied between farms from 53 to 92%.
12. Avoiding stress or annoyance to the cows before and after insemination can significantly increase conception rates.

Feeding and management of dairy heifers from birth to first calving can have a major impact on their performance as adult cows, and on their fertility, health and welfare. For example, in an experiment carried out by

DeNise and others (1989) involving over 700 heifers in the USA, first lactation milk yield was higher for cows which had a high concentration of immunoglobulins (Ig) in their blood when they were 1 to 2 days old than for cows which had a low concentration of immunoglobulins in their blood after birth. As immunoglobulins, which enhance the animals' resistance to disease, are obtained from colostrum by the newborn calf, these results emphasize the importance of ensuring that newborn calves receive an adequate intake of colostrum, as this has been found to minimise the incidence of disease during the first weeks of life and may also enhance milk yield in the animal when it is an adult.

Feeding heifers before puberty

Foldager and Sejrsen (1987) reviewed an extensive series of experiments which they had undertaken at the National Institute of Animal Science in Denmark to examine the effects of the rate at which dairy heifers were grown at various stages between three months of age and first calving on subsequent milk yield. From the results of their experiments and other research, they concluded that the mammary gland of dairy heifers grows little from birth to three months of age, and that this is normally followed by a period of rapid growth and development of the gland from about 3 to 9 months of age. They also found that milk yield during the first lactation could be greatly influenced by the growth rate of the heifers during this pre-pubertal period from 3 to 9 months of age. For example, they found that when traditional European type heifers which produced 5100 kg of milk in the first 250 days of their first lactation, had a live-weight gain of 0.6 kg/day from around 3 to 9 months of age, they produced 300 to 1000 kg more milk in the first 250 days of their first lactation than heifers which had had a live-weight gain of 0.8 to 0.9 kg/day from about 3 to 8 months of age. The results of six experiments in which traditional European type heifers were fed to achieve low and high live-weight gains before puberty are summarised in Table 41. These experiments were undertaken in Great Britain by Little and Kay (1979) and Little and Harrison (1981) and in Denmark by Sejrsen and Brolund-Larsen (1977); Foldager and Sejrsen (1987) and Hohenboken and others (1995).

On average over the six experiments, increasing live-weight gain before puberty from 0.6 to 0.9 kg/day reduced milk yield during the first 250 to 305 days of the first lactation by 760 kg/cow. This reduction in milk yield during the first lactation when heifers have had a higher growth rate before puberty has been linked to the effects of growth rate on the amounts of fat and milk secreting tissue produced in the udder at this stage when it is developing rapidly, and subsequently (Carson and others, 2002b). From the results of experiments involving traditional European type dairy heifers, Foldager and Sejrsen (1987) concluded that the live-weight gain of this type of heifer should not exceed 0.7 kg/day before puberty if a reduction in first lactation milk yield is to be avoided.

Holstein heifers of North American breeding are generally bigger than traditional British or European heifers of the same age, and have grown into cows with a much higher mature weight than traditional British Friesian type cows (Gordon and others, 1995). Consequently Holstein heifers may tolerate higher growth rates before puberty without becoming fatter. The results of six experiments in which Holstein heifers were fed to achieve different live-weight

TABLE 41 THE EFFECT OF GROWTH RATE BEFORE PUBERTY ON THE MILK YIELD OF HEIFERS DURING THEIR FIRST LACTATION. (AVERAGE RESULTS OF SIX EXPERIMENTS INVOLVING TRADITIONAL EUROPEAN TYPE HEIFERS)

	LIVE-WEIGHT GAINS 0.6 VERSUS 0.9 KG/DAY
Approximate age when heifers had low or high live-weight gain	2/3 months to 9/12 months
Period of 1st lactation when milk yield was recorded	250 to 305 days
Effect of higher live-weight gain before puberty on milk yield	Reduced by 760 kg/heifer

TABLE 42 THE EFFECT OF GROWTH RATE BEFORE PUBERTY ON THE MILK YIELD OF HEIFERS DURING THEIR FIRST LACTATION. (AVERAGE RESULTS OF SIX EXPERIMENTS INVOLVING HOLSTEIN HEIFERS).

