RESEARCH TOPIC REVIEW: Dairy Cow Breeding for Organic Farming

Author: Stephen Roderick

1. Scope and Objectives of the Research Topic Review

The Organic Standards (Defra, 2006) state "In *the choice of breeds or strains, account must be taken of the capacity of animals to adapt to local conditions; their vitality, and their resistance to disease. In addition, breeds or strains of animals shall be selected to avoid specific diseases or health problems associated with some breeds or strains used in intensive production.* Further, the standards state: *Preference is to be given to indigenous breeds and strains* and EU regulations recommend that '*a wide biological diversity should be encouraged and the choice of breeds should take account of their capacity to adopt to local conditions'.*

Despite these legislative requirements, and the fact that organic standards require changes in health management practices so as to ensure health, fertility and overall fitness, many converting farmers tend to keep the same pre-organic livestock (Boelling et al., 2003). The Farm Animal Welfare Council (2004) express the view that the welfare of some breeds of high performance potential may be adversely affected when kept in more extensive or organic environments. Pryce et al (2004) identify the existence of the 'genotype – environment interaction' and the requirement for additional characteristics beyond the production focussed non-organic approach to breeding as being the two main reasons why there may be a requirement for different strains or breeds in organic farming.

There is a very large body of published information on dairy cattle breeding. This research review will describe the outputs from a range of studies that have specific relevance to organic farming conditions.

The objectives of the main Defra, SEERAD and EU-funded research dairy breeding projects relevant to organic production are described below. The main research outputs from these projects form the basis of the Summary of Research Projects and the Results. These are supplemented with a wide range of published material drawn from scientific publications, conference proceedings and relevant websites, including the OrgEprints database.

Breeding Strategies for Organic Dairy Cattle
The objectives of SEERAD/Defra-funded project "Breeding Strategies for Organic Dairy Cattle" were: (i) to determine if there is any evidence of heterosis in animal characteristics which are potentially important to organic systems, (ii) to develop, test and apply computer models to compare alternative breeding strategies, and (iii) to identify gaps in knowledge where further research is required (Brotherstone et al., 2003).

Identifying and characterising 'robust' dairy cows
An SAC Defra-LINK project (RobustCow) is assessing whether increased lifespan, health and welfare can all be delivered through the inclusion of traits related to robustness in a broader breeding index. The background to this project is the perception modern dairy cows are less 'robust' or adaptable than in the past and that this problem may be exacerbated by the fact that the same breed of cow are being managed in a wide range of farm environments, whilst being expected to maintain high milk production. Details of this project are available at: http://www.sac.ac.uk/research/publications/sls/researchnotes/longlivedhealthydairycows

An electronic compendium of information on animal health and welfare in organic farming
This project provides advisory material on an extensive range of health conditions and welfare situations formulated from a wide source of research material. There is a section on breeds and breeding and reference to disease resistance within specific disease sections. The compendium is accessible at www.organicvet.co.uk

Comparison of the physical and financial performance of organic dairy systems
Defra-funded project OF0146 examined the physical and financial performance of Holstein cattle managed under two scenario: self sufficient and purchased concentrate and thus provided evidence of the performance of animals of a particular genetic merit under different environments (management) conditions.

Longevity and lifetime efficiency of pure and crossbred dairy cows
The objectives of Defra project IS0213 *Longevity and lifetime efficiency of pure and crossbred dairy cows* was to review literature on the effect of dairy cow breed and cross-breed on lifetime performance, longevity, and efficiency, and production of a model of lifetime production and economic efficiency of different breeds of dairy cattle. Although not specifically focussed on organic cattle, the results are relevant.

A UK Fertility Index For Dairy Cattle
A research collaboration between SAC, University of Edinburgh, Roslin Institute and University of Nottingham, part-funded by Defra and others through the LINK programme is developing the UK's first Fertility Index which will enable producers to select bulls with fertile daughters (see selection tools for more).

Genotype by system interactions for health and welfare related traits in dairy cattle
This SAC project will investigate the genetic relationships between health, fertility and production in concentrate-based and grass-based production systems. The aim is to investigate the importance of genotype x feed system interactions in dairy cattle, especially between production, feed intake, fertility, health, condition score and energy balance.

Improving selection and management strategies for cowsof differing genetic merit for production managed in different systems
A new programme of research through the LINK programme at the SAC Dairy Research Centre is investigating the matching of genotypes to systems. The premise to this project is that when selection indices are too narrow, selected animals may not be best suited to any management system.

Sustaining Animal Health and Food Safety in Organic Farming
SAFO is a European Commission funded Concerted Action, which was carried out from March 2003 until August 2006. The objective of the project was to improve food safety and animal health in organic livestock production systems through active communication of research results and conclusions. Furthermore, the project has supported the development of subtle EU-standards on organic livestock production. The project involved partners from 26 European countries. Programmes, proceedings, and summaries of the proceedings published in the languages represented in SAFO can all be found at www.safonetwork.org.

Network of Animal Health and Welfare in Organic Agriculture
Network for Animal Health and Welfare in Organic Agriculture (NAHWOA) is a Concerted Action Project funded by the European Commission. The main aim of the project was to provide a joint platform for research organisations and institutions involved in organic livestock production, to enable sharing of information and ideas along with development of new research priorities, and to analyse the conventional research methodologies and their suitability to organic livestock research. Proceedings of NAHWOA workshops can be found at www.veeru.reading.ac.uk/organic/.

2. Summary of Research Projects and the Results

Breeds used in organic dairy farming

Breed characteristics of the UK dairy herd

The main breeding goal of the dominant breed of dairy cows in the UK, the Holstein-Friesian, has been for increased milk yields. This has meant that other genetic traits such as longevity, fertility and animal health have been compromised. Scandinavian Red dairy cattle have been bred with these factors as specific breeding criteria for many years. The average herd life in the UK was 4.76 lactations thirty years ago. Now it is 3.44. On average, dairy cows can be expected to reach an age of 8 years old (i.e. about 6 lactation) before their health starts to become a major economic issue. Fertility parameters of UK dairy cows have changed over the last twenty years, with increased calving interval, reduced heat detection rates, and increased services per conception. Such changes have added significant cost of milk production (Defra project IS0213 Longevity and lifetime efficiency of pure and crossbred dairy cows).

Breed characteristics in organic dairy herds

A survey of UK organic production in 1995 showed the domination of the Friesian Holstein breed, with Channel Island (Jersey and Guernsey) breeds also popular (26% of herds). Other indigenous breeds such as the Dairy Shorthorn and Ayrshire are also represented (Roderick et al., 1996). More recently, a survey of organic dairy herds in Cornwall showed that the Holstein still dominate, with 52% of herds composed of more than 10% of this breed. 29% of herds were mainly Friesian. Other dairy breeds present as more than 10% of a herd were Jersey (13% of herds), Guernsey (3%) and Ayrshire (6%). Some producers were adapting existing herds to organic production through breeding programmes whilst others had started conversion with new animals. A recurring theme in the comments from producers on breeds and breeding was that of the suitability of the Holstein breed and high genetic merit animals to organic systems of production (Roderick et al., 2005; Roderick and Burke, 2004).

In Germany, there is a wide diversity of dairy cow breeds in the organic sector, although again the Holstein dominates (45 % of farms with an average performance of 5924 kg/cow) followed by the Simmental (33 % of farms with an average performance of, 5634 kg/cow) (Rahmann and Nieberg, 2005). Unlike the UK, Holsteins are not common in Swiss organic systems (Haas and Bapst, 2004). A survey of Swiss organic dairying showed that 68% of dairy the cows were Simmental or Simmental × Red Holstein crossbreds, 29% were Brown Swiss whilst only 3% were Holstein–Friesians (Trachsel et al., 2000). In Denmark, Danish Holstein Friesian dominate but Red Danish and Danish Red and White are also important. The Holstein was the most prevalent breed amongst a sample of organic dairy farms in Ontario, Canada (Rozzi et al., 2007).

The Holstein in organic systems

Defra project OF0146 illustrated the limitations of the Holstein breed under low input organic conditions. Whilst under a system of purchased concentrates the Holstein maintained adequate body condition scores throughout the different stages of lactation, in the self-sufficient system some cows recorded a higher loss of body condition, lower milk persistency during lactation and poorer reproductive performance (IGER, 2002). The Holstein-Friesian breed appeared to be well suited to a system where concentrates were fed at >1.0 t/cow/annum dairy cows. Under a self-sufficiency scenario where the quantity of concentrates fed was dependent on the annual grain yields from the cereal crops, there was insufficient feed energy in the total diet during the early lactation period, which in turn led to problems of reduced milk persistency during lactation, lower milk protein concentrations and either delayed conception or a failure to conceive that resulted in reduced pregnancy rates. One of the conclusions from this study was that in a system where the quantity of concentrates fed is low a different type of cow (e.g. dual-purpose breed, cross bred) would have the potential to improve the balance between the cow's nutrient requirements and the quality of the diet and also lead to an improvement in the quality of milk that is produced for both the liquid and processing markets (Weller, 2006).

It has been shown that Holstein cows of high genetic potential might have more reproductive problems and lower lifetime performance than other breeds or crosses under a grazing system (Harris and Kolver., 2001; Dillon et al., 2003a; Dillon et al., 2003b).

A German study of organic farms showed that Holstein-Friesian cows had a longer calving interval than Brown Swiss or Simmental cows. Holstein-Friesians had the highest percentage of mastitis as culling reason and body condition scores were lowest in Holstein-Friesians (Hoerning et al., 2005).

An analysis of the impact of North American-derived Holstein cows into the New Zealand dairying systems showed that these animals were heavier, produced more milk volume and protein yield, had lower concentrations of fat and protein, and had poorer fertility and survival than New Zealand Holstein Friesian cows. Failure to get in calf and maintain a 365-d calving interval appears to be one of the key reasons for the reduced survival of North American Holstein cows within a seasonal dairying system. One of the key recommendations from the study, in the face of the prospect of introducing non-New Zealand Holstein genetics was the requirement for inclusion of fertility traits in the national breeding objectives (Harris and Kolver, 2001).

