




Genetic Characteristics Required in Dairy and Beef Cattle for Temperate Grazing Systems

F. Buckley
Dairy Production Research Centre, Teagasc, Ireland

C. Holmes
Massey University, New Zealand

M. G. Keane
Beef Production Research Centre, Teagasc, Ireland

Follow this and additional works at: <https://uknowledge.uky.edu/igc>

 Part of the [Agricultural Science Commons](#), [Agronomy and Crop Sciences Commons](#), [Plant Biology Commons](#), [Plant Pathology Commons](#), [Soil Science Commons](#), and the [Weed Science Commons](#)

This document is available at <https://uknowledge.uky.edu/igc/20/satellitesymposium4/4>

The XX International Grassland Congress took place in Ireland and the UK in June-July 2005.

The main congress took place in Dublin from 26 June to 1 July and was followed by post congress satellite workshops in Aberystwyth, Belfast, Cork, Glasgow and Oxford. The meeting was hosted by the Irish Grassland Association and the British Grassland Society.

Proceedings Editor: D. A. McGilloway

Publisher: Wageningen Academic Publishers, The Netherlands

© Wageningen Academic Publishers, The Netherlands, 2005

The copyright holder has granted the permission for posting the proceedings here.

Genetic characteristics required in dairy and beef cattle for temperate grazing systems

F. Buckley¹, C. Holmes² and M.G. Keane³

¹*Dairy Production Research Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland, Email: fbuckley@moorepark.teagasc.ie*

²*IVABS, Massey University, Palmerston North, New Zealand*

³*Beef Production Research Centre, Teagasc, Grange, Dunsany, Co. Meath, Ireland*

Key points

1. Only about 10% of the world's milk is produced from grazing systems. Consequently the majority of dairy cattle have not been selected under grazing, nor on seasonal systems. This is not true for beef cattle, for which the majority, especially the dams, are managed under seasonal grazing systems.
2. In grazing systems daily feed intake is limited to lower levels than are achievable on concentrate plus conserved forage rations. Consequently, cows most suited to grazing environments are likely to have a lower genetic potential for milk production than cows selected in high concentrate systems, to minimise their relative energy deficit.
3. The traits required under grazing will include those for other systems; high yields of milk with high milk solids, efficient converters of feed to product, functionality, good fertility, health and longevity. Successful grazing systems require dairy cows that are adapted to achieving large intakes of forage relative to their potential milk yields, and therefore able to meet production potential exclusively from forage. Grazing cattle must also be able to walk long distances, and in seasonal systems, must be able to conceive and calve once every year. The ability to be productive when milked once daily may also be desirable in low cost grazing systems in the future.
4. Intensive selection for milk production within the Holstein-Friesian breed on high concentrate diets has generally resulted in a genotype that is not well suited to grazing (high forage) systems, in which these cows exist in permanent energy deficit. This unsuitability is particularly true for seasonal systems, for which good fertility is an essential trait.
5. There is now strong evidence for the existence of interactions between genotype of dairy cattle and feeding system, where the genetics and the systems differ widely. Therefore mutual compatibility between the cow and the system must be optimised for production and profit.
6. The New Zealand Friesian and New Zealand Jersey, and crosses between them, or with other dairy breeds, including the North American Holstein-Friesian, have been shown to be well suited to grazing systems. Increasing evidence suggests that genetics from some Scandinavian breeding programs, e.g. the Norwegian Red, may also be suited to grazing systems, where good fertility is essential.
7. Developments in international sire evaluation (adaptations of multiple across country evaluation (MACE)) that enable differences in management systems to be taken into account will provide different breeding values for different conditions. Until then, sires should be proven in the same general management conditions in which the daughters are to be managed.
8. There is little evidence of important G×E interactions in beef cattle, for growth rate, food intake or carcass traits.
9. But beef cows from large, late maturing breeds are relatively more restricted by inadequate nutrition than smaller early maturing types. As a result both their fertility and milk production can be impaired leading to a lower weaning percentage and lighter weaning weight.

10. Interactions between the effects of genotype and nutrition on carcass composition can occur where the level of energy intake is above the muscle deposition capacity of some breeds.

Keywords: grazing, cattle, dairy, beef, genetics, G×E

Introduction

Until recently, in the world of dairy cattle breeding, the term “high genetic merit” was synonymous with high milk production potential. Now it is acknowledged that the complete index for high genetic merit should reflect as many characteristics as are required to reflect total economic profitability. In particular, due to the decline in reproductive efficiency within the Holstein, many countries have diversified their breeding goals to include measures of survivability or functionality (Philipsson *et al.*, 1994; Visscher *et al.*, 1994; Veerkamp *et al.*, 2002). However, economic and physical conditions, and production systems differ widely between countries, so that the optimum complete selection index must also differ widely between countries. World-wide, cattle are farmed under a wide range of environments and management systems. Even within temperate conditions, these can range from grazing on lush temperate pastures or on low quality range-lands, to totally non-grazing or confinement systems, fed on concentrates and conserved roughages. Only about 10% of the world’s milk comes from grazing systems (World Animal Review 1995), consequently the majority of dairy cattle have not been selected under grazing. Cattle on grazing systems must be able to graze effectively and to walk long distances, abilities that are not required in confinement systems. In seasonal grazing systems cattle must also conceive and calve at the right time every year. Cattle on non-grazing systems on the other hand can achieve higher total daily feed intakes and consequently higher growth rates or milk yields than those on grazing systems. There is now strong evidence to show that the cattle that are genetically best suited to non-grazing systems are not best suited to grazing systems, an interaction between genotype and feeding system.

In contrast to dairy cattle, the majority of beef cows are managed under seasonal grazing systems, even if their progeny are grown under more intensive systems in some cases. Therefore it is less likely that interactions between genotypes and feeding systems will be found in beef cattle. Pasture finished cattle have a tendency towards yellow fat (Priolo *et al.*, 2001). Some consumers find this undesirable and require that cattle have a period of feedlot finishing to whiten the fat. Other consumers regard fat yellowness as an indicator of more extensive production systems with better animal welfare and more naturally produced beef. There are clear regional differences between consumers on this matter. Pastured finished cattle have lower levels of carcass and intramuscular fat, higher mono and polyunsaturated fatty acids and higher omega 3 and conjugated linoleic acids (Keane & Allen, 1998; French *et al.*, 2000).

New Zealand and Australia have for many years competed profitably at low world market prices, exporting the majority of dairy produce and meat with no subsidies or incentives. Within Europe, the continued reform of the Common Agricultural Policy (CAP) in order to be more market-focused and future WTO agriculture negotiations, suggests a more unstable and unpredictable time ahead. The potential for dairy farmers to secure higher prices for their output to compensate for their increasing costs and downward pressure in product prices as a result of policies at EU level is very limited. Compliance with Directives on the environment and food safety (Nitrogen Vulnerable Zones, Water Framework and Strategic Environmental Assessment) and with International Agreements (Kyoto Protocol and Gothenburg Protocol)

will be required. Worldwide, farming systems will have to focus on costs of production, and be sustainable in terms of the environment, people and animal welfare.

Features of intensive grazing systems

Dairy production

Milk production in countries such as New Zealand and Ireland is based on the efficient conversion of high quality grazed grass to milk (Penno, 2000; Dillon *et al.*, 1995). Pasture based systems are capable of low cost milk production with high milk output per hectare. Hence, countries like New Zealand and Ireland have developed widely used production systems in which the herd's pattern of feed demand and milk supply is harmonized to the seasonal production of grazed grass. The principal characteristic of the system is that the entire herd is calved (including the heifers which calve at 2 years) over a short period of time, usually 10 to 14 weeks, at the beginning of the grass-growing season, so that the increasing feed demand of lactation coincides with the increasing pasture growth of spring. In Ireland, but less commonly in New Zealand, supplementation, in the form of conserved forage/hay and/or concentrates/by-products, is offered until grass supply meets cow demand early in the grazing season. Supplementation may also be offered in late lactation to maintain yield and extend lactation. Less supplementary feed is generally offered in New Zealand, and cows tend to be dried off in late summer/autumn before the slower pasture growth of winter, in order to prevent a feed (grass supply) deficit and excessive loss of body condition. Consequently lactation lengths are relatively shorter in New Zealand (230 to 260 days), than in Ireland (260 to 300 days). In total, grazed grass/conserved forage will usually account for at least 90% of the diet. The differences in management practices between New Zealand and Ireland reflect differences in grass growth patterns between the two countries. Grazing systems generally carry lower direct costs than most other more intensive systems (International Farm Comparison Network Report, 2004).