	LIVE-WEIGHT GAINS 0.72 VERSUS 0.92 KG/DAY
Approximate age when heifers had low and high live-weight gains	3 to 10/12 months
Period of 1st lactation when milk yield was recorded	250 to 305 days
Effect of higher live-weight gain before puberty on milk yield	Reduced by 460 kg/heifer

gain before puberty are summarised in Table 42. These experiments were undertaken at Hillsborough by Carson and others (2000), in the United States by Gardner and others (1977); Gardner and others (1988) and Van Amburgh and others (1998), in Italy by Pirlo and others (1997) and in Israel by Peri and others (1993).

The results of these experiments are more variable than those of the experiments undertaken with heifers of traditional European origin. In five of the six experiments, the heifers which had the higher live-weight gain before puberty (0.92 kg/day on average), produced less milk during the first 250 to 305 days of their first lactation than the heifers which had a lower average live-weight gain before puberty of only 0.72 kg/day on average. Over the five experiments the heifers which had the higher growth rate before puberty produced 626 kg less milk than those which had the lower live-weight gain before puberty. Gardner and others (1977) also found that the heifers which had the lower growth rate during rearing continued to produce slightly more milk during subsequent lactations than those which had the higher growth rate during rearing. However the growth rates used in these experiments with Holstein heifers were slightly higher than those used in the experiments with the European heifers.

Also in one of the experiments which was undertaken at Hillsborough, Carson and others (2000) found that heifers which had a higher growth rate before puberty produced more milk than those which had a lower growth rate before puberty. In this experiment the heifers which had the lower growth rate from 3 to 10 months of age did not express compensatory growth after 10 months of age when all the heifers were on the same diet, and so the heifers which had the lower growth rate from 3 to 10 months were 43 kg lighter before calving than those which had the higher growth rate before 10 months. This is in contrast to the results of the other experiments in which heifers which had a lower growth rate before puberty generally exhibited compensatory growth after puberty when all the heifers were given the same diet, and consequently growth rate before puberty had little effect on live weight at calving. However in the experiment undertaken at Hillsborough all of the heifers had a low growth rate of only about 0.5 kg/day from 10 months of age until post-calving. Consequently the feeding and management of the heifers at this stage may not have been suitable to allow them to express compensatory growth and so the heifers with the lower growth rate before 10 months were considerably lighter at calving. Increasing the live weight of heifers at calving has generally been found to increase first lactation milk yield as discussed in the next section. Consequently in the experiment undertaken by Carson and others (2000), any reduction in milk yield as a result of the higher growth rate before puberty would appear to have been more than offset by the increase in the weight of the heifers at calving.

However the heifers which had the higher live-weight gain from 3 to 10 months had poorer fertility than those which had the lower growth rate before 10 months. Overall the results of these experiments would indicate that Holstein heifers can be fed to achieve live-weight gains of up to about 0.8 kg/day before puberty without causing a major reduction in first lactation milk yield.

Feeding heifers after puberty

Milk yield of first lactation heifers has been found to be more closely related to the live weight of the heifers at calving than to their age at calving (Keown and Everett, 1986; Foldager and Sejrsen, 1987). Consequently reducing the age at which heifers produced their first calf from 30 to 24 months did not affect milk yield, provided the heifers were well grown at 24 months. However a further reduction in age at calving to 20 to 21 months produced a substantial reduction in milk yield. Increasing the growth rate of heifers after puberty, and especially during pregnancy, resulting in an increase in live weight at calving, has generally been found to increase first lactation milk yield (e.g. Martysarri and others, 1999; Carson and others, 2000 and 2002a). However in some experiments when live weight at calving has been increased up to or above 600 kg, there has been no increase, or even a slight decrease, in milk fat plus protein yield during the first lactation (e.g. Lacasse and others, 1993; Stelwagen and Grieve, 1992).

Waldo and others (1998) also found that when the live-weight gain of Holstein heifers was increased from 0.78 to 0.99 kg/day between about 8 and 13 months of age, milk yield in the first lactation was reduced by about 350 kg when the heifers were calved at the same live weight.