Identifying and characterising 'robust' dairy cows

An SAC Defra-LINK project (RobustCow) is assessing whether increased lifespan, health and welfare can all be delivered through the inclusion of traits related to robustness in a broader breeding index. The background to this project is the perception modern dairy cows are less 'robust' or adaptable than in the past and that this problem may be exacerbated by the fact that the same breed of cow are being managed in a wide range of farm environments, whilst being expected to maintain high milk production.. There are a number of candidate traits that may underlie robustness (SAC, 2005):

- Lifetime Energy Balance (LEB) (Coffey et al., 2002) refers to the amount of body fat carried, and the way it is mobilised during lactation varies between cows. Traits underlying robustness, such as health and fertility, are compromised when body fat levels are extremely low during early lactation. A means of quantifying body energy change is required.
- Maturity: During the first lactation, heifers are still growing, but must also sustain a first lactation and a second pregnancy, and eventually replenish lost body fat. Achieving a greater degree of maturity in body size by first calving contributes to robustness.
- Behaviour: A robust animal must be able to gain access to sufficient feed, water etc, without becoming stressed, overly aggressive, or by becoming completely non-reactive to the environment.
- Health traits and physical characteristics: A wide range of type traits and other physical characteristics may also contribute to robustness.

Crossbreeding and heterosis

Heterosis (hybrid vigour) is the average difference in expression of a trait between crossbred and purebred animals and is considered useful when a desired trait is expressed more in the crossbred offspring than in either of its purebred parents. Usually it is associated with an increase in health and fertility and therefore would be of some use in a breeding programme aimed at organic producers (http://www.sac.ac.uk/research/animalhealthwelfare/dairy/breeding/organics/).

Literature values for heterosis (or hybrid vigour) in production traits are variable and often not applicable to the UK environment. For milk yield, estimates range from 1.7% in the Ayrshire X Brown Swiss to 8.1% in the Holstein X Guernsey. Few published estimates of heterosis for health, fertility and survival traits exist. The project "Breeding Strategies for Organic Dairy Cattle" established a database of all milk recorded cows in the UK. For each cow the proportion of each breed in the cow was calculated (e.g. 50% Holstein, 25% Ayrshire, 25% Brown Swiss) which enabled estimates of pure and cross-bred differences for breeds in the UK national herd and for traits of interest to the organic sector (Brotherstone et al., 2003).

'Useful' heterosis is found when the cross-bred mean is more advantageous than either of the pure-bred means e.g. when the cross-bred mean for milk yield is higher than either of the pure-bred means, or the cross-bred mean for somatic cell count (a predictor of mastitis) is lower than either of the pure-bred means. Irrespective of the breeds involved, the project "Breeding Strategies for Organic Dairy Cattle" found no useful heterosis was found for any of production traits (Brotherstone et al., 2003).

Useful heterosis was found for SCC in the Holstein-Friesian cross, the Holstein-Jersey cross, the Jersey-Guernsey cross, the Ayrshire-Jersey cross and the Ayrshire-Shorthorn cross. Heterosis was estimated for survival from 1st lactation to 2nd lactation and useful heterosis was found in the Ayrshire-Jersey cross and the Ayrshire-Shorthorn cross. Only the Ayrshire-Jersey cross exhibited useful heterosis for calving interval.

Research at SAC found that whilst no useful heterosis was found in any cross for production traits (milk, fat and protein yields, fat % and protein %), useful heterosis was found for somatic cell count (SCC) (correlated with mastitis incidence) in first cross animals. Useful heterosis was also found for survival from 1st to 2nd lactation and for calving interval in Ayrshire X Jersey animals.

Crossbreeding also provides an opportunity to increase the reproductive performance, health, and efficiency of cattle by incorporating favorable genes from numerous breeds, by removing inbreeding depression, and by capitalizing on gene interactions that cause heterosis. There tends to be a much higher rate of crossbreeding on organic farms (Rozzi et al., 2007).

Crossbred cows appear to be competitive in pastoral systems. Heterosis is greater in crosses between two genetically diverse breeds or species (i.e. beef breed × dairy breed or Bos indicus × Bos taurus), and heterosis is usually least for traits such as growth and milk yield.

An organic dairy survey conducted in Ontario by Rozzi et al., (2007) showed that the most frequent crosses there were 3-way rotational crosses with Holstein, Brown Swiss, and Jersey (all in 1 herd), followed by crosses between Holstein and Dutch Belted, Milking Shorthorn, Simmental, Brown Swiss, Ayrshire or Jersey. Although fat and protein yields were not affected by the extent of crossbreeding, the Canadian survey showed a strong association between percentage of Holstein in the herd and milk production level.

Nauta et al (2006a) noted widespread crossbreeding and many different options within Dutch organic dairy farms. In New Zealand approximately 30% of dairy cattle are crossbred, predominantly Jersey crossed with Holstein-Friesian (Pryce et al., 2004).

Genotype × environment interactions

A new programme of SEERAD and Defra LINK-funded research at the SAC Dairy Research Centre "Improving Selection & Management Strategies For Cows Of Differing Genetic Merit For Production Managed In Different Systems" is investigating the matching of genotypes to systems. When selection indices are too narrow, cows may not be best suited to any management system. The project concludes that the consequences of a genotype environment mismatch can be identified before it becomes a national problem through the propagation of inappropriate genotypes.

Estimates of the heritability of milk production traits under organic farming conditions are provided by Nauta et al., (2006b). Heritabilities of milk, fat and protein yield, and somatic cell score (SCS) were higher under organic farming conditions. The findings of this study indicate that moderate genetic-environment interaction was present for yield traits but not for percentage of fat and protein and SCS (Nauta et al., 2006b).

There is evidence from studies at the University of Edinburgh/SAC Langhill Dairy Cattle Research Centre of emerging genotype × environment (GxE) interactions in a range of traits related to production and fertility (IGER, 2003). Dairy cows selected mainly for production are currently kept in a range of management systems. When selection indices are too narrow, selected animals may not be best suited to any management system. The research at SAC Langhill involves select and control lines of dairy cows managed as a single group but fed 2 distinct diets; a home grown forage based diet and a high concentrate diet.

In the opinion of Rozzi et al (2007), genotype-by-environment interaction between conventional and organic production should be estimated because, if significant, it would decrease the effectiveness of using breeding values estimated in conventional herds (Nauta, 2001; Pryce et al., 2001). Given the potential importance of interactions between specific genotypes and environments on animal welfare, FAWC (2004) suggest that there should be greater consideration of genotype and environment interactions in future breeding programmes.

Although Boelling et al. (2003) state that there are no GxE estimates for conventional versus organic systems, more recently differences in interactions between organic and non-organic have been estimated from Swiss and German data sets (Simianer et al., 2007). In general, GxE interactions between organic and conventional dairy herds were absent for production trait and very moderate for functional traits, although the latter result were based on weak data. From the Swiss data on Brown Swiss and Simmental cattle, correlations were > 0.9 for milk production traits and slightly lower (0.8 to 0.9) for functional traits such as service period and somatic cell score. These results were confirmed using German data for Holstein Friesian cattle.

Analysis of organic and conventional Dutch dairy farms found genetic correlations significantly lower than unity between organic and conventional farms: 0.80 for milk and 0.78 for protein yield (Nauta et al., 2006b), although the standard error of the estimates has been deemed to be too large to conclude that a separate organic breeding program was necessary (Rozzi et al., 2007).

If the main differences between conventional and organic herds were only due to pasture availability, then little or no G×E interaction would be expected (Rozzi et al., 2007) as the significant effects of different feeding systems on genetic evaluations have not been found (Boettcher et al., 2003). However, this may not be the case as organic standards also affect other aspects of dairy production.

In Switzerland successful breeding programmes have been achieved with both the Brown Swiss and Swiss Red & White breeds to improve the compatibility between genetics and the system of management (Bapst, 2001).

Across countries, differences in genetic evaluations resulting from GxE interactions are considered by Interbull through the use of Multiple Across Country Evaluation (MACE) to calculate International Genetic Evaluations (www-interbull.slu.se/).

N.B The International Bull Evaluation Service (Interbull) is a sub-committee of the International Committee for Animal Recording (ICAR) and, as a non-profit organisation, responsible for promoting the development and execution of international genetic evaluations for cattle. It achieves this through co-ordinating international communication and research efforts, and providing a number of services to participating countries through the activities of the Interbull Centre in Uppsala, Sweden.

Kin breeding

In the Netherlands, the concept of kin breeding and selection for organic production conditions has been the focus of attention at the Lois Bolk Research Institute (Baars and Nauta, 1998). The assumption is that cows that survive have all the desirable traits for sustainable production over many lactations. With family or kin breeding, breeding is entirely based on the farm herd, as this is believed to avoid G x E. It relies on the farmer knowing which animals exhibit the desirable traits. It is based on 'low scale' inbreeding, where most animals are related, but the same ancestor appears more than once in an animal's pedigree four or more generations back.

What are the desired traits in organic farming?

The organic farmers' view

The SAC Defra-LINK project (RobustCow) included a survey of organic dairy farmers in order to establish a ranking of desired traits. The top 10 traits (from 28) ranked were all related to health, fertility and longevity. Milk yield was ranked at 17 whilst general disease resistance was ranked at 1 (At: http://www.sac.ac.uk/research/animalhealthwelfare/dairy/breeding/organics/). The emphasis on functional traits suggest that "robustness" is a desired characteristic of organic dairy animals.

As part of SEERAD/Defra-funded project "Breeding Strategies for Organic Dairy Cattle", stakeholders allocated a score, according to their perceived importance, to each of 28 possible breeding goal traits including production traits, fitness and human health benefits. The characteristics which were consistently ranked highly by group members included general disease resistance, mastitis resistance, longevity, somatic cell count and female fertility.