Beef production

In regions where there is grass growth in winter but drought in summer (e.g. Australia) calving is typically in autumn, whereas, in regions where grass growth ceases in winter but continues throughout the summer (e.g. Ireland) calving is typically in spring. In both situations the objective is the same, namely to have the calves weaned and have cows dry with low feed requirements when grass availability is least. Calf growth rate is closely related to cow milk production. This is a function of grass supply and quality. When these are adequate calf growth rate exceeds 1 kg/day from birth to weaning resulting in weanling weights in excess of 300 kg (McGee *et al.*, 1995). As with dairy cows, the objective with beef cows is also compact calving close to the start of the grazing season. At pasture, cows regain body condition quickly and conceive readily when the breeding season commences, thus maintaining a 365-day calving interval. Cows continue to increase in body condition throughout the grazing season resulting in a large reserve at the start of the following winter. This is then depleted over the winter (or drought period) thus minimising expensive feed inputs (Drennan, 1993). In range conditions weaned calves are generally sold for finishing elsewhere either on pasture or in feedlots and males may be castrated or left entire. In the more productive grassland areas the males are generally castrated and both males and females are either finished entirely on pasture or remain at pasture until 3-5 months before slaughter and are then feedlot finished. Subsequently, they exhibit compensatory growth at pasture and generally two thirds or more of the short-fall in weight gain is compensated for by the end of the grazing season (Keane, 2002). Where light

grass-finished carcasses are required animals are slaughtered at the end of this grazing season with none or a low level of concentrate supplementation over the final 2-3 months. Where heavier carcasses and/or higher levels of fatness are required animals receive about a 5-month finishing period. Alternatively, they may be fed for moderate gains again in their second winter and finished off pasture the following grazing season. Where animals are slaughtered at 19-21 months of age, towards the end of their second grazing season, grazed grass provides 75-80% of their lifetime feed dry matter intake and half of the remainder comes from grass silage conserved as a necessary component of grassland management. Where animals are finished indoors in their second winter, grazed grass comprises about 50% of their total lifetime dry matter intake with a further 30% coming from grass silage. Animals retained for slaughter until their third season consume about 70% of their lifetime dry matter intake as grazed grass and 25% as grass silage (Keane, 1996).

Traits required by grazing dairy cattle

The need to farm profitably and be sustainable in the future will continue to be a main aim of all future grass-based farming systems. To this end the type of cattle farmed are required to be compatible with the system. In broad terms the definition of a “high merit animal” will continue to be the animal that can produce the largest quantities of high-value milk solids and/or meat most efficiently and sustainably, from the smallest amounts of physical and financial inputs (including feed, and the various costs of labour, health and reproduction). In Ireland, and probably more generally, maximum profitability in grazing systems is achieved by minimising costs and increasing the proportion of grazed grass in the diet of the lactating dairy cow (Shalloo *et al.*, 2004). The traits required under grazing will include those for other systems; high yields of milk with high contents of fat and protein, functional (easily milked) udders, efficient conversion of feed to product, good health, easy care and long, productive lives. Systems based on grazed grass can limit daily feed intake, for example by 20% in Holstein-Friesians (Kolver & Muller, 1998; Kolver *et al.*, 2002), which may be due to a combination of slower rates of intake when grazing, and slower rates of digestion on roughage diets. Increasing the energy concentration of the diet through concentrate supplementation can reduce these physical limitations. Successful grazing systems require dairy cows that are capable of achieving large intakes of forage relative to their genetic potential for milk production so that they are able to meet the requirements almost entirely from grazing. This should also increase the likelihood of survival in the seasonal grazing systems, for which the maintenance of a 365-day calving interval, and good fertility are essential to optimal financial performance (Lopez-Villalobos *et al.*, 2000). This limit to intake when grazing also suggests that cows most suited to grazing environments are likely to have lower genetic potentials for milk production and live weight, than cows best suited to more intensive diets. A requirement to walk long distances is another basic requirement for cows in grazing systems. Some aspects of the cows’ legs and feet, which are associated with lameness and the “walkability trait”, are under genetic control (Boelling & Pollott, 1998; Goddard & Wiggins, 1999). Therefore, selection under grazing may have led to an increased ability to walk long distances. The ability to be productive when milked only once daily is likely to be an important characteristic in cows managed in large, seasonal grazing systems, focussed on low-cost profitable farming (Dalley & Bateup, 2004).

The proportion of North American Holstein-Friesian (NAHF) genetics has increased dramatically in Ireland from 9% in 1990 to 63% in 2001 (Evans *et al.*, 2004), and in New Zealand too, from 2% in 1978 to 50% (estimated) in 2002 (Harris & Winkelmann, 2000). The sires used have generally been selected for high milk production in a predominantly confined

environment (Rauw *et al.*, 1998). There is increasing evidence that intensive selection for milk production within the NAHF breed has generally resulted in a genotype that is less suited to low input (high forage) and grazing systems. This inappropriateness is compounded when seasonality or a requirement for good reproductive efficiency is demanded. The dramatic decline in reproductive performance that has occurred within the NAHF has been well documented (Hoekstra *et al.*, 1994; Pryce & Veerkamp, 2001; Lucy, 2001). In all production systems, but particularly in a seasonal pasture based system, characteristics other than milk production such as reproductive performance and animal health are very important (Veerkamp *et al.*, 2002).

Results from an on-going collaborative study involving Dexcel, Livestock Improvement and Massey University (in New Zealand), and Teagasc, Moorepark (in Ireland), comparing New Zealand-Friesians (NZHF) and the NAHF under grazing but with different systems of supplementation (in New Zealand: Macdonald *et al.*, 2005; Kolver *et al.*, 2004; in Ireland: Horan *et al.*, 2004; Horan *et al.*, 2005a; Horan *et al.*, 2005b; Horan *et al.*, 2005c; Linnane *et al.*, 2004), clearly demonstrate that cows selected under intensive seasonal grazing, NZHF, are more adapted to that environment. Daily milk yield (and total lactation milk yield under Irish conditions, and when given large amounts of supplementation in New Zealand) is higher for the NAHF highly selected for milk production. However, reproductive efficiency and survival is substantially higher for the NZHF cows (Table 1).

Table 1 Effect of strain of Holstein-Friesian on reproductive performance (Horan *et al.*, 2004; Horan *et al.*, 2005a) (and raw means from the New Zealand study in brackets)

| | NAHF | NZHF |
|---|-------------|-------------|
| Milk yield (kg) | 6958 (5130) | 6141 (4970) |
| Fat (kg) | 279 (216) | 275 (236) |
| Protein (kg) | 241 (175) | 224 (179) |
| Pregnancy rate to 1 st service (%) | 47 (39) | 60 (46) |
| 6 week in calf rate (%) | 59 (54) | 73 (69) |
| Empty rate after 14 weeks (%) | 21 (13) | 9 (7) |

The final results in New Zealand have not been analysed yet, but some average data for 2003/04, with 2, 3 and 4 year old cows, are presented in Figure 1. The NZ70 and NZ90 (NZ90 identical to the NZHF in Ireland) strains represent high New Zealand Breeding Worth (BW) cows of the 1970s and 1990s, with at least proportionately 0.9 NZ genetics. The OS90 cows represent high BW cows with at least proportionately 0.9 overseas genetics of the 1990s (identical to the NAHF in Ireland).

As expected, the NZ90 cows achieved higher yields per cow and per hectare than the NZ70 cows at all levels of feed allowance. The NZ90 cows produced much more milk solids than the OS90 cows, when both were fed at the two moderate feed allowances (5.5 and 6.0 t DM/cow), mainly because the OS90 were dried off earlier after shorter lactations at these allowances, because of their thinner body condition. However, at their two higher feed allowances, the OS90 cows produced similar yields to the NZ90 cows. Nevertheless, the NZ90 were more profitable than the OS90 cows at all allowances, because of the high cost of the supplements relative to the price for milk (Kolver *et al.*, 2004).