Furthermore, in a major study at Hillsborough and on 11 farms across Northern Ireland, Carson and others (2002a and 2002b) found that increasing the live weight of high genetic merit Holstein heifers at calving from 540 to 620 kg live weight increased milk yield in their first lactation by 737 kg, but tended to reduce subsequent milk yield per year of the cows' productive life by over 500 kg/cow/year. The results of this experiment are summarised in Table 43.

Although the heifers which had higher growth rates between 2 and 24 months of age (0.69 versus 0.79 kg live-weight gain/day) and consequently were heavier and had a higher body condition score at calving produced more milk in the first lactation, they had poorer fertility and consequently had a longer calving interval than those which were lighter at their first calving. The longer calving interval tended to reduce the total amount of milk produced per year of productive life, and so the total yield of milk over 34 months from their first calving was 339 kg less for the heifers which were 620 kg live weight at their first calving than for those which were 540 kg. This overall slight negative effect on long-term performance by the heifers which were heavier at calving was obtained despite the fact that live-weight gain during the "critical" period from 3 to 10 months of age was restricted to less than 0.7 kg/day as a higher growth rate at this stage may have further reduced milk yield in later life.

Consequently, Carson and others (2002b) concluded that the target body size for high genetic merit Holstein heifers at calving should be 540 to 560 kg live weight at a body condition score of 2.75 to 3.00. This conclusion is in close agreement with the results of Keown and Everett (1986) who found that the optimum live weight for Holstein heifers before first calving in Canada was 544 to 567 kg.

Carson and others (2002b) also found that heifers which were kept indoors for the first summer of their lives on a controlled diet had substantially more lesions and heel erosions in their feet than heifers which were turned out to pasture. This could have implications for lameness in later life.

TABLE 43 THE EFFECT OF GROWTH RATE FROM 2 TO 24 MONTHS OF AGE AND LIVE WEIGHT AT CALVING ON THE PERFORMANCE OF HIGH GENETIC MERIT HOLSTEIN HEIFERS

	REARING SYSTEM	
	MODERATE GROWTH RATE	HIGH GROWTH RATE
Live-weight gain from 2 to 24 months of age (kg/day)	0.69	0.79
Live-weight gain from 3 to 7 months (kg/day)	0.61	0.69
Live weight at calving (kg)	540	620
Condition score before calving	2.8	3.5
Milk yield during the first lactation (kg)	7222	7959
Fat (%)	3.81	3.72
Protein (%)	3.27	3.19
Subsequent milk yield over the next 24 months (kg)	12973	11897
Total milk yield over 34 months from first calving (kg)	20195	19856
Reproductive performance		
During first lactation		
No of services/conception	1.7	2.0
Calving interval (days)	394	440
During second lactation		
No of services/conception	1.9	2.0
Calving interval (days)	400	437

From: Carson and others (2002a)

1. The milk yield of first lactation heifers has been found to be more closely related to the size of the heifer at calving than to her age.
2. Reducing age at first calving from 30 to 24 months has not affected milk yield providing the heifers were well grown at 24 months, but a further reduction to 20 to 21 months resulted in a substantial reduction in milk yield.
3. Increasing the live-weight gain of traditional European Friesian, Ayrshire type heifers or New Zealand Friesian type heifers above 0.7 kg/day from 3 to 10 months of age reduced milk yield in the first lactation.
4. Increasing the live-weight gain of high genetic merit Holstein heifers above 0.7 kg/day between 3 and 10 months of age has reduced milk yield in some experiments, but the effect has not been consistent.
5. The optimum live weight at calving has been estimated to be 540 to 560 kg for high genetic merit Holstein heifers (Carson and others, 2002b) and 500 to 520 kg for traditional European or New Zealand Friesian type heifers.
6. Achieving higher live weights at calving by higher live-weight gains after puberty increased milk yield during the first lactation but did not increase milk yield per year of productive life because the heifers which were heavier and fatter at first calving had poorer subsequent fertility.
7. On the basis of these findings it would seem to be prudent to restrict live-weight gains before puberty to 0.7 kg/day for New Zealand Friesian and Ayrshire type heifers and to 0.8 kg/day for Holstein heifers to avoid a depression in milk yield in later life, as the target live weight for first calving can easily be achieved by feeding heifers to achieve higher live-weight gains after puberty.

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