Canadian organic dairy farmers emphasized grazing traits, fertility, health and longevity as the most important areas of concern that should be addressed through breeding selection and many farmers felt that present production was high enough, or even too high, and that more attention should be applied to functional traits, particularly to grazing traits, to increase the cow's genetic ability to produce on grass alone without adverse effects on fertility and health in general (Rozzi et al., 2007).

In Switzerland organic farmers identified the most important criteria for breeding selection as fertility, low cell count, good milk production from forage, longevity and milk quality, especially protein content (Haas and Bapst, 2004). A similar preference for functional over production traits was observed on organic farms in Austria (Schwarzenbacher, 2001, cited by Haas and Bapst, 2004). In the Swiss situation, there were regional differences, in part reflecting the different regional emphasis on dual-purpose production. Yield persistence was a preferred criteria in the French part of Switzerland and on farms with high milk yield but this was not true in other situations (Haas and Bapst, 2004). For farmers keeping Simmental cattle, speed of milking was an important factor.

The survey of Ontario organic farmers (Rozzi et al., 2007) gave scores to traits which already have a genetic evaluation. Average scores showed functional traits came first, with feet and legs and overall udder, followed by fat yield, body capacity, protein yield, and SCC. Body capacity scores were high because more capacity was associated with higher forage intake. Somatic cell count, as an indicator of udder health and mastitis resistance and longevity, had similar scores. Milk production was apparently the least important trait.

A survey of Dutch organic farmers showed that in general farmers wanted a robust, long living cow, with good udder health and fertility (Nauta et al., 2006a). Farmers wanted a weighting of about 43 % placed on functional traits, 32% for production traits and 25% for conformation traits. For production traits, the main focus was on a long productive life, a good milk yield per lactation and high protein and fat content. The most important functional traits were fertility and udder health. For conformation, udder and quality of legs were most important. However, there were differences in the means by which these goals were being implemented. Nauta et al (2006a) describe two distinct categories of organic dairy producer in Holland: the specialist producer and the multi-functional producer. Distinct differences were noted between the two types with regard to the approach to animal breeding. 29% of specialist dairy farmers used pure bred Holstein cows and 51 % chose cross breeding with more robust breeds. Whilst 57% of multi-functional farms used cross breeding, a further 30% chose native Dutch breeds and only 2% kept Hosteins (Nauta et al., 2006a). Many combinations of cross breeding were noted. The results of this work emphasise the issues associated with developing a single organic breeding approach.

Although there is an increasing emphasis on functional traits, worldwide the emphasis on production traits in the Holstein breed ranges from 29 to 80%, with most countries placing at least 50% emphasis on production. In the Scandinavian countries the relative weight on production is around 30% (Rozzi et al., 2007).The most important functional traits included in Holstein selection indices worldwide are described, in decreasing order, by Miglior et al (2005) as longevity, SCC, overall udder, feet and legs, fertility, overall conformation, calving ease, growth, and milking temperament.

<u>What do organic farmers select for in practice?</u>
Analyses of production data of more than 450 organic dairy farms and farmer surveys showed that the difference in the stated breeding objectives between organic and conventional farms was very minor and practically non-existent in terms of the actual breeding activities (Simianer et al., 2007).

A comparison of the breeding values of the Swiss Braunvieh (Brown Swiss) sires used in organic and conventional dairy farms in Switzerland showed that functional traits were not important in practice despite organic farmers expressing their preference for these traits over those influencing production (Bapst et al., 2005).

Economic considerations
The project "Breeding Strategies for Organic Dairy Cattle" developed a new method of deriving economic values (EVs) using an environmental economics approach where the resource under consideration is managed within biological constraints.

Pure-bred and cross-bred economic values for production traits, longevity, mastitis, fertility and lameness under organic farming assumptions were similar to those derived using conventional farming assumptions. For example, for the Holstein-Friesian cross the EV for an additional lactation under conventional farming assumptions was £24 whereas under organic farming assumptions it was £26.

The similarity in economic values across systems may be a consequence of limited information on organic systems. For example, information on the incidence of mastitis and lameness in organic dairy herds was not available, so incidences in conventional farming systems had to be used.

Environmental values, which are based on land values and take account of soil quality and composition, were substantially higher in an organic system than in a conventional system for all traits and all breeds/crosses. For example, for Guernseys, the environmental value of an average increase of one lactation rises from £23 in a conventional farming system to £94 in an organic system.

A comparative analysis indicated that, for both standard economic values and environmental economic values, Holsteins performed best, irrespective of farming system. Ayrshires and Ayrshire-Shorthorn crosses were better suited to an organic system than to a conventional farming system. Milk prices have a greater impact on profitability in organic systems than in conventional systems.

A non-market value can be a value representing animal welfare and societal influences for animal production, which can be added to market economic values in the breeding goal to define sustainable breeding goals. The concept of non-market values to quantify functional traits such as disease resistance and reproductive efficiency are described and discussed by Nielsen *et al.*, (2006) and Nielsen *et al.*, (2005).

The most profitable cows selected for largely pasture-based systems have been shown to be different from those selected under a high-concentrate regime (Dillon et al., 2003a and Dillon et al., 2003b).

Alternative breeding plans for organic cattle breeding have been developed by Harder et al., (2004) and studied with regard to population size, use of AI and the influence of the economic value of functional traits. The selection responses were shown to increase with increasing population size due to improved selection of bull sires. The reduction in the use of artificial insemination below 50% led to high losses in final discounted profit. An increase of the economic weights applied to functional traits by 50% led to tolerable decreases in the natural selection response of production traits.

Breeding for production and health and welfare

Disease resistance and health

Ignoring diseases in breeding programs may lead to undesirable correlated selection responses when selecting on milk yield (Simianer et al., 1991) and there is evidence to suggest that selection for milk production traits may have led to an increase in the incidence of some health disorders, such as mastitis and lameness (e.g. Emanuelson, 1988; Lyons et al., 1991; Uribe et al., 1995; Pryce et al., 1997 and Pryce et al., 1998 – all cited by Broom, 2001). In these studies there is general agreement that the heritabilities of health and fertility traits are low, but it has been argued that there is sufficient genetic variation to make genetic progress in some of these traits (Jansen, 1985 and Emanuelson, 1988). Although the heritabilities are low, the genetic variability has been shown to be reasonably high, suggesting that a significant genetic improvement of the disease resistance is achievable if proper procedures are applied (Pryce et al., 2004).

Mastitis

It is possible to obtain considerable selection response for some conditions, such as clinical mastitis. Genetic variability of mastitis resistance is well established in dairy cattle and there is more and more evidence that mastitis should be included in the breeding objective of dairy cattle breeds. Selection for increased milk production will result in an unfavourable correlated increase in mastitis incidence if mastitis is ignored in the breeding programme (Heringstad et al., 2003). Many countries have implemented selection for mastitis resistance based on linear decrease of somatic cell counts (Rupp and Boichard, 2003). Positive selection responses for disease resistance (mastitis, ketosis and retained placenta) in the Norwegian Red breed over five generations are reported by Heringstad et al., (2007).

Well integrated recording schemes in the Scandinavian countries have enabled the adoption of total merit indexes (TMI), including reproduction and health traits, into selection schemes (Philipsson and Lindhé, 2003). In spite of low heritabilities for disease traits, genetic variation for disease incidence is economically important and justifies including disease in breeding programs (Shook, 1989). Genetic selection for health disorders recorded in on-farm software programs can be effective (Zwald et al., 2004).

Genetic resistance to mastitis has been well researched and there is a body of work on the genetics of SCC and subclinical and clinical mastitis (Poso and Mantysaari, 1996) which has established a favourable genetic correlation between low SCC and mastitis incidence at the cow level. Others have reported on the significance of certain BoLA alleles in resistance to Staphylococcus aureus-infection (Aarestrup *et al*., 1995).

In the past, efforts to introduce mastitis resistance traits into dairy cow breeding schemes have also been hampered by the negative genetic correlation with increased milk yield. It has often been considered uneconomic to attempt to improve both mastitis resistance and milk yield simultaneously, particularly since the heritability of milk yield is markedly higher than that of mastitis resistance (Strandberg and Shook, 1989).

Hovi (2004) identified the need to develop breeding programmes for organic farmers to help in improving mastitis resistant cows. Recently, bull proofs have included the PTA (potential transmitting ability) values for SCC to help in choosing sires that will confer to their daughters a greater ability to resist mastitis and thus increase the herd's resistance to mastitis. Somatic Cell Counts PTAs are expressed as a percentage with a general range of +/- 20. For every 1% in SCC PTA a change of 1% in cow SCC is predicted, with negative % PTA SCC indicating a reduction in SCC and is therefore better (MDC, 2007).

Non-lactational traits such as udder health as measured by somatic cell score are quantitative, meaning that the phenotype in the whole animal represents the sum of lesser traits that cannot be easily measured. The physiological mechanisms that underlie quantitative traits are extremely complex. Genetic selection can be applied to quantitative traits but it is difficult to link successful genetic selection with the underlying physiological mechanisms (Lucy, 2005).

Epidemiological studies comparing risk factors for subclinical mastitis in organic and conventional dairy production systems showed that breed was the only factor that was significantly associated with the risk for sub-clinical mastitis in both systems (Doherr *et al.,* 2007). The difference between the breeds may be in part associated with udder conformation, genetic traits (Schukken et al., 1990), and with metabolic, endocrine and immunological differences.

Clinical mastitis has been utilised in the Norwegian national selection scheme since 1980. Initially, economic weight for milk yield compared to mastitis in the total merit index was 4.5:1 in favour of milk yield. From 1990 it became 1.6:1 and later 1:1. Data from the national health card system have enabled genetic selection against mastitis. The weights used in the total merit index until 1990 allowed genetic progress for milk yield without unfavourable response in mastitis. The weights used later have allowed genetic response for mastitis at some expense of response in milk yield in the cow population, but so far without reduced response for milk yield in the sons. Large daughter groups together with proper weights are necessary for reliable and effective selection against mastitis. The yearly cohort of test bulls must be large to secure the existence of enough bulls excellent for both milk yield and mastitis to be used as bull sires (Svendsen, 1999).