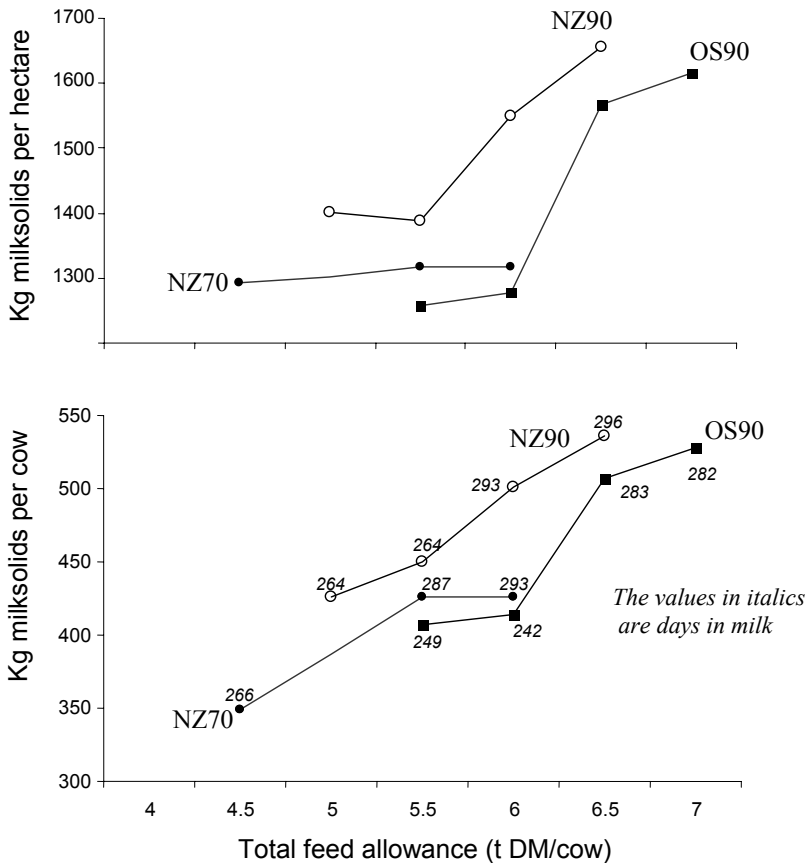


Figure 1 Mean values for yields of milk-solids per cow and per hectare in 2003/04, by three strains of Holstein Friesian cows, on grazing with different levels of supplementation in Hamilton, NZ (Macdonald, 2004).

Although not fully analysed yet, these data from New Zealand and Ireland, do indicate the presence of an interaction between genotype \times feeding level or system, which would be of great practical importance. Similar evidence was provided by Fulkerson (2000) for two strains of HF cows grazed on subtropical pastures, with three levels of concentrate feeding.

Body condition and live weight

The importance of body condition score (BCS) in achieving good reproductive performance has been highlighted by many studies (Villa-Godoy *et al.*, 1988; Butler & Smith, 1989; Nebel & McGilliard, 1993; Senatore *et al.*, 1996; Domecq *et al.*, 1997; Buckley *et al.*, 2003; Berry *et al.*, 2003). Other studies suggest that high genetic merit (for yield) cows may have higher energy requirements for maintenance when expressed per kg^{0.75}, because one kg of their live weight contains higher proportions of metabolically active tissues (eg:- lean; digestive tract) (Agnew & Yan, 2000; Ferrell & Jenkins, 1985). Historic breeding schemes of the NAHF

almost worldwide have focussed solely on increased milk production, which has increased the gap between energy intake and output in early lactation, a gap that is exacerbated on pasture. The correlated response in feed intake in early lactation, due to selection for milk yield, can cover only 40-48% of the extra requirement (Van Arendonk *et al.*, 1991), resulting in a greater mobilization of body reserves (body condition). Experiments comparing cows of high and moderate genetic merit for milk production, associate high genetic merit with more severe negative energy balance (NEB) in early lactation (Holmes, 1988; Gordon, 1996; Veerkamp & Emmans 1995; Oldenbroek, 1984; Buckley *et al.*, 2000, Kennedy *et al.*, 2003). Holmes (1988) also showed that at any given level of BCS at parturition, higher merit cows (for fat yield), lost more body condition (or gained less) post partum, as recently suggested by Dechow *et al.*, (2002). These problems caused by selection for yield, “angularity” (or sharpness, and thinness) and large size, were reviewed by Hansen (2000).

In the New Zealand study outlined above (Kolver *et al.*, 2004; Macdonald *et al.*, 2005) all cows calved in condition scores above 5 (scale 1-10), but by mid to late lactation the OS90 cows were thinnest (about 3.5), with the NZ90 cows intermediate (about 4.0) and the NZ70 cows fattest (about 4.5). The live weights before calving were about 520, 550 and 590 kg for the NZ70, NZ90 and OS90, respectively.

Just as in the New Zealand study, Horan *et al.*, (2005a), have shown that in Ireland the NZHF cows tended to be lighter than the NAHF cows, but tended to have a higher BCS at all times. The NZ strain had BCS values of 3.37 (Scale 1-5) immediately post partum, 2.84 at nadir and 3.13 at drying-off. The BCS of the high production NAHF strain tended to be lower at 3.17, 2.45 and 2.68, respectively, while that of the more moderately selected ‘high durability’ NAHF strain was intermediate at 3.24, 2.65 and 2.93, for the same times, respectively.

A recent analysis of 100,000 first lactation cows from sire proving herds under seasonal grazing in New Zealand from 1987 to 1999 (Harris & Winkelman 2000) measured the main differences between the NZHF and OSHF two-year olds. Those with a high proportion of OS genetics: were heavier (+43 kg), produced the same fat yield but more protein (8 kg) and more milk (390 litres); but were less likely to conceive to AI (47% vs. 61%), in a 5 to 7 week mating period; and had lower survival rates from first to second lactation (78% vs. 89%), and especially from first to fifth lactation (33% vs. 60%).

The lower body weight (BW) and higher BCS of the NZ strain is likely to be a consequence of more than 50 years of selection for higher yields of milk fat, and later protein also, in cows managed under grazing conditions, with the associated restrictions on maximum daily feed intake and milk yield. Maintenance of these characteristics will probably be helped by the recently included negative weighting on milk volume and BW within the New Zealand Breeding Worth Index (Harris *et al.*, 1996). However, the superior BCS of the NZHF is also likely due to historic culling of relatively infertile cows that failed to meet the targets for seasonal calving, in New Zealand herds, and the moderate to strong positive genetic association that exists between BCS and reproductive efficiency (Pryce *et al.*, 2001; Berry *et al.*, 2003).

Meeting energy demands from grass

Kennedy *et al.*, (2003) showed that with a high proportion of grass in the diet, NAHF cows highly selected for milk production were not capable of eating much more than NAHF cows of a lower production potential. On high concentrate diets however, high producing NAHF

cows achieved higher DM intakes. Similar conclusions can be drawn from the results of Kolver *et al.*, (2002), for NZHF and NAHF on either pasture or TMR. Hence the difference in milk yield between genotypes which differ in genetic potential for milk yield are smaller under grazing because intake is limited by the constraining factors discussed by Kolver & Muller (1998).

Dry matter intake, estimated using the n-alkane technique as modified by Dillon & Stakelum (1989), differed by only 0.4kgDM/day between the high production NAHF and the NZHF strains (17.9 v. 17.5) on grass only (Horan *et al.*, 2005c). A greater differential in total DM intake (1.9kg) was observed with cows offered a daily allowance of 3.7kg concentrate DM (20.8 v. 18.9 kgDM/day) while grazing. This is supported by the findings in New Zealand (Kolver *et al.*, 2004). The NZ70 is able to maximise yield per cow on grazing only, with no supplementary feed; the NZ90 is superior to the NZ70 with or without supplementary feed, but shows increases in yields with supplementary feed; whereas the OS90 is no better than the NZ70 without supplement but with generous supplementation it is almost equal to the NZ90, in milk yields but not in profit. This is in agreement with the results of Kolver *et al.*, (2002), who reported values for daily DMI of 16.6 and 20.4 for grazed pasture and 17.3 and 24.0 on TMR, for New Zealand HF cows or Overseas HF cows respectively. For both strains, intakes were lower on pasture than on TMR, but on TMR the OS cows showed a much bigger increase in intake (3.6) than the New Zealand cows (0.7). This feature of a high grass-concentrate substitution rate (resulting in a low response to concentrate supplementation), coupled with a higher BCS in the NZHF cows suggests that these animals achieve a greater proportion of their potential milk production on grass alone than do the high production potential NAHF cows. Linnane *et al.* (2004) concluded that the grazing appetite of the NZHF is compromised by the provision of supplementary food. Energy balance calculations also revealed that the energy balance of the NZHF was more positive than that of the NAHF in early lactation. When adjusted for BCS, Horan *et al.*, (2005c) found that the lighter NZHF had the highest grass DM intake per kg live-weight, in agreement with the results of Caicedo-Caldas *et al.*, (2001) for a lighter and heavier strains of NAHF cows, and of Grainger & Goddard (2004) who compared Jerseys and NZHF. Faverdin *et al.*, (1991) showed that substitution rate is lower with high yielding cows when energy requirements are not being met. In such situations, concentrate supplementation only slightly reduces herbage intake and appreciably improves animal performance. The high producing NAHF cows put the extra energy from the concentrate-based diet into milk rather than reducing their energy deficit, and showed lower substitution rates than the NZHF cows (Horan *et al.*, 2005c). The decreased energy balance during early lactation maybe primarily the result of genetically controlled energy partitioning rather than the result of feed intake not keeping up with yield, and that the physiological processes may be similar to those normally associated with under nutrition (Veerkamp *et al.*, 2003). It appears that the NZ strain can achieve a greater proportion of its energy requirement from a grass-only diet, and increased intake of concentrates reduces the intake of grass; on the other hand, increased concentrate supplementation resulted in higher energy intakes with the high producing NAHF and appear to be necessary to achieve its genetic production potential. The key common factor is the size of the “relative energy deficit”, between the cow’s potential yield and energy demand, and its actual energy intake (Penno *et al.*, 2001).

Convincing evidence of a G×E interaction was also provided by Kolver *et al.*, (2002), who compared widely different feeding systems and two distinctly different genetic strains of Holstein-Friesian cows. For yields of milk and milk solids, the New Zealand strain was slightly superior on pasture, but the overseas strain was much superior on TMR. This was

due, at least in part, to the inability of the OS strain to eat enough pasture to meet the needs of its heavier live weight and extra lactose synthesis (in higher milk volumes), which resulted in thinner body condition. In terms of overall merit, the OS strain would have been a complete failure on pasture because of its high proportion of non-pregnant cows (63%). However, current studies are showing that the OS (NAHF) strain may be suitable for extended lactations in non-seasonal systems with generous pasture and concentrates, where they can maintain high yields for longer periods of time (over 500 days up to the end of 2004; Eric Kolver, unpublished data).

Lactation profiles

Horan *et al.*, (2005b) showed that the high producing NAHF production profile is characterised by a steeper incline from calving to peak and a greater decline from peak to the end of lactation (i.e. lower persistency). The persistency of the NZ strain was superior at low concentrate levels. However, the difference in persistency between the strains was reduced by adding supplement to the diet. Kolver *et al.*, (2000) showed that on a total mixed ration diet there was no difference in the persistency between NAHF and NZHF animals, but Kolver *et al.*, (2002) reported that the genotype \times feeding system interactions tended to increase as lactation progressed. This is likely to have implications for survival on seasonal pasture-based systems, because very high milk yield at the beginning of lactation (steep lactation curve) followed by reduced persistency exposes the cow to greater physiological stress, often increasing the frequency of reproductive disorders or metabolic diseases (Madsen, 1975).

Other breeds and cross breeding

To date the use of non-additive genetic variance has been uncommon in dairy cattle breeding compared with other domestic species. This is most likely because past experience showed that in general crosses did not exceed the best parental breed for milk volume (Willham, 1985), namely the Holstein-Friesian, and because of inadequate attention to performance components other than milk volume that influence the life-cycle efficiency. However, due to genetic improvement for milk production in other dairy breeds and a decline in fertility/survival within the Holstein-Friesian, crossbreeding may now be more attractive.

The use of alternative breeds or crossbreeding to counter the decline in reproductive efficiency and health within NAHF populations is now being considered as a solution by some farmers in many countries. Lopez-Villalobos (1998) concluded that breeds other than NAHF, or crossbreds involving NAHF might be superior in providing a higher net farm income. The use of crossbreeding to counter the decreases in reproductive abilities, health and survival, and inbreeding, was discussed by McAllister (2002) and VanRaden & Sanders (2003). Lopez-Villalobos *et al.*, (2000) showed a dual effect of increased survival on profitability through lower replacement rates and through higher milk yields with higher proportions of mature animals in a simulation study of seasonal calving herds in New Zealand.

The lack of an across-breed evaluation procedure is an obstacle to the efficiency of this strategy in many countries, paradoxically due to a lack of data on which an evaluation system could be based. However, in New Zealand, with 25% of Jersey \times Friesian cows, an across-breed evaluation has existed for the last 15 years, and within-breed selection (mainly Jersey and Friesians) has been carried out successfully for over 50 years. A recent study by Harris *et al.*, (1999) showed that crossbreeding brought considerable merits in terms of fertility and

survival. Heterosis values of 5-6% for production traits and up to 18% for reproduction and health traits were observed. Twenty percent more crossbred cows survived to 5th lactation than did Holstein-Friesians, with the largest effect of heterosis in the NAHF×Jersey cross, and smallest in the NAHF×NZ HF cross. The Jersey breed, with its small size, represents the extreme of the dairy type, but its small size limits its value for beef although it enables it to eat more per kg live weight than other breeds (Grainger & Goddard, 2004). Under grazing in New Zealand, Jerseys produced less milk and solids per cow than Holstein Friesians but more per ha when both breeds were stocked at the same live weight/ha, or for maximum milk solids/ha (Ahlborn & Bryant, 1992). Slightly higher maximum net incomes were predicted for the Jerseys, at stocking rates of 3.7 Jerseys and 3.0 Holstein Friesians per ha. The Jersey has a slightly shorter period from calving to first mating but a slightly lower conception rate, and slightly lower survival to 5th lactation than the NZHF (Harris & Winkelman, 2000). Jerseys had significantly higher yields of milk solids on once-a-day milking in grazing systems, than NZHF cows (Dalley & Bateup, 2004; R. Gale unpublished report 2005).

Holstein Friesians and Jerseys were managed either on confined feeding systems or on grazed pasture plus haylage and concentrates in the USA, and calved in spring and autumn (White *et al.*, 2002; Washburn *et al.*, 2002). The authors concluded that “maintaining seasonal reproduction appears more feasible with Jerseys than with Holsteins, regardless of production system”.

Scandinavian countries, particularly Norway and Sweden have included health and fertility traits, in addition to yield, in their total merit index for the past 30 years. As a result, fertility performance has not decreased in these breeds over time (Lindhe & Philipsson, 2001). These cattle (Norwegian Red (NRF)) are now the subject of considerable interest in Ireland (Buckley *et al.*, 2004; Ferris *et al.*, 2004) as potentially suitable for cross breeding with the NAHF. Results presented by Buckley *et al.*, 2004, highlighted the benefits of the Norwegian selection program, attributes that are similar to those observed with the NZHF (Table 2).

Table 2 Effect of breed of dairy cow on reproductive performance (Buckley *et al.*, 2004)

| | NAHF | NRF |
|---|------|-----|
| Pregnancy rate to 1 st service (%) | 42 | 59 |
| 6 week in calf rate (%) | 56 | 75 |
| Empty rate after 14 weeks (%) | 19 | 10 |

Dillon *et al.*, (2003) reported higher BCS and superior fertility/survival with the French dual-purpose Montbeliarde and Normande breeds compared to NAHF when evaluated under pasture-based systems of milk production in Ireland. Breeding schemes for dual-purpose dairy breeds in France are designed to improve dairy attributes and functional traits in addition to beefing qualities, including growth and conformation. Heifers on seasonal grass based systems must typically calve at 2 years of age, and must therefore reach puberty by 12 to 14 months of age. However, in France the age and live weight at which puberty occurs is 10 months of age and 260 kg, and 16 months of age and 340 kg, for the Holstein-Friesian and Montbeliarde, respectively (Coulon *et al.*, 1997). No data are available for puberty in crosses between these breeds. In New Zealand, Holstein-Friesians with higher proportions of North American genetics generally reached puberty at older ages and heavier weights than NZHF

(Garcia-Muniz *et al.*, 1997; McNaughton *et al.*, 2002). These differences may have implications for the suitability of various breeds on seasonal grazing systems.