Roderick & Hovi (1999) reported a non-significant difference between breeds in the level of somatic cell counts in the milk, with black and white cows having a slightly lower average cell count than other breeds (375,000 v 384,000 cells/ml).

Lameness

Differences have been found between breeds in claw score traits for certain foot conditions (Huang et al., 1995). Ayrshires and Jerseys had better scores than other breeds. The Brown Swiss had the worst scores for corkscrew claws, laminitis and sole ulcers. White line score was worst in Guernseys and heel erosion and digital dermatitis were worst in Friesians. There is evidence that Jerseys tend to have harder feet and less lameness (Chesterton et al., 1989). It has also been suggested that heavier cows are more prone to clinical lameness (Boettcher et al., 1998). Claw colour has also been implicated in lameness, with cattle with less pigmented feet being more prone to lameness (Chesterton et al., 1989). The heritability of clinical lameness in dairy cows from 24 herds was estimated as 0.10 and 0.22 using linear and threshold model analysis respectively (Boettcher et al., 1998).

Holstein and British Friesian cattle with white feet tend to have softer claws and are more prone to lameness problems than other breeds such as the Jersey and Brown Swiss with harder black hooves (Webster, 1993). Organic farmers perceive lameness as being more problematic in Holstein and British Friesian cattle compared with other breeds and Peterse (1985) showed a greater susceptibility to lameness compared with either the Jersey or Montbeliarde.

Milk fever

Jerseys, Norwegian Reds and Swedish Red breeds have been reported to be more prone to milk fever Bakke (2003) and organic farmers in the UK perceive milk fever to be more problematic in non-Holstein and Friesians (Roderick and Hovi, 1999).

Production and fertility

There is evidence to suggest that selection for milk production traits can result in negative energy balance, metabolic stress, poor fertility associated with large losses of body condition during early lactation and reduced conception rates (Nielsen, 1999; Veerkamp et al., 1995; Jansen, 1985; van Arendonk et al., 1989; Oltenacu et al., 1991 and Hoekstra et al., 1994). In cows producing lactation yields from 3,500 to 10,500 kg, Mee et al. (1999) found increasing milk yield per cow was correlated to declining herd fertility. A negative genetic correlation between increasing milk yield and the incidence of health and fertility traits in Holstein-Friesian herds has been reported (Pryce et al., 1997). Snijders *et al.* (1997) compared low and high genetic merit cows and found a higher incidence of failure to conceive and more cows culled for infertility in high genetic merit animals compared with those with a low genetic potential. Weller and Bowling (2004) showed that in an organic system aiming for self-sufficiency of feed, high genetic merit Holstein-Friesian cows can suffer early lactation energy deficiency which can in turn severely delay conception, reduce pregnancy rate and potentially increase culling.

Loss of body fat is greatest for cows fed a high forage diet. Research at SAC has shown that selection for yield alone has led to a genetic decline in fertility - work by SAC and others in a LINK project has led to the development of a UK fertility index, allowing future selection for both production and good fertility.

Defra-funded studies at SAC confirmed the genetic correlation that improved milk yields lead to poorer fertility. However, this it was not a "one for one" relationship, suggesting that there is scope to include production and fertility together in balanced selection decisions. A strong relationship between all fertility traits was also found, suggesting that improving one will lead to improvements in the others. Bull proofs show sufficient genetic variation in fertility to allow improvements to be made in fertility. Fertility traits were combined in an index, weighted by their economic weight. Available at http://www.sac.ac.uk/research/publications/sls/researchnotes/ukfertilityindexdairycattle.

Reproduction and health traits are of significant economic importance. Most of these traits are traditionally expressed in a categorical way and show heritabilities of 5% or less. Nevertheless, their additive genetic variation is considerable. Philipsson and Lindhé (2003) use the example of the incidence of clinical mastitis in the first lactation which varies among daughter groups of Swedish Holstein bulls between 10 and 26%, stillbirth rate at first parity between 3 and 16%, and the number of inseminations per serviced cow between 1.6 and 1.9. Unfavourable genetic correlations in the range 0.2–0.4 between production on one side, and mastitis and female fertility on the other, have generally been found.

Breeding and Nutritional efficiency

Differences have been shown between breeds in the efficiency of the ruminal digestive process (Voigt et al., 2000). Jersey cattle apparently have a higher feed intake capacity per kg liveweight compared to Holstein Friesians, especially when fed high levels of roughages (Ingvartsen and Weisberg, 1993 cited by Nielsen et al., 2004). Jersey cows have been reported as more efficient converters of pasture dry matter into milk solids, primarily because of a greater efficiency in milk fat production (Mackle et al., 1996).

Condition score has commonly been used to indirectly monitor feeding levels, but several studies in recent years have demonstrated that there it has a substantial genetic component as well. Heritability estimates for condition score are around 0.3 (e.g. Koenen and Veerkamp, 1998; Pryce et al., 1999; Harris, 2002).

Dhour et al., (1991) compared voluntary feed intake in 1-2 year old heifers of different breeds and showed that at the same body weight there was no difference in the feed intake capacity between Holstein Friesian, Montbeliarde and Tarentaise (local Austrian breed) breeds. The intake of the beef breed Saler was approximately 15% lower than the dairy breeds.

In Switzerland, organically managed Simmental and Simmental × Red Holstein cows produced on average 12% and Brown Swiss 5% less milk than the corresponding reference populations with feeding restrictions and a possibly lower genetic potential on organic farms being cited as the possible reasons for this difference. Milk fat and milk protein contents were considered normal (Trachsel et al., 2000).

Environmental Considerations

Breed effect on nitrogen utilisation efficiency

Breed effect is unlikely to have a large impact on nitrogen utilisation efficiency because the greatest improvements on N use efficiency are mediated through the rumen environment.

Defra project ISO213 on “Longevity and lifetime efficiency of pure and crossbred dairy cows” examined the breed effect on nitrogen efficiency utilisation and found that this is unlikely to have a large impact because the greatest improvements on N use efficiency are mediated through the rumen environment (IGER, 2003). At similar rates of turnover in high- and low-yielding herds, lifetime N use efficiency is higher in the high-yielding herd because fewer animals are needed to meet replacement needs. However, this must be balanced against potentially shorter life expectancy in higher-yielding cows than in lower-yielding cows.

Selection tools

A UK fertility index

The research project *A UK Fertility Index For Dairy Cattle* has shown that there is scope to include production and fertility together in balanced selection decisions. A strong relationship between all fertility traits was also found, suggesting that improving one will lead to improvements in the others. Bull proofs show sufficient genetic variation in fertility to allow improvements to be made in fertility. Fertility traits were combined in an index, weighted by their economic weight and good correlation was found between £PLI (the current UK dairy selection index) and the fertility index. (http://www.sac.ac.uk/research/publications/sls/researchnotes/ukfertilityindexdairycattle).

Total merit indices

It has been suggested that there is need to develop an ecological total merit index based on the available breeding values for different trait complexes, in which functional traits, such as disease resistance, should receive a higher weight (Simianer et al., 2007).

Total merit indices specific for organic dairy farmers are currently available in a few countries: in Switzerland (Bapst, 2001) and, for dual purpose populations, in the Bavarian region of Germany (Krogmeier, 2003) and in Austria (Baumung et al., 2001). The breeding criteria of all Scandinavian countries include indices for somatic cell count, mastitis resistance, non-return rate, calving ease and stillbirths. Scandinavian Red dairy cattle have been bred with longevity, fertility and animal health as specific breeding criteria for many years. Well integrated recording schemes in the Scandinavian countries enabled early adoption of total merit indexes (TMI), including reproduction and health traits, into their selection schemes.

An organic total merit index was developed based on the subjective scores for traits with a genetic evaluation in Canada (Rozzi *et al.*, 2007). The relative weights of production to fitness traits were substantially different from those used conventionally in Canada, but similar to those used in conventional indices in Sweden and Denmark and in the Swiss organic index. Overall weight on health traits was 2.5 times higher in the organic index and, among fitness traits, the emphasis was substantially higher for lactation persistency, somatic cell score, and body capacity.

In the Canadian organic index the relative weights of production to fitness traits were 28:72 which is substantially different from the 54:46 weighting in the Canadian official selection index but similar to those used in conventional indices in Sweden and Denmark and in the Swiss organic index. The overall weight on health traits was 2.5 times higher in the organic index and, among fitness traits, the emphasis was substantially higher for lactation persistency, somatic cell score, and body capacity. Correlations between the organic index and Lifetime Profit Index were 0.88 for all bulls proven in Canada, 0.70 for the top 1,000, and 0.65 for the top 100. So, the two indices would have a different group of bulls ranked at the top. Comparing the qualitites of the bulls ranked top in the two indices, the best ‘organic-ranked’ bulls had lower yield potential but were better for body capacity, somatic cell count, longevity, feet and legs, udder conformation and lactation persistency.

The organic total merit index developed in Canada was built based on the traits chosen by organic farmers and their relative subjective scores. At the time of surveying farmers, calving ease was initially chosen as a fertility trait, but these were replaced by actual fertility as genetic evaluations became available. Calving ease was seen as a trait to avoid problems rather than being selected for directly (Rozzi et al., 2007).

Baumung et al. (2001) used a herd simulation approach and showed that the organic selection index developed in Austria was sufficiently robust to be applicable to a range of farming situations and that changes in returns and costs only slightly affected the weights in the index.

Krogmeier (2003) describes the organic total merit index (ÖZW) developed for organic dairy cattle breeding in Germany. ÖZW presents biological ranking of the AI bulls. Krogmeier (2003) views the index as being a potentially powerful tool for organic dairy breeding when the results of newly developed breeding value estimations are included and when the actual weights for single traits are adjusted according to individual farm needs.