Cross breeding in beef production

The advantages of heterosis for reproduction and maternal traits in beef cows have been widely demonstrated and there are further advantages in progeny performance from using a sire from a third breed. Ideally therefore, beef cows should be crossbred and should be mated to a bull from a third breed (Cundiff *et al.*, 1992). This happens in controlled, well managed, large herds where it is practical to allocate a proportion of the herd and use separate sires or artificial insemination specifically for the production of replacements. In practice, many beef cow herds are small and have a requirement for only one bull. In such circumstances a choice has to be made between use of a bull to produce replacements or to produce slaughter animals. The latter option is usually preferred with the intention of sourcing replacements from outside the herd. In the past, such replacements were available as beef crosses from the dairy herd (i.e. Hereford or Limousin cross Friesians). These were very suitable as suckler cows with hybrid vigour, good fertility and good milk production (Drennan, 1993). When crossed with a bull of late maturing breed type the resultant progeny had high overall performance.

Genetic evaluations across countries and systems

Currently Interbull routinely provides across country evaluations for production and some linear traits. This ‘globalization’ of dairy cattle breeding allows the provision of proofs from sires all around the world to be compared on a country’s own base through the Multiple Trait Across Country Evaluation procedure (MACE) (Schaeffer, 1994). To date Interbull does not routinely apply MACE procedures (or Multiple-Trait Herd Cluster techniques) to fertility information. However initial studies (van der Linde & de Jong, 2003) have reported low (–0.05) genetic correlations between longevity across some countries; the average genetic correlation between countries for direct longevity was 0.60. Nevertheless, such low correlations are partially attributable to the diversity in definition of longevity related traits between the different countries. Similarly, the European countries that use survival analysis to measure longevity exhibited genetic correlations between 0.56 and 0.88 (Van der Linde & de Jong, 2003). Despite this van der Linde & de Jong (2003) concluded that MACE for longevity traits is feasible. Recent studies (Weigel & Rekaya, 2000; Zwald *et al.*, 2003) have been published which employ cluster analysis techniques or associated procedures to group herds of similar characteristics together thereby facilitating a borderless genetic evaluation of dairy cattle. Such techniques, if adopted, could increase genetic progress through improved accuracy of genetic evaluations for each management category.

Traits required by grazing beef cattle

Many of the comments on dairy systems apply equally to beef systems. On temperate grassland, beef production, like milk production, is based on the efficient conversion of grass (grazed and conserved) to meat. Biological efficiency is optimised when beef cows calve in late winter/early spring and increasing herd feed demand at least to mid season is matched by increasing grass growth and herbage supply. In winter when cows are dry and for a short period after calving they mobilise body reserves to meet a portion of their nutrient requirements, and then replenish these reserves during the grazing season when herbage

supply is abundant. Growing cattle can be “stored” in winter and subsequently exhibit compensatory growth at pasture.

Unlike, Holstein-Friesian dairy cows, different strains of individual beef breeds have, either not evolved from selection in different production environments, or they have not spread outside of their own environment or geographical area. Thus, experiments like those described earlier where various Holstein-Friesian strains were compared in different production environments do not exist for beef breeds. In beef production, genotype×environment interactions usually refer to different breed types compared in different production environments. Geay & Robelin (1979) recommended that comparisons of different genotypes of cattle should include various feeding levels, as variability in performance is enhanced when animals are fed a high energy diet *ad libitum* which allows them express their growth potential, particularly for muscle. Since then, many studies have investigated genotype×environment (including nutrition) effects. Most of these studies have compared different breeds, with very few comparing cattle from one breed with different genetic merits, and few have included a total grazing system.

Reproductive and maternal traits

One report showed small but significant interactions between breed and grazing environment in New Zealand, for weight of calf weaned per cow mated (Morris *et al.*, 1993). In general the large European breeds grew faster to heavier mature weights, but reached puberty at older ages and had lower reproductive efficiency, especially in less favourable conditions. Clearly, if cow breeds differing in mature size (and hence in maintenance requirements) are compared in an environment where nutrition is limiting, those with the highest requirement will be most adversely affected. This may result in impaired fertility and consequent knock-on effects on calf production. Similarly, if cow breeds differing in milk production potential are compared, inadequate nutrition will cause a greater reduction in milk yield in those of higher potential with consequent effects on calf performance. When nutrition is not limiting all breeds can perform to their genetic potential for reproduction and milk production.

Weight gains

There is general agreement that large late maturing continental breeds (e.g. Charolais, Belgian Blue) have higher live weight gains than smaller late maturing breeds (e.g. Limousin, Piedmontese), early maturing breeds (e.g. Hereford, Angus) and dairy breeds (e.g. Friesian, Normand). However, the extent to which differences between breed types depend on plane of nutrition is unclear. There were no significant genotype by level of nutrition interactions in the studies of Lanholz (1977), Ferrell *et al.*, (1978), Ferrell & Jenkins (1998) or Steen and Kilpatrick (1995), which included a range of non-grazing diets and breeds. Similar conclusions can be drawn from studies which did include pasture in the system (Baker, 1977, Liboriussen *et al.*, 1977), and from a study of progeny from bulls of 11 breeds, grazing at three locations in New Zealand, which differed in their ability to support high levels of animal production (Baker *et al.*, 1990). Liboriussen *et al.*, (1977) studied the progeny from four sires, which were different in genetic merit for growth rate, and reared on four planes of nutrition. There was no significant interaction for live weight gain but there was for carcass gain. The ranking of the sires did not differ significantly for the different feeding levels but the superiority of one sire decreased with a decrease in feeding level.

Feed intake

In most of the studies where different breed types were subjected to different levels of nutrition, the feeding levels were controlled, so no interactions between genotype and nutritional level for feed intake were possible. Furthermore breed type and weight were often confounded. It is generally accepted that Holstein-Friesians, other dairy breeds and perhaps also dual purpose breeds have a higher intake capacity than beef breeds, but differences between beef breeds are small and there was no evidence of interactions between genotype and feeding level (Geay & Robelin, 1979; Steen, 1995; Keane *et al.*, 1989; Keane, 1994).

Carcass composition

An interaction between genotype and nutrition for carcass composition was described by Geay & Robelin (1979). A reduction of 17% in ME intake of early maturing Salers bulls between 9 and 15 months of age, reduced the proportion of fat in the carcass without a significant effect on rate of body weight gain. A similar reduction in the intake of Charolais reduced body weight gain but had no effect on body composition. The authors suggested that the effects of a reduction in energy intake depends on the protein deposition capacity of the animal relative to its energy intake. When energy intake is greater than protein deposition capacity, restriction reduces lipid deposition only and thus changes composition. Conversely, when energy intake just matches protein deposition capacity, restriction reduces both lipid and protein deposition with little change in composition. The rate of live weight gain in Friesian bulls declined linearly after about 300kg live weight and protein deposition followed the same pattern. In contrast, the rates of gain in live weight and protein in Charolais bulls increased up to about 480kg live weight before then declining. At the same feed intake, Friesians have a higher maintenance requirement than Charolais so the latter have more energy for growth which they use to deposit more protein and associated water and less lipid (Geay & Robelin, 1979). The intake capacity of Charolais matches their protein deposition capacity but Friesians, with their higher intake capacity have energy in excess of their protein deposition capacity, which is deposited as lipid, (Geay & Robelin, 1979). Growth of muscle was affected by level of feeding to a greater extent in Angus than in Friesians (Fortin *et al.*, 1981), and the interaction was significant, but a similar study by Steen & Kilpatrick (1995) showed no significant interaction. A lower level of feeding increased the proportions of muscle and bone, but decreased the proportion of fat in Angus and Holstein cattle (Fortin *et al.*, 1981), and in Friesian, Limousin×Friesian and Belgian Blue×Friesian cattle (Steen & Kilpatrick, 1995). In the former study, the interaction was significant because the lower feeding caused a decrease in the weight of muscle in the Angus but not in the Holstein. The interaction was not significant in the latter study, or in two other similar studies (Ferrell *et al.*, 1978; Ferrell & Jenkins, 1998). There were no interactions between the effects of breed and location for 13 months weight, slaughter weight or slaughter traits of the progeny (up to 13 months), of 11 sire breeds, including 6 European beef breeds, plus Angus, Hereford, Friesian and Jersey, and grazed at three different sites, ranging from favourable to moderately hard grazing conditions in NZ (Baker *et al.*, 1990).

Conclusions and implications

Genetic selection for yields of milk and solids has generally had similar effects regardless of production system; higher yields, thinner cows, and a decline in longevity. However, with intensive grazing systems where seasonal calving is required, good reproductive efficiency/survival is essential, and potential daily intake is lower than for cattle on concentrated rations. Because only about 10% of the world's milk production is from grazing

systems the majority of dairy cattle have not been selected under grazing. Until recently most experimental results have indicated little or no important breed/strain×feeding system interactions in temperate dairying systems (Holmes, 1995). However, there is increasing evidence to suggest that the highly selected (for milk production) NAHF is unable to express its full genetic potential for milk production in a grass-based environment. Cows selected under grazing conditions do appear to exhibit characteristics that make them suited to production from a grass only diet; a lower genetic potential for milk yield, an ability to consume high intake of herbage relative to their potential energy demand, an ability to maintain body condition (energy balance), a minimal requirement for concentrate supplementation, and an ability to reproduce and survive within the constraints of the seasonal system. Crossbreeding provides a simple method to increase the health and efficiency of strains such as the NAHF through the introduction of favourable genes governing some of these characteristics, and through heterosis.

In future, improvement programmes should use a selection index that combines all the economically important traits appropriately for the local conditions and systems. Genetic proofs should be based on the performance of daughters managed under these local conditions, although this may become less necessary as further and more detailed genetic information about individuals becomes available in a range of systems. In the future, however, the cows must be compatible with the system used, and prediction of the phenotypic performance of dairy cattle must be based on knowledge of the cow's genotype as well as the environment in which they are managed. Polarisation of dairy cattle breeding is therefore likely in the coming years as the selection criteria chosen are refined to best reflect the profitability of various different systems of milk production.

In marked contrast, almost all beef cows and most growing cattle are managed under grazing systems. Therefore there has been much less tendency to select cattle for a particular system of feeding or management and selection has probably not resulted in such extremely high genetic potential for energy required per day, as in dairy cows. The relatively limited amount of research has shown few important interactions between genotype×feeding systems.

Where beef cow breeds of different mature size are managed in a sub-optimal nutritional environment, the larger breeds with higher requirements are more adversely affected by inadequate nutrition with consequent effects on calf performance. Aside from fertility and milk production, there is little evidence of genotype×environment in interactions for growth rate, weight for age, slaughter weight or the common slaughter traits. The ranking of widely different breeds for these traits is consistent across a wide range of production environments. There is also little evidence for a genotype×environment interaction for intake, but the issue has not been studied in detail.

Genotype x environment interactions for carcass composition depend on the animals genetic potential capacity for muscle deposition relative to its dietary intake of energy. When energy intake is higher than the capacity to deposit protein, surplus energy is deposited as fat; this will occur more readily, and at lower intakes in animals with lower protein deposition capacities, due to genetics and/or to age and growth phase.

References

Agnew, R.E. & T. Yan (2000). Impact of recent research on energy feeding systems for dairy cattle. *Livestock Production Science*, 66, 197-215.

- Ahlborn, G. & A.M. Bryant (1992). Production, economic performance and optimum stocking rates of Holstein-Friesian and Jersey Cows. *Proceedings of the New Zealand Society of Animal Production*, 52, 7-10.
- Baker, H.K. (1977). Notes on genotype - nutrition interactions. In "Crossbreeding Experiments and Strategy of Beef Utilisation to Increase Beef Production". Published by Commission of the European Communities, 414-426.
- Baker, R.L., A.M. Carter, C.A. Morris & D.L. Johnson (1990). Evaluation of 11 cattle breeds for crossbred beef production: performance of progeny up to 13 months of age. *Animal Production*, 50, 63-77
- Boelling, D. & G.E. Pollott (1998). Locomotion, lameness, hoof and leg traits in cattle. 2. Genetic relationships and breeding values. *Livestock Production Science*, 54, 203-213
- Berry, D.P., F. Buckley, P. Dillon, R.D. Evans, M. Rath & R.F. Veerkamp (2003b). Genetic relationships among body condition score, body weight, milk yield, and fertility in dairy cows. *Journal of Dairy Science*, 86, 2193-2204.
- Buckley, F., K. O' Sullivan, J.F. Mee, R.D. Evans & P. Dillon (2003). Relationships among milk yield, body condition, cow weight, and reproduction in spring-calved Holstein-Friesians. *Journal of Dairy Science*, 86, 2308-2319.
- Buckley, F., P. Dillon, M. Rath & R.F. Veerkamp (2000). The relationship between genetic merit for yield and live weight, condition score, and energy balance of spring calving Holstein Friesian dairy cows on grass based systems of milk production. *Journal of Dairy Science*, 83, 1878-1886.
- Buckley, F., J.F. Mee, N. Byrne, M. Herlihy & P. Dillon. (2004). A comparison of reproductive efficiency in four breeds of dairy cow and two crossbreeds under seasonal grass-based production systems in Ireland. *Journal of Dairy Science*, 87, Supplement 1, Abstract 526.
- Butler, W.R. & R.D. Smith (1989). Interrelationships between energy balance and postpartum reproductive function in dairy cattle. *Journal of Dairy Science*, 72, 767-783.
- Caicedo-Caldas, A., V. Lemus-Ramirez, C.W. Holmes & N. Lopez-Villalobos (2001). Feed intake capacity in Holstein-Friesian cows which differed genetically for body weight. *Proceedings of the New Zealand Society of Animal Production*, 61, 207-209.
- Coulon, J.B., A. Hauway, B. Martin & J.F. Chamba (1997). Pratiques d'élevage, production laitière et caractéristiques des fromages dans les Alpes du Nord. *INRA Productions Animales*, 10, 195-205.
- Cundiff, L.V., R. Nunez-Dominguez, G.E. Dickerson, K.E. Gregory & R.M. Koch (1992). Heterosis for lifetime production in Hereford, Angus, Shorthorn and crossbred cows. *Journal of Animal Science*, 70, 2397-2410.
- Dalley, D. & N. Bateup (2004). Once-a-day-milking; is it opportunity knocking. Proceedings of Dairy 3. 1-6; Massey University and Dexel Ltd.
- Dechow, C.D., G.W. Rogers & J.S. Clay (2002). Heritability and correlations among body condition score loss, body condition score, production and reproductive performance. *Journal of Dairy Science*, 85, 3062-3070.
- Dillon, P., S. Snijders, F. Buckley, B. Harris, P. O'Connor & J.F. Mee (2003). A comparison of different dairy cow breeds on a seasonal grass-based system of milk production: 2. Reproduction and survival. *Livestock Production Science*, 83, 35-42.
- Dillon, P., S. Crosse, G. Stakelum & F. Flynn (1995). The effect of calving date and stocking rate on the performance of spring-calving dairy cows. *Grass and Forage Science*, 50, 286-299.
- Dillon, P. & G. Stakelum (1989). Herbage and dosed alkanes as a grass measurement technique for dairy cows. *Irish Journal of Agricultural Research*, 28, 104 (Abstract).
- Domecq, J.J., A.L. Skidmore, J.W. Lloyd & J.B. Kaneene (1997). Relationship between body condition scores and conception at first artificial insemination in a large dairy herd of high yielding Holstein cows. *Journal of Dairy Science*, 80, 113-120.
- Drennan, M.J. (1993). Planned Suckler Beef Production. Beef Series No 4, Published by Teagasc, ISBN 0948321709, 38-47.
- Evans, R., P. Dillon, F. Buckley, M. Wallace, V. Ducrocq & D.J. Garrick (2004). Trends in milk production, fertility and survival of Irish dairy cows as a result of the introgression of Holstein-Friesian genes. *Animal Science*, Submitted November 2004.
- Faverdin, P., J.P. Dulphy, J.B. Coulon, R. Verite, J.P. Garel, J. Rouel & B. Marquis (1991). Substitution of roughage by concentrates for dairy cows. *Livestock Production Science*, 27, 137-156.
- Ferrell, C.L. & T.C. Jenkins (1985). Cow type and the nutritional environment. *Journal of Animal Science*, 61, 725 - 741.
- Ferrell, C.L. & T.G. Jenkins (1998). Body composition and energy utilisation by steers of diverse genotypes fed a high concentrate diet during the finishing period. 1. Angus, Belgian Blue, Hereford and Piedmontese sires. *Journal of Animal Science*, 76, 637-646.
- Ferrell, C.L., R.H. Kohlmeier, J.D. Crouse & H. Glimp (1978). Influence of dietary energy, protein and biological type of steer upon rate of gain and carcass characteristics. *Journal of Animal Science*, 46, 225-270.