The ecological breeding index (EBI) was introduced in Switzerland in 2000. It ranks sires based on a quality evaluation of their off-spring regarding functional and performance traits. Its use and knowledge of its value varies between regions of the country and between system types, with organic farmers keeping Brown Swiss and Holstein cattle being familiar with its value but less so amongst those keeping Simmental. The index seemed to be more important for farmers using low or no concentrate feeds, although the level of satisfaction with its value was low amongst farmers keeping high yielding herds (Haas and Bapst, 2004). There was also a similar diversity of opinion regarding the relative weight applied to functional traits such as udder health, fertility, longevity, milk contents and forage absorption capacity compared with economic traits i.e milk yield. The latter being more important for high yielding, high concentrate situations.

3. Analysis and Conclusions

<u>Is there a need for an organic approach to breeding</u>

There are two reasons why different strains or breeds may be needed for organic livestock production:

- There may be a difference in the emphasis and range of traits required under organic conditions i.e. as well as production, other more functional traits may also be desirable;

- The 'genotype by environment interaction' (or 'G x E') is a phenomena whereby animals being selected for performance traits in one environment rank very differently in another environment (Pryce *et al*., 2004).

Whilst it is debatable whether or not organic farming systems are sufficiently different to non-organic systems to justify a different approach to breeding, there are a number of key elements of organic standards and principles that suggest that a different type of animal may be required. These are:

- The need for a largely forage based feeding system (whereas breeds used in non-organic systems have tended to be those selected for high concentrate diets)
- The emphasis on reduced veterinary inputs and disease tolerance and resistance (in non-organic systems health has not been a selection parameter and some positive health traits may have been lost as a consequence of a production oriented selection process).
- The requirement for outdoor exercise may necessitate a more hardy animal than is currently the norm in non-organic systems, although there is little evidence to show that organic animals are more exposed to more 'natural' conditions than non-organic.
- High animal welfare aspirations suggest that achieving certain key parameters such as longevity are desirable (over recent years, the longevity of non-organic dairy herds is low as a consequence of the high production stress on animals)
- Organic systems tend to be more multi-functional than non-organic systems, and this may necessitate a requirement for dual purpose production and the selection of breeds that are better suited to both milk and beef production. In addition to this, a current poor market for 'dairy' calves has resulted in very high slaughter rates of young offspring.
- The organic standards stress the requirement for the choice of breeds or strains to account for the capacity of animals to adapt to local conditions, their vitality and their resistance to disease.

There may also be market opportunities associated with the end product that dictate the breed type required, although this is not likely to be an issue for the majority of organic milk producers, it will be a consideration for those involved in processing of milk products.

Organic farming is diverse in its conditions, strategies and objectives (Roderick *et al.*, 2004., Padel, 2000; Verhoog *et al*., 2003). Given this diversity, and despite the specific emphasis on biodiversity and breed requirements in the legislation, there are likely to be different approaches to breeding and breeding goals. Olesen *et al.* (2000) discuss how the characteristics of different farming systems should affect the selection goals and animal breeding should contribute to optimizing the whole production system. Rozzi et al (2007) provides the example where economics forces a change from high energy diets to roughage based systems and how selection for breeds suited to such diets should be a part of the strategy. Likewise in situations where veterinary medicine use is being reduced and a greater dependence on disease resistance is required.

<u>The suitability of high genetic merit dairy breeds</u>

Genetic selection has increased production levels of livestock species considerably. However, apart from a favourable increase in production, animals in a population that have been selected for high production efficiency seem to be more at risk for behavioural, physiological and immunological problems (Rauw et al., 1998).

Although there is significant debate regarding the suitability of high genetic merit dairy breeds, and in particular the Holstein breed, there has been very little research to determine whether some breeds are better suited than others. The main breeding goal of the dominant dairy breed in the UK, the Holstein-Friesian, has been for increased milk yields. This has meant that other genetic traits such as longevity, fertility and animal health have been compromised (Pryce *et al*., 1999). This has relevance for organic systems in that: 1) the responses to selection on a low input feed system tend to be lower than those in a high input system (IGER, 2002); 2) there is a requirement for robustness and disease resistance.

As an alternative to the controversial approach of specifying particular breeds in organic standards, The Soil Association are currently considering the approach of applying outcome-based standards which would allow identification of individual animals that may not be suited to organic production conditions (Isabel Griffiths, pers.comm).

The current situation

There is evidence from the literature that there is a conflict between organic producers apparent desire to select for functional traits and breeds that are suited to organic conditions and the breeding practices being adopted in practice. The Holstein does not apparently meet the requirements and yet these are by far the most common breed found in organic dairy systems. Whilst organic farmers have expressed a preference for more functional traits, evidence from practice indicate that the actual selection criteria applied are similar to those in conventional systems.

Organic livestock production focuses on producing animals from a predominantly forage-based system, with an emphasis on maintaining animal health through improved welfare and a reduction in the use of routine, conventional veterinary treatments. However, many of the breeds used in conventional farming could be considered as 'high maintenance' animals, requiring regular prophylactic veterinary treatments and high energy concentrated feeds to meet their potential. Such breeds may be unable to fulfil their potential performance under an organic system (van Diepen et al., 2007). Further, given the different production conditions and breeding requirements on organic farms, traditional breeding selection tools and indices may not be best suited to organic systems (Nauta et al., 2006a and 2006b).

Dealing with genetic x environmental interactions

It is not clear whether organic dairy production requires specific selective breeding programs distinct from conventional production. An important consideration is the magnitude of genotype by environment interactions for desired traits. For traits with significant interaction, different estimates may be required for organic farming situations operating under different environmental conditions to those found in non-organic situations. Estimating G×E between organic and conventional herds can be problematic because of the small size of many organic populations and the heterogeneity among organic farms within and across countries (Pryce *et al*., 2001., Rozzi *et al*., 2007).

The kin breeding approach is believed to reduce GxE interaction (Baars and Nauta, 1998). Pryce *et al*. (2004) view this approach as having only limited impact on making genetic progress in health and fertility traits, as it is realistic only with large-scale progeny testing because of the low heritability estimates of these traits.

The role of crossbreeding

Crossbred animals can be profitable where conditions are difficult. This is why crossbreeding is common in New Zealand and Australia, where animals are kept in continuous grazing, low-cost environments (Pryce et al., 2004).

Crossbreeding can be very effective in improving fitness traits through hybrid vigor and decreased homozygosity and eliminating inbreeding. The choice of breed or breeds is critical as is the choice of bull. Whilst information on actual breeding values is widely available for individual bulls, there is little information available with respect to specific and general combining ability for dairy crossbreeding (Rozzi et al., 2007). Whilst the use of traditional breeds is often emphasised within the organic sector, Rozzi et al (2007) highlight the issue of using breeds that have not been selected through an effective breeding programme and so the risks associated with progeny testing falls onto the farmer. There appear to be no breeds or cross breeds which consistently produce higher yields of milk or milk solids on an individual animal basis than pure bred Holsteins. However, this is not the case when production is considered on an area basis (IGER, 2003).

The requirement to maintain a closed herd encourages selection on the basis of farm needs, and the development of greater resistance to the spectrum of disease present. A closed herd policy also encourages more pure-breeding. While individual farmers may attempt to select for a particular trait, the accuracy of selection may be limited by the selection tools currently available (Baars and Nauta, 1998).

Making the most of heterosis

The project "Breeding Strategies for Organic Dairy Cattle" recommended that better pedigree recording would enable more accurate estimates of heterosis to be made, and the ability to identify herds as conventional, converting or fully organic would allow a dramatic improvement in the knowledge base. Such information would enable us to estimate whether mastitis, lameness, fertility problems are more prevalent in organic systems than in conventional systems and whether lactation curves differ between the two systems. It would also be possible to determine whether a bull's daughters perform better in an organic system than in a conventional system. Identification of herds as conventional, converting or organic could be simply made by the milk recording organisation but would have to be updated as the herd progressed through the transition to fully organic.

The first cross between two breeds (F1) shows 100% of heterosis. There is then a choice of what to do after the first cross. One strategy is continuous production of F1s, which involves maintaining a proportion of the population or herd as purebred and mating the best within each breed to maintain the purebred population, while mating the rest of the purebreds to the desired male of the other breed to provide replacements for the crossbred part of the population or herd. An alternative is a continuous rotational crossbreeding strategy. A two-breed rotational cross maintains 67% of the direct heterosis, while three- and four-breed crosses maintain 86% and 94% of the direct heterosis respectively. The problem is to find several breeds of suitable merit such that the crossbred population is better than the purebred population (Pryce et al., 2004).

Robustness and condition score

Robustness can be defined in a number of different ways and the expression of robustness may differ across the range of environments. This variability needs to be incorporated into breed evaluation. Condition score has the potential to be used in breeding programmes. Genetic differences in the shape of the profile of depletion of reserves in early to peak lactation followed by recovery during the rest of the lactation may help to identify animals most suitable for organic production. Also, a flatter lactation curve may be a way of avoiding short-term nutrient deficits in organic dairy herds (Pryce et al., 2004).

Longevity

A literature review conducted as part of Defra project IS0213 "Longevity and lifetime efficiency of pure and crossbred dairy cows" concluded that there has been little work in the UK investigating the true effects of breed and cross-breed production, welfare and fertility. There appear to be no breeds or cross-breed that produces higher yields of milk than a pure bred Holstein on an individual basis. However, this does not hold true when stocking rate is taken into account. Since high yielding Holstein-Friesian cattle have been bred with a focus on production from high concentrate diets and there is now an increased reliance on forages, this may mean that longevity of these cattle will be further reduced and crossbred cows may be competitive in pastoral systems.

Selecting for fertility

Development of a fertility index provides breeders with a facility to choose bulls with good production and fertility traits and will enable the avoidance of bulls that produce offspring with poor fertility. However, care should be taken in placing over-emphasis on the relationship between breeding and fertility as fertility is multi-factorial influenced by nutrition, health and husbandry as well as genetics. Improved fertility will also allow culling to be focused on other traits.

Breed effect on nitrogen utilisation efficiency

Breed effect is unlikely to have a large impact on nitrogen utilisation efficiency because the greatest improvements on N use efficiency are mediated through the rumen environment.

Management issues

Selection programmes can indirectly affect welfare where there are genetic changes in welfare-related traits but changes to management or housing do not keep pace with the demands of the changing genotype.

Issues with selecting for disease resistance and health

It has been suggested that future breeding programmes for dairy cattle should ideally include selection for resistance (Fitzpatrick et al., 1999), although there are risks that improvements in one trait achieved by selective breeding are often associated with losses in other traits (Williams, 2005).

Pryce et al (2004) identified the following main limitations to genetic progress in disease traits:

- the low heritability estimates of such traits
- the lack of reliable phenotypic records
- the unfavourable genetic relationship between production and fitness traits
- the number of offspring required to get an accurate breeding value (about 4 to 10 times as many as for production traits).

Mastitis resistance has a low heritability, so large daughter groups together with a high index weight are essential for reliable and effective selection (Pryce et al., 2004). One of the issues with recording mastitis incidence and using this data for selection purposes, may be more associated with differences in risk of treatment rather than risk of getting infected. Calculated risks (or incidence) may be a combination of the level of infection, the farmers' ability to detect mastitis and their management strategies (Valde et al., 2004). A particular concern with regard to breeding for mastitis resistance is that factors increasing resistance to one udder pathogen might predispose to mastitis caused by other pathogens.

With regard to lameness, sires with good linear scores for shape of foot, depth of heel, depth of hock and pastern angle should be selected. Cows with a severe clinical lameness or badly deformed legs or feet should not be used for breeding. This is particularly the case with sole ulcers and corkscrew claws.

The need for recording

Progeny testing in dairy cattle relies on accurate phenotypic records. Milk volume and constituent components are routinely collected by recording agencies in most countries. Records used to produce genetic evaluations on disease resistance, longevity and fertility are either estimated using measurements on the trait itself (such as records of clinical disease), or traits known to be closely genetically related to the trait of interest (such as SCC to select for mastitis resistance).

The importance of welfare surveillance to animal breeding strategies has been demonstrated in Scandinavia where, for the last 20 years, integrated databases and comprehensive recording schemes have been developed for both cattle and pig breeding. In the 1970s Scandinavia developed a philosophy that breeding objectives should include health and production traits rather than just production goals. It was recognised that an essential prerequisite for the efficient operation of such breeding objectives was the accurate recording of health, reproduction and production traits. Integrated databases, initially between the milk-recording scheme and the artificial insemination (AI) service, were developed and subsequently expanded to include health traits. For example, in all Scandinavian countries, veterinary reports on clinical treatments are now incorporated into the databases. The result is that Scandinavian countries have adopted Total Merit Indices (TMI) in selection programmes. Not only has such an approach improved animal health, as demonstrated for example, by a steady decline in mastitis levels in dairy cattle, but the total economic % superior to single trait selection, despite a reduced gain in milk production levels.

Identification of organic dairy farms in the databases used in breeding programs has been proposed as a necessary prerequisite to enable a better breeding programme for organic dairy production (Brotherstone et al., 2003 and Simianer et al., 2007).

The Scandinavian model has shown the importance of integrated databases and comprehensive recording schemes. In practice, TMI selection has proven to be effective in maintaining functional efficiency of the cows simultaneously with a sharp increase in production (Philipsson and Lindhé, 2003).

Organic breeding indices

Applying existing selection indexes to organic production depends on: 1) whether the right traits are recorded and available; 2) whether weightings applied to each of the traits are appropriate for organic circumstances; and 3) whether the genetic evaluations gained from conventional systems are appropriate for organic farms (Pryce et al., 2004).

Based on estimated parameters, Simianer et al. (2007) suggest that neither a closed nor an open specialised ecological breeding program would be economically justified or viable. The preference would be for organic dairy farms to participate more actively in established breeding programs by using, for example, more test bulls in their herds. It is suggested that an ecological total merit index be developed based on the available breeding values for different trait complexes, in which functional traits should receive a higher weight. An internet portal and specific mating software developed have been developed to support this proposal (Simianer et al., 2007).

Although the organic index would allow producers to rank proven bulls in accordance with their perceived needs, Rozzi et al (2007) conclude that given the small population size, a separate breeding program for organic farms is not viable in the foreseeable future. Pryce et al. (2004) view customized selection index for organic farms to be feasible only if the variation in the existing population is large enough to provide suitable selection candidates, and if genetic evaluations for the desired traits are available.

Whilst the breadth of information available on the genetic evaluations is currently greater than ever, and the sophistication of the methodologies used to predict their value is now extremely powerful, there is a general dearth of knowledge on some of the non-productive parameters of interest to organic producers.

While individual farmers may attempt to select for a particular trait, the accuracy of selection may be limited by the selection tools currently available (Baars and Nauta, 1998), the relative heritability of the desired trait, and the potentially negative correlation with other traits. Experiences with an "Ecological Breeding Index" suggest that it would be difficult to breed an "organic dairy cow" that would be suitable for all farms and that there is a need for farm specific breeding criteria and that selection tools need to be sufficiently flexible and encompass significant knowledge.

Applying economic values

The practical integration of functional traits in dairy cattle breeding goals is still a major challenge for animal breeders. A genetically and socio-economically balanced selection for production (milk and beef) and functional traits (health, fertility, efficiency of feed utilisation and milkability) in dairy cattle requires correct economic values. The derivation of economic values requires a good theoretical basis, proper methodology in term of models including physiological modelling of animal production, farm economics and social aspects, and appropriate assumptions on future production circumstances . The inclusion of social aspects in deriving economic values for functional traits is a major challenge for animal breeders (Groen et al., 1997)

Breeding technologies

The commercial applications in agriculture of new breeding technologies, as well as conventional breeding strategies, have the potential to influence animal welfare in both positive and negative ways. For example, the sexing of cattle semen might be used to reduce the number of unwanted male dairy calves provided that the technique had not been shown to produce adverse effects. On the other hand, inappropriate use of some breeding technologies may create new problems, or exacerbate welfare problems that may already have arisen within conventional livestock breeding (MacArthur Clark *et al*., 2006).

Good Practice

With regard to breed selection, the Compendium of Organic Health and Welfare (www.organicvet.co.uk) propose the following elements of good practice:

- Where relevant information is available, resistance to disease should be taken into consideration over productivity when breeding decisions are made.
- Mismatching of bull and dam, resulting in calving difficulties, should be avoided.
- Whilst animals suffering from disease or injury should be culled in good time, longevity should be encouraged in dairy and suckler cows.
- The opportunity to select bulls with low SCC levels in daughters should be utilised.
- Overall lifetime productivity should be considered above high productivity alone in dairy bull selection.

Research recommendations

- Development of methods and guidance for the appropriate weighting and incorporation of functional traits into breeding indices for organic herds;
- Improved understanding of the genetic x environment interactions for key functional traits in organic system, and how these may be used in breed improvement.
- Improved techniques for the use of animal-based health and welfare measures to assess the suitability of breeds to organic systems;
- Development of improved guidance on selecting for disease resistance in organic herds;
- Comparative analysis of the suitability of different breeds and cross-breeds for organic systems, incorporating functional traits associated with health and welfare and environmental impact;
- Modelling of the economic viability, welfare quality and environmental impact of lower milk output and dual-purpose systems;
- Development of innovative systems of production of male calves from the dairy sector;
- Development of approaches and models of ethical analyses to evaluate the appropriateness of new breeding technologies for organic production;

4. References

Aarestrup, F. M., Jensen, N. E. and Ostergard, H. (1995) Analysis of association between major histocompatibility complex (BoLa) Class I haplotypes and subclinical mastitis of dairy cows. Journal of Dairy Science 78: 1684-1692

Bakke M.J. (2003) Feeding and management of Jerseys and Holsteins: should there be a difference?. In: Recent Advances in Animal Nutrition (Eds: P.C. Garnsworthy & J.Wiseman). Published by Nottingham University Press. pp. 191-198.

Bapst B. (2001) Swiss experiences on practical cattle breeding strategies for organic dairy herds. In: Breeding and feeding for animal health and welfare in organic livestock systems. Proceedings of the 4th NAHWOA Workshop, Wagenningen, 2001. pp.44-50.

Brotherstone S., Santarossa J., Simm G., Coffey M.P. & Stott A.W. (2003) Breeding strategies for organic dairy cattle. Final Report to Seerad & Defra.

Baars, T. and Nauta, W. (1998) Sires and clover - breeding without bulls from embryo transplantation: report from a conference. Newsletter of the Network for Scientific Research Co-ordination in Organic Farming 7, 17-19.

Bapst, B., Bieber, A. and Haas, E. (2005) Untersuchungen zur Zuchtstrategie in Schweizer Bio-Braunviehbetrieben [Analysis of breeding strategies on Swiss organic Braunvieh-farms]. Paper presented at 8. Wissenschaftstagung Ökologischer Landbau – Ende der Nische, Kassel, 01.03.2005 - 04.03.2005; Published in Heß, J and Rahmann, G, Eds. Ende der Nische, Beiträge zur 8. Wissenschaftstagung Ökologischer Landbau. kassel university press GmbH, Kassel.

Bapst, B (2001) Swiss experience on practical cattle breeding strategies for organic dairy. Proc. 4th NAHWOA Workshop, Wageningen, The Netherlands. Network for Animal Health and Welfare in Organic Agriculture (NAHWOA), Univ. Reading, UK.

Baumung, R., Solkner, J., Gierzinger, E. and Willam, A (2001) Ecological total merit index for an Austrian dual purpose cattle breed. Archiv Fur Tierzucht - Archives of Animal Breeding, 44: 5-13

Baumung, R., Solkner, J. , Gierzinger, E. and William, A (2001) Ecological total merit index for an Austrian dual-purpose cattle breed. Proc. 4th NAHWOA Workshop, Wageningen, the Netherlands. Network for Animal Health and Welfare in Organic Agriculture (NAHWOA), Univ. Reading, UK

Boelling, D., Groen, A.F., Sørensen, P., Madsen, P. and Jensen, J. (2003) Genetic Improvement of Livestock for Organic Farming Systems. *Livestock Production Science* 80(1):pp. 79-88.