- Ferris, C.P., D.C. Patterson & J.A. McKeague. (2004) A comparison of the first lactation performance of Holstein-Friesian and Norwegian dairy cows on Northern Ireland dairy farms. *Proceedings of the British Society of Animal Science*, Winter Meeting, York. Paper No.47.
- Fortin, A., J.T. Reid, A.M. Maiga, D.W. Sim & G.H. Wellington (1981). Effect of energy intake level and influence of breed and sex on the physical composition of the carcass of cattle. *Journal of Animal Science* 51:331-339.
- French, P., C. Stanton, F. Lawless, E. O'Riordan, F.J. Monahan, P.J. Caffrey & A.P. Moloney (2000). Fatty acid composition including conjugated linoleic acid of intramuscular fat from steers offered grazed grass, grass silage or concentrate based diets. *Journal of Animal Science*, 78, 2849-2855.
- Fulkerson, W.J. (2000). The productivity of Friesian cows; effects of genetic merit and level of concentrate feeding. Final Report DAN 082; Wollongbar Agricultural Institute, New South Wales Agriculture, xxpp.
- Garcia-Muniz, J.G., C.W. Holmes, D.J. Garrick & B. Wickham (1997). Growth and onset of puberty in two genetically different lines of Holstein Friesian heifers selected for either heavy or light liveweight. *Proceedings of the New Zealand Society of Animal Production*, 57, 46-47.
- Geay, Y. & J. Robelin (1979). Variation of meat production capacity in cattle due to genotype and level of feeding: genotype - nutrition interaction. *Livestock Production Science*, 6, 263-276.
- Goddard, M.E. & G.R. Wiggans (1999). Chapter 18. In: R.Fries & A. Ruvinsky (eds.) *The Genetics of Cattle*, C.A.B.I. Publishing.
- Gordon, I. (1996). Controlled reproduction in cattle and buffaloes. *Controlled Reproduction in Farm Animals*, Volume 1, CAB International, UK.
- Grainger, C. & M.E. Goddard (2004). A review of the effects of dairy breed on feed conversion efficiency. *Proceedings of the Australian Society of Animal Production*, 25,
- Hansen, L.B. (2000). Consequences of selection for milk yield from a geneticist's viewpoint. *Journal of Dairy Science*, 83, 1145-1150.
- Harris, B. L. & A. M. Winkelman (2000). Influence of North American Holstein genetics on dairy cattle performance in New Zealand. *Proceedings of the Australian Large Herds Conference*, 122-136.
- Harris, B.L., C.W. Holmes, A.M. Winkelman, Z.Z. Xu (1999). Comparisons between fertility and survival of strains of Holstein-Friesian cows, Jersey cows and their crosses in New Zealand. Fertility in the High-Producing Dairy Cow. *British Society of Animal Science Occasional Publication No. 26 Volume 2*, 491-493.
- Harris, B.L., J.M. Clark & R.G. Jackson (1996) Across breed evaluation of dairy cattle. *Proceedings of the New Zealand Society of Animal Production Vol. 56*, 12-15.
- Holmes, C.W. (1988). Genetic merit and efficiency of milk production by the dairy cow. In: P.C. Garnsworthy (ed.) *Nutrition and lactation in the dairy cow*. Published by Butterworths, UK., xxpp.
- Holmes, C. W. (1995). Genotype x environment interactions in dairy cattle: A New Zealand perspective. In: T.L.J. Lawrence, F.J. Gordon and A. Carson (eds.) *Breeding and Feeding the High Genetic Merit Dairy Cow*. Occasional Publication No 19, *British Society of Animal Science*, 51-58.
- Hoekstra J, A.W. Van der Lugt, J.H.J. Van der Werf, W. Ouweltjes (1994). Genetic and phenotypic parameters for milk production and fertility traits in upgraded dairy cattle. *Livestock Production Science*, 40, 225-232.
- Horan, B., J. F. Mee, M. Rath, P. O'Connor & P. Dillon (2004). The effect of strain of Holstein-Friesian cow and feed system on reproductive performance in seasonal-calving milk production systems. *Animal Science*, 79, 453 – 468.
- Horan, B., P. Dillon, P. Faverdin, L. Delaby, F. Buckley & M. Rath (2005a). Strain of Holstein-Friesian by pasture-based feed system interaction for milk production; bodyweight and body condition score. *Journal of Dairy Science*, (in press).
- Horan, B., P. Dillon, D.P. Berry, P. O'Connor & M. Rath (2005b). The Effect of Strain of Holstein-Friesian, Feeding System and Parity on Lactation Curves Characteristics of Spring Calving Dairy Cows. *Livestock Production Science*, (in press).
- Horan, B., P. Faverdin, L. Delaby, F. Buckley, M. Rath & P. Dillon (2005c). The effect of Strain of Holstein-Friesian Dairy Cow on Grass Intake and Milk Production in Various Pasture-based Systems. *Animal Science*, (submitted).
- International Farm Comparison Network (2004). In: T. Hemme (ed.) *Dairy Report*, www.ifcndairy.org
- Keane, M.G. (1994). Productivity and carcass composition of Friesian, Meuse-Rhine-Issel (MRI) x Friesian and Belgian Blue x Friesian steers. *Animal Production*, 59, 197-208.
- Keane, M.G., G.J. More O'Ferrell & J. Connolly (1989). Growth and carcass composition of Friesian, Limousin x Friesian and Blonde d'Aquitaine x Friesian steers. *Animal Production*, 48, 353-365.
- Keane, M.G. (1996). Beef Systems in Ireland - Role of Forage. In "Grass and Forage for Cattle of High Genetic Merit". *Proceedings British Grassland Society Winter Meeting*, 6 pages.
- Keane, M.G. & P. Allen (1998). Effects of production system intensity on performance, carcass composition and meat quality of beef cattle. *Livestock Production Science*, 56, 203-214.

- Keane, M.G. (2002). Response in weanlings to supplementary concentrates and subsequent performance. Occasional Series No 4. Grange Research Centre, Published by Teagasc, ISBN 12 184170 3117, 36pp.
- Kennedy, J., P. Dillon, K. O' Sullivan, F. Buckley & M. Rath (2003). The effect of genetic merit for milk production and concentrate feeding level on the reproductive performance of Holstein-Friesian cows in a grass-based system. *Animal Science*, 76, 297-308.
- Kolver, E.S. & L.D. Muller (1998). Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. *Journal of Dairy Science*, 81, 1403-1411.
- Kolver, E.S., Napper, A.R., Copeman, P.J.A., and Muller, L.D. 2000. A Comparison of New Zealand and Overseas Holstein Friesian heifers. *Proceedings of the New Zealand Society of Animal Production*, 60, 265-269.
- Kolver, E.S., J.R. Roche, M.J. de Veth, P.L. Thorne & A.R. Napper (2002). Total mixed rations versus pasture diets: Evidence for a genotype x diet interaction in dairy cow performance. *Proceedings of the New Zealand Society of Animal Production*, 62, 246-251.
- Kolver, E., B. Thorrold, K. Macdonald, C. Glassey, & J.R. Roche (2004). Black and White answers on the modern dairy cows. South Island Dairy Event, Lincoln University and Dexcel, 168-185.
- Langholz, H.J. (1977). Interaction between growth potential and feeding level in beef production. In "Crossbreeding Experiments and Strategy of Beef Utilisation to Increase Beef Production. Published by Commission of the European Communities, 445-463.
- Liboriussen, T., A. Sorensen & B. Andersen, (1977). Genotype x Environment interactions in beef production. In: "Crossbreeding Experiments and Strategy of Beef Utilisation to Increase Beef Production. Published by Commission of the European Communities", 427-444.
- Lindhe, B. & J. Philipsson (2001). The Scandinavian experience of including reproductive traits in breeding programmes. Fertility in the High-Producing Dairy Cow. British Society of Animal Science Occasional Publication No. 26, 251-261.
- Linnane, M., B. Horan, J. Conolly, P O'Connor, F. Buckley & P. Dillon (2004). The effect of strain of Holstein-Friesian w and feed system on reproductive performance in seasonal-calving milk production systems. *Animal Science*, 78, 169 – 178.
- Lopez-Villalobos, N., D.J. Garrick, H.T. Blair & C.W. Holmes (2000). Possible effects of twenty five years of selection and crossbreeding on the genetic merit and productivity of New Zealand dairy cattle. *Journal of Dairy Science*, 83, 154-163
- Lopez Villalobos, N., D.J. Garrick, C.W. Holmes (2002). Genetic opportunities to improve milk value in New Zealand. *Proceedings of the New Zealand Society of Animal Production*, 62, 90-94.
- Lopez Villalobos, N. (1998). Effects of crossbreeding and selection on the productivity and profitability of the New Zealand dairy industry. PhD Thesis, Massey University, Palmerston North, New Zealand.
- Lucy, M.C. (2001). Reproductive loss in high-producing dairy cattle: where will it end? *Journal of Dairy Science*, 84, 1277-1293.
- McAllister, A.J. (2002). Is crossbreeding the answer to questions of dairy breed utilization? *Journal of Dairy Science*, 85, 2352-2357.
- Macdonald, K. (2004). Unpublished report on the Holstein Friesian Strain Trial; Dexcel Ltd, Hamilton.
- Macdonald, K., B. Thorrold, C. Glassey, J. Lancaster, G. A. Verkerk, J.E. Pryce & C. W. Holmes (2005). Farm performance of Holstein-Friesian cows of three genetic strains on grazed pasture. International Grassland Conference, Satellite Workshop at Cork; July 2005, (in press)
- Madsen, O. (1975). A comparison of some suggested measures of persistency of milk yield in dairy cows. *Animal Production*, 20, 191-197.
- McGee, M., M.J. Drennan & P.J. Caffrey (1995). Suckler cow milk production and calf performance. In: P. O' Kiely, J.F. Collins & T. Storey (eds.), *Proceedings Agricultural Research Forum*, Published by Teagasc, Dublin, 87-88,
- McNaughton, J. R., S. R. Morgan, P. Gore, G. A. Verkerk, C. W. Holmes & T. J. Parkinson (2002). Monitoring onset of puberty in three genetic strains of Holstein Friesian dairy cattle. *Proceedings of the New Zealand Society of Animal Production*, 62, 30-33
- Morris, C.A., R.C. Baker, S.M. Hickey, D.L. Johnson, N.G. Cullery & J.A. Wilson (1993) Evidence of a genotype by environment interaction for reproductive and maternal traits. *Animal Production*, 56, 69-83
- Nebel, R.L., M.L. Mc Gilliard (1993). Interactions of high milk yield and reproductive performance in dairy cows. *Journal of Dairy Science*, 76, 3257-3268.
- Oldenbroek, J. K. (1984). A comparison of Holstein Friesian, Dutch Friesians and Dutch Red and Whites. Production characteristics. *Livestock Production Science*, 11, 69-81.
- Penno, J. W., K. A. Macdonald & C. W. Holmes (2001). Towards a predictive model of supplementary feed response from grazing dairy cows. *Proceedings of the New Zealand Society of Animal Production*, 61, 229-233.
- Penno, J.W. (2000). Profitable milk production from pasture. *Irish Grassland and Animal Production Association Journal*, 34, 78-86.

- Philipsson, J., G. Banos & T. Arnason (1994). Present and future uses of selection index methodology in dairy cattle. *Journal of Dairy Science*, 77, 3252-3261.
- Priolo, A., D. Micol & J. Agabriel (2001). Effects of grass feeding systems on ruminant meat colour and flavour. A review. *Animal Research*, 50, 185-200.
- Pryce, J.E., R.F. Veerkamp & G. Simm (1998). Expected correlated responses in health and fertility traits to selection on production in dairy cattle. Proceedings of the 6th World Congress on Genetics applied to Livestock Production, 383-386.
- Pryce, J.E. & R.F. Veerkamp (2001). The incorporation of fertility indices in genetic improvement programmes. Fertility in the High-Producing Dairy Cow. British Society of Animal Science Occasional Publication No. 26, 237-249.
- Pryce, J.E., M.P. Coffey & G. Simm (2001). The relationship between body condition score and reproductive performance. *Journal of Dairy Science*, 84, 1508-1515.
- Rauw, W.M., E. Kanis, E.N. Noordhuizen-Stassen & F.J. Grommers (1998). Undesirable side effects of selection for high production efficiency in farm animals: a review. *Livestock Production Science*, 56, 15-33.
- Senatore, E.M., W.R. Butler & P.A. Oltenacu (1996). Relationships between energy balance and post-partum ovarian activity and fertility in first lactation dairy cows. *Animal Science*, 62, 17-23.
- Schaeffer, L. R. (1994). Multiple-country comparison of dairy sires. *Journal of Dairy Science*, 77, 2671-2678.
- Shalloo, L., P. Dillon, M. Rath & M. Wallace (2004). Description and validation of the Moorepark Dairy Systems Model. *Journal of Dairy Science*, 87, 1945-1958.
- Steen, R.W.J. (1995). The effect of plane of nutrition and slaughter weight on growth and food efficiency in bulls, steers and heifers of three breed crosses. *Livestock Production Science*, 42, 1-11.
- Steen, R.W.J. and D.J. Kilpatrick (1995). Effect of plane of nutrition and slaughter weight on the carcass composition of serially slaughtered bulls, steers and heifers of three breed crosses. *Livestock Production Science*, 43, 205-213.
- Van Arendonk, J.A.M., G.J. Nieuwhof, H. Vos & S. Korver (1991). Genetic aspects of feed intake and efficiency in lactating dairy heifers. *Livestock Production Science*, 29, 263-275
- Van der Linde, C. & G. de Jong (2003). MACE for longevity traits. INTERBULL Bulletin No. 30, 3-9.
- VanRaden, P.M. & A.H. Sanders (2003). Economic merit of crossbred and purebred US dairy cattle. *Journal of Dairy Science*, 86, 1036-1044.
- Veerkamp, R.F. & G.C. Emmans (1995). Sources of genetic variation in energetic efficiency of dairy cows. *Livestock Production Science*, 44, 87-97.
- Veerkamp, R.F., P. Dillon, E. Kelly, A.R. Cromie & A.F. Groen, (2002). Dairy cattle breeding objectives combining yield, survival and calving interval for pasture-based systems in Ireland under different milk quota scenarios. *Livestock Production Science*, 76, 137-151.
- Veerkamp, R.F. (1998). Selection for economic efficiency of dairy cattle using information on live weight and feed intake: A review. *Journal of Dairy Science*, 81, 1109-1119.
- Veerkamp R.F., B. Beerda & T. Van der Lende (2003). Effects of genetic selection for milk yield on energy balance, level of hormones, and metabolites in lactating cattle, and possible links to reduced fertility. *Livestock Production Science*, 83, 257-275.
- Villa-Godoy, A., T.L. Hughs, R.S. Emery, L.T. Chapin & R.L. Fogwell (1988). Associations between energy balance and luteal function in lactating dairy cows. *Journal of Dairy Science*, 71, 1063-.
- Washburn, S.P., S.L. White, J.T. Green & G.A. Benson, G.A. (2002). Reproduction, mastitis and body condition of seasonally calved Holstein and Jersey cows in confinement or pasture systems. *Journal of Dairy Science*, 85, 105-111
- Weigel, K.A. & R. Rekaya (2000). A multiple-trait herd cluster model for international dairy sire evaluation. *Journal of Dairy Science*, 83, 815-821.
- White, S.L., G.A. Benson, G.A., S.P. Washburn, & J.T. Green (2003). Reproduction, mastitis and body condition of seasonally calved Holstein and Jersey cows. *Journal of Dairy Science*, 85, 95-104
- Willham, R.L. & Pollak, E. (1985). Theory of Heterosis. *Journal of Dairy Science*, 68, 2411-2417
- World Animal Review (1995). A classification of livestock production systems. 84/85, (3-4), 83-93
- Zwald, N.R., K.A. Weigel, W.F. Fikse & R. Rekaya (2003). Application of a multiple-trait herd cluster model for genetic evaluation of dairy sires from seventeen countries. *Journal of Dairy Science*, 86, 376-382.