Boettcher, P. J., Fatehi, J. and Schutz, M. M (2003) Genotype×environment interactions in conventional versus pasture-based dairies in Canada. J. Dairy Sci. 86:383–389.

Boettcher, P. J. Dekkers, J. C. M., Warnick, L. D., and Wells, S. J. (1998) Genetic analysis of clinical lameness in dairy cattle. *Journal of Dairy Science* 81: 4, 1148-1156.

Broom, D.M. (2001) Effects of Dairy Cattle Breeding and Production Methods on Animal Welfare. Proceedings of the 21st World Buiatrics Congress, 1-7. Montevideo, Uruguay: Sociedad de Medicina Veterinaria del Uruguay.

Brotherstone, S., Santarrosa, J., Simm, G and Coffey, M. P.(2003) Breeding Strategies for Organic Dairy Cattle. Final Report to SEERAD/Defra.

Coffey, M.P., Simm, G and Brotherstone, S (2002) Energy Balance Profiles for the First Three Lactations of Dairy Cows Estimated Using Random Regression. Journal of Dairy Science , 85 (10): 2669-2678

Chesterton, R. N. Pfeiffer, D. U. Morris, R. S and Tanner, C. M. (1989) Environmental and behavioural factors affecting the prevalence of foot lameness in New Zealand dairy herds - a case-control study. *New Zealand Veterinary Journal* 37: 4, 135-142.

Defra (2006) Compendium of UK Organic Standards.

Dhour, P., Coulon, JB. And Garel, JP (1991) Voluntary feed-intake in heifers – influence of breed, age and the hay characteristics Annales de Zootechnie 40: 171-179

Dillon, P., F. Buckley, P. O'Connor, D. Hegarty, and M. Rath (2003a) A comparison of different dairy cow breeds on a seasonal grassbased system of milk production. 1. Milk production, live weight, body condition score and DM intake. Livest. Prod. Sci. 83:21–33.

Dillon, P., S. Snijders, F. Buckley, B. Harris, P. O'Connor, and J. F. Mee. (2003b) A comparison of different dairy cow breeds on a seasonal grass-based system of milk production. 2. Reproduction and survival. Livest. Prod. Sci. 83:35–42.

Doherr, M. G., Roesch, M., Schaeren, W., Schallibaum, M. and Blum, J. W (2007) Risk factors associated with subclinical mastitis in dairy cows on Swiss organic and conventional production system farms. Veterinarni Medicina, 52 (11): 487–495

Emanuelson, U. (1988) Recording of production diseases in cattle and possibilities for genetic improvements: a review. Livest.Prod. Sci. 20:89.

FAWC (2004) Report on the Welfare Implications of Animal Breeding and Breeding Technologies in Commercial Agriculture. Farm Animal Welfare Council. 1A Page Street, London, SW1P 4PQ. At: http://www.fawc.org.uk/pdf/breedingreport.pdf.

Fitzpatrick, J.L., Logan, K.E., Young, F.J., Stear, M.J., Platt, D.J and McGuirk, B.J (1999) Breeding Cattle for Mastitis Resistance.Proceedings of the British Mastitis Conference (1999) p 46-53.

Groen AF, Steine T, Colleau JJ, Pedersen J, Pribyl J, Reinsch N (1997) Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-working. Livestock Production Science 49: 1-21

Huang, Y. C. Shanks, R. D. McCoy, G. C. (1995) Evaluation of fixed factors affecting hoof health. *Livestock Production Science* 44: 2, 115-124

Haas E. and Bapst B. (2004) Swiss organic dairy farmer survey: Which path for the organic cow in the future? In: Hovi, Malla; Sundrum, Albert and Padel, Susanne, Eds. (2004) Organic livestock farming: potential and limitations of husbandry practice to secure animal health and welfare and food quality. Proceedings of 2nd SAFO Workshop, Witzenhausen, Germany, 25.-27.03.2004.

Harris, B.L. (2002) Genetics of body condition score in New Zealand dairy cattle. In: *7th World Congress on Genetics Applied to Livestock Production*. CD-ROM Abstract (cited by Pryce et al., 2004).

Haas, E and Bapst, B (2004) Swiss organic dairy farmer survey: Which path for the organic cow in the future?, in Hovi, Malla; Sundrum, Albert and Padel, Susanne, Eds. Organic livestock farming:

potential and limitations of husbandry practice to secure animal health and welfare and food quality. Proceedings of the 2nd SAFO Workshop 25-27 March 2004, Witzenhausen, Germany, page pp. 35-41

Harris, B. L., and Kolver, E. S (2001) Review of Holsteinization on intensive pastoral dairy farming in New Zealand. J. Dairy Sci. 84 (E Suppl.):E56–E61.

Heringstad B., Klemetsdal G and Steine T (2003) Selection responses for clinical mastitis and protein yield in two Norwegian dairy cattle selection experiments. J Dairy Sci. 86(9):2990-9.

Heringstad B, Klemetsdal G and Steine T (2007) Selection responses for disease resistance in two selection experiments with Norwegian red cows. J Dairy Sci 90(5):2419-26

Heringstad, B., Klemetsdal G., u. J. Ruane (2000) Selection for mastitis resistance in dairy cattle: a review with focus on the situation in the Nordic countries, Livestock Production Science, 64, S.95-106

Hoekstra, J., Lugt, A.W., van der, Werf, J.H.J., and Ouweltjes, W (1994) Genetic and phenotypic parameters for milk production and fertility traits in upgraded dairy cattle Livestock Production Science. 40(3) 225-232

Hoerning, B., Simantke, C and Aubel, E (2005) Investigations on dairy welfare and performance on German organic farms. Paper presented at Researching Sustainable Systems - International Scientific Conference on Organic Agriculture, Adelaide, Australia, September 21-23, 2005.

Hovi M. and Roderick S (1999) An investigation of the incidence, treatment strategies and financial implications of mastitis in organic and conventionally managed UK dairy herds. Report to Defra.

Hovi (2004) Approaches to mastitis control in well-established organic dairy herds in England and Wales. PhD Thesis. University of Reading

IGER (2002) Comparison of the physical and financial performance of organic dairy systems. Final report to Defra on Project OF0146

IGER (2003) Longevity and lifetime efficiency of pure and crossbred dairy cows. Final report to Defra.

Ingvartsen K.L and. Weisberg, M.R (1993) Jersey cows have a higher feed intake capacity and higher rate of passage then Friesians cows. Arch. Tierz., Dummerstorf 5 (1993), pp. 495–498

Jansen, J (1985) Genetic aspects of fertility in dairy cattle based on analysis of A. I. data—a review with emphasis on areas for further research. Livest. Prod. Sci. 12:1.

Koenen, E.P.C. and Veerkamp, R.F. (1998) Genetic covariance functions for live weight, condition score and dry matter intake measured at different stages of Holstein Friesian heifers. Livestock Production Science 57, 67-77.

Krogmeier, D. (2003) Der O¨ kologische Gesamtzuchtwert fu¨ r Fleckvieh, Braunvieh und Gelbvieh. [Biological total merit index for Simmental, Brown Swiss and Gelbvieh cattle]. Paper presented at Forschung fu¨ r den o¨kologischen Landbau in Bayern,O¨ kolandbautag der LfL, Triesdorf, pages 77–86. Schriftenreihe der Bayerischen Landesanstalt fu¨ r Landwirtschaft 3/03. Bayerische Landesanstalt fu¨ r Landwirtschaft (LfL), Freising, Germany.

Lindhé B and Philipsson J. (1998) Conventional breeding programmes and genetic resistance to animal diseases. Rev Sci Tech.17(1):291-301

Lucy MC (2005) Non-lactational traits of importance in dairy cows and applications for emerging biotechnologies. N Z Vet J. 53(6):406-15

Lyons, D.T., Freeman, A.E. and Kuck, A.L. (1991). Genetics of health traits. Journal of Dairy Science 74: 1092-1100

MDC (2007) Milk Development Council Breeding+ Bull Evaluations. Accessed at: http://62.25.97.246/

MacArthur Clark, J.A. Potter M. and Harding E.(2006) The welfare implications of animal breeding and breeding technologies in commercial agriculture Livestock Science, 103 (3): 270-281

Mackle, T.R. Parr, C.R. Stakelum, G.K. Bryant A.M. and MacMillan, K.L. (1996) Feed conversion efficiency, daily pasture intake, and milk production of primiparous Friesian and Jersey cows calved at two different liveweights. N.Z. J. Agric. Res. 39 3: 357–370

Mee J.F., Fahey J. and Crilly J. (1999). Breeding the dairy cow of the future – today's challenges. National Dairy Conference, Teagasc Publication 1999. www.teagasc.ie/publications.

Miglior, F., Muir, B. L. and Van Doormaal, B. J. (2005) Selection indices in Holstein Cattle of various countries. J. Dairy Sci. 88:1255–1263

Nauta, W; Baars, T., Groen, A; Veerkamp, R and Roep, D (2001) Animal breeding in organic farming: Discussion paper. Louis Bolk Instituut Publications no. LV45, Livestock production / Animal, Louis Bolk Instituut, Wageningen UR.

Nauta, W.J.; Saatkamp, H.; Baars, T. and Roep, D. (2006a) Breeding in organic farming: different strategies, different demands. Paper presented at Joint Organic Congress, Odense, Denmark, May 30-31, 2006

Nauta WJ, Veerkamp RF, Brascamp EW and Bovenhuis H. (2006b) Genotype by environment interaction for milk production traits between organic and conventional dairy cattle production in The Netherlands. J Dairy Sci. 89(7):2729-37

Nielsen HM, Christensen LG and Groen AF (2005) Derivation of sustainable breeding goals for dairy cattle using selection index theory. J Dairy Sci. 88(5):1882-90

Nielsen HM, Christensen LG and Odegård J (2006) A method to define breeding goals for sustainable dairy cattle production. J Dairy Sci. 89(9):3615-25.

Nielsen B, Thamsborg SM, Andersen HR and Kristensen T (2004) Herbage intake in Danish Jersey and Danish Holstein steers on perennial ryegrass/white clover pasture Livestock Production Science 86 (1-3): 261-267

Nielsen B.L. (1999). Perceived welfare issues in dairy cattle, with special emphasis on metabolic stress. In: Metabolic Stress, BSAS Occasional Publication No.24. pp.1-7.

Olesen, I. Groen, A. F. and Gjerde, B (2000) Definition of animal breeding goals for sustainable production systems. Journal of Animal Science, 78, (3) 570-582

Oltenacu, P. A., Frick, A and Lindhé, B. (1991) Relationship of Fertility to Milk Yield in Swedish Cattle. Journal of Dairy Science 74 (1): 264-268

Padel, S., (2000). "Strategies of organic milk production". In Hovi, M., Bouilhol, M., (eds.). Human-animal relationships: Stockmanship and housing in organic livestock systems. Proceedings of the 3th NAHWOA Workshop, 21-24 October, Clermont-Ferrand, 121-135.

Peterse D.J. (1985). Breeding, In: Cattle footcare and claw trimming. Published by Farming Press, Ipswich, UK. pp.121-123.

Philipsson, J. (2001): Breeding for animal health - the Scandinavian experience. www.hgen.slu.se 30.01.03

Philipsson, J and Lindhé, B (2003) Experiences of including reproduction and health traits in Scandinavian dairy cattle breeding programmes. Livestock Production Science. 83: 99-112

Poso, J. and Maantisary, E. A. (1996) Relationship between clinical mastitis, somatic cell score and production for the first three lactations of Finnish Ayrshire. Journal of Dairy Science 79: 1284-1291

Pryce J.E., Veerkamp R.F., Thompson R., Hill W.G. and Simm G. (1997). Genetic aspects of common health disorders and measures of fertility in Holsetien Friesian dairy cattle. Animal Science 65:353-360.

Pryce, J.E., R.J. Esslemont, R. Thompson, R.F. Veerkamp, M.A. Kossaibati and G. Simm (1998). Estimation of genetic parameters using health, fertility and production data from a management recording system for dairy cattle. Animal Science 66: 577-584.

Pryce, J.E., Nielsen, B.L., Veerkamp, R.F. and Simm, G (1999) Genotype and feeding system effects and interactions for health and fertility traits in dairy cattle. Livest. Prod. Sci. 57, 193–201.

Pryce, J.E., Coffey, M.P. and Brotherstone, S (2000) The genetic relationship between calving interval, body condition score and linear type and management traits in registered Holsteins. Journal of Dairy Science 83, 2664-2671

Pryce, J. E., E. E. Wall, A. B. Lawrence, and G. Simm (2001) Breeding strategies for organic dairy cows. Proc. 4th NAHWOA Workshop, Wageningen, The Netherlands. Network for Animal Health and Welfare in Organic Agriculture (NAHWOA), Univ. Reading, UK.

Pryce, J.E., Conington,J., Sorensen,P., Kelly H R C and Rydhmer L (2004) Breeding strategies for organic livestock. In: Vaarst, M., Roderick, S., Lund, V. and Lockeretz, W (eds) Animal Health and Welfare in Organic Agriculture. CABI Publishing, Wallingford. pp 357-388.

Rahmann, G and Nieberg, H (2005) New insights into organic farming in Germany – empirical results of a survey in 218 farms *Landbauforschung Völkenrode* 3(55):pp. 193-202.

Rauw, W.M. Kanis, E. Noordhuizen-Stassen E.N. and Grommers, F.J. (1998) Undesirable side-effects of selection for high production efficiency in farm animals: a review, Livest. Prod. Sci. 56: 15–33

Rozzi, P., Miglior, F. and Hand, K. J. (2007) A total merit selection index for Ontario organic dairy farmers. Journal of Dairy Science 90 (3): 1584-1593

Roderick, S., Henriksen, B., Trujillo, R.G., Bestman, M and Walkenhorst, M (2004) The Diversity of Organic Livestock Systems in Europe. In: Animal Health and Welfare in Organic Agriculture, CABI Publishing, Wallingford. pp29-56

Roderick, S. Short, N. and Hovi, M. (1996) Organic livestock production – Animal health and welfare research priorities. Technical Report – VEERU, University of Reading, 1996.

Roderick, S and Burke, J (2004) Organic Farming in Cornwall. Results of the 2002 Farmer Survey. Organic Studies Centre, Cornwall.

Roderick, S, Burke, J and LeGrice, P (2005) The characteristics of organic dairy systems in Cornwall, UK. In: *Shaping Sustainable Systems – Proceedings of the 15th IFOAM Organic World Congress*. Adelaide, 20-23 September 2005, pp140-141

Roderick, S. and Hovi, M. (1999) Animal Health and Welfare in Organic Livestock Systems: Identification of Constraints and Priorities. A report to the Ministry of Agriculture, Fisheries and Food, University of Reading.

Rupp, R and Boichard, D (2003) Genetics of resistance to mastitis in dairy cattle. Vet Res. 34(5): 671-88

SAC (2005) Can We Breed For A Long-lived & Healthy Dairy Cow Suited To A Variety Of Systems? At: http://www.sac.ac.uk/research/publications/sls/researchnotes/

Schwarzenbacher, H. (2001) Vergleich von biologischen mit konventionellen Milchviehbetrieben in Niederösterreich. Diplomarbeit. Institut für Nutztierwissenschaften, Universität für Bodenkultur, Wien.

Schukken, Y. H., Grommers, F. J., Geer, D. Van De, Erb, H. N. and Brand, A (1990). Risk factors for clinical mastitis in herds with low bulk milk somatic cell count. I. The data and risk factors for all cases. In Epidemiological studies on clinical mastitis in dairy herds with low bulk tank somatic cell count. Rijksuniversiteit Utrecht, Faculty of Veterinary Medicine: 70-75.

Simianer, H., Augsten, F., Bapst, B., Franke, E., Maschka, R., Reinhardt, F., Schmidtko, J. and Stricker, C. (2007) Breeding dairy cattle for organic farming: Development and assessment of breeding approaches considering genotype x environment interactions, and creation of an information system for sustainable breeding strategies (German). Report, Institut für Tierzucht und Haustiergenetik, Georg-August-Universität Göttingen, Göttingen.

Simianer, H., Solbu, H., and Schaeffer, L.R (1991) Estimated genetic correlations between disease and yield traits in dairy cattle. Journal of dairy science 74 (12): 4358-4365

Snijders S.E.M., Dillon P., Sreenan J., Diskin M., O'Callaghan D., Boland M.P. and O'Farrell K. (1997). Effect of genotype on follicular dynamics and subsequebt reproductive performance. Irish Journal of Agricultural and Food Research 36: 96

Strandberg, E. and Shook, G. E. (1989). Genetic and economic responses to breeding programs that consider mastitis. Journal of Dairy Science 72: 2136-2142.

Svendsen, M. (1999) A retrospective study of selection against clinical mastitis in the Norwegian dairy cow population. Interbull Bulletin 23, 99-106.

Shook GE (1989) Selection for disease resistance. J Dairy Sci. (5):1349-62.

Trachsel, P., Busato, A and Blum, J.W (2000) Body conditions scores of dairy cattle in organic farms. Journal of Animal Physiology and Animal Nutrition 84 (3-4) , 112–124

Uribe, H.A., B.W. Kennedy, S.W. Martin, and D.F. Kelton (1995). Genetic parameters for common health disorders of Holsteins. Journal of Dairy Science 78: 421-430.

Van Arendonk, J.A.M., Hovenier, R and De Boer, W (1989) Phenotypic and genetic association between fertility and production in dairy cows. Livest. Prod. Sci. 21: 1–12

Van Diepen, P; McLean, B and Frost, D (2007) Livestock breeds and Organic farming systems. Report, ADAS Pwllpeiran.

Valde JP, Lawson LG, Lindberg A, Agger JF, Saloniemi H and Østerås O (2004) Cumulative risk of bovine mastitis treatments in Denmark, Finland, Norway and Sweden. Acta vet. scand. 45, 201-210.

Verhoog, H., Matze, M., Lammerts Van Bueren, E. and T. Baars, (2003). Integrity, ecology and environmental care: aspects to understand the concept of naturalness in organic farming. *Agricultural and Environmental Ethics* 16: 29–49.

Veerkamp R.F., Simm G. and Oldham J.D. (1995). Genotype x environment interactions: experience from Langhill. In Breeding and feeding the high genetic merit dairy cow (Ed: T.L.J.Lawrence, F.J.Gordon & A.Carson). British Society of Animal Science Occasional Publication No.19. pp.59-66.

Voigt J, Jentsch W, Kuhla S, Matthes HD and Derno M (2000) Rumen fermentation and retention time of the digests in growing cattle of the breeds Black-White Dairy Cattle, Galloway, and Highland Archiv Fur Tierzucht - Archives of Animal Breeding 43 (6): 609-620

Webster, J. (1993) Understanding the Dairy Cow, 374 pages. Blackwell Scientific Publications, London. pp. 95-103.

Weller, R (2006) The development of organic milk production systems. Report, Trawscoed, Institute for Grassland and Environmental Research.

Weller R.F. and Bowling P.J. (2004). The performance and nutrient use efficiency of two contrasting systems of organic milk production. Biological Agriculture and Horticulture 22:261-270.

Zwald NR, Weigel KA, Chang YM, Welper RD and Clay JS (2004) Genetic selection for health traits using producer-recorded data. II. Genetic correlations, disease probabilities, and relationships with existing traits. J Dairy Sci. 87(12):4295-302.