The role of crossbreeding in UK dairy breeding

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OVERVIEW

Crossbreeding[1] has been used in livestock breeding to improve yield, quality, disease resistance and hardiness for many generations. Beef, swine and poultry breeders have all used this tool effectively. Yet, in the dairy industry, pure-breeding has remained the main method of breeding. Today there is increased interest in crossbreeding around the world for dairy cattle. This has been driven by numerous factors:

- The domination of the Holstein breed and questions regarding its relevance in all systems and environments
- Increased inbreeding[2] and concerns about the effects
- Breeding objectives have broadened to include additional functional traits, rather than an emphasis on milk yield
- Concerns regarding decreasing reproductive performance in purebred dairy cows
- Producers concerns regarding decreased viability and hardiness in their herds
- Payment systems now often include significant premiums for constituents and/or penalties for volume

The objective of this paper is to review the current crossbreeding research around the world and consider this research in terms of dairy breeding in the UK.

This report covers:

1. The role of genetics in herd improvement and profitability
2. Why consider crossbreeding
3. The science and theory behind crossbreeding
4. The results of research
    a. Production and health
    b. Calving ease and calves
    c. Survivability
    d. Effects of Genetic and Environmental interactions (GxE) “horses for courses”
    e. Organic systems
    f. Sustainability
    g. Profitability
5. Potential impact of adopting crossbreeding
    a. Producer
    b. Industry
    c. Consumer
6. Crossbreeding systems
7. Identify gaps in research/knowledge

[1] CROSSBREEDING: Mating animals of different breeds
[2] INBREEDING: Mating of animals that have common ancestors

It is important to consider that genetics are just one part of the total production system on farm. Results achieved in milk production per lactation are influenced by genetics (the heritability, in the UK approximately 55% http://www.interbull.org/national_ges_info2/framesida-ges.htm) plus management and environment (approximately 45%).

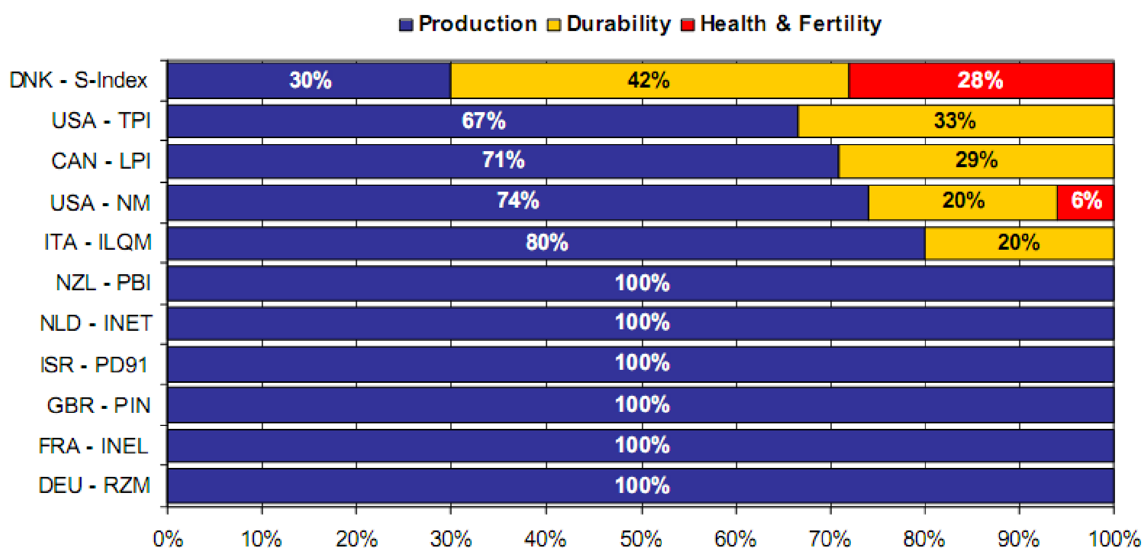
For health and fertility traits, it is approximately 90-95% management and only 5-10% genetics. (Zwald et al., 2004)

So improvement is the result of both genetics and management at the same time. Any breeding programme, including crossbreeding is one part of overall herd improvement.

But it is an extremely important part. Genetics provide the foundation for the performance of the herd. Due to the interaction of genetics and environment (referred to as GxE), creating the correct foundation, using the right genetics for a particular milk payment system, environment, management and feeding systems has a large impact on the success (or failure) of a farm.

The view of “right” genetics has evolved over time. Figure 1 shows that in 1994 the emphasis on genetic selection was essentially on increased production, both here in the UK and around the world. The Scandinavian countries (Denmark DNK in the chart below is an example) were unique in their larger emphasis on health traits.

Figure 1: Selection of various countries’ total index systems 1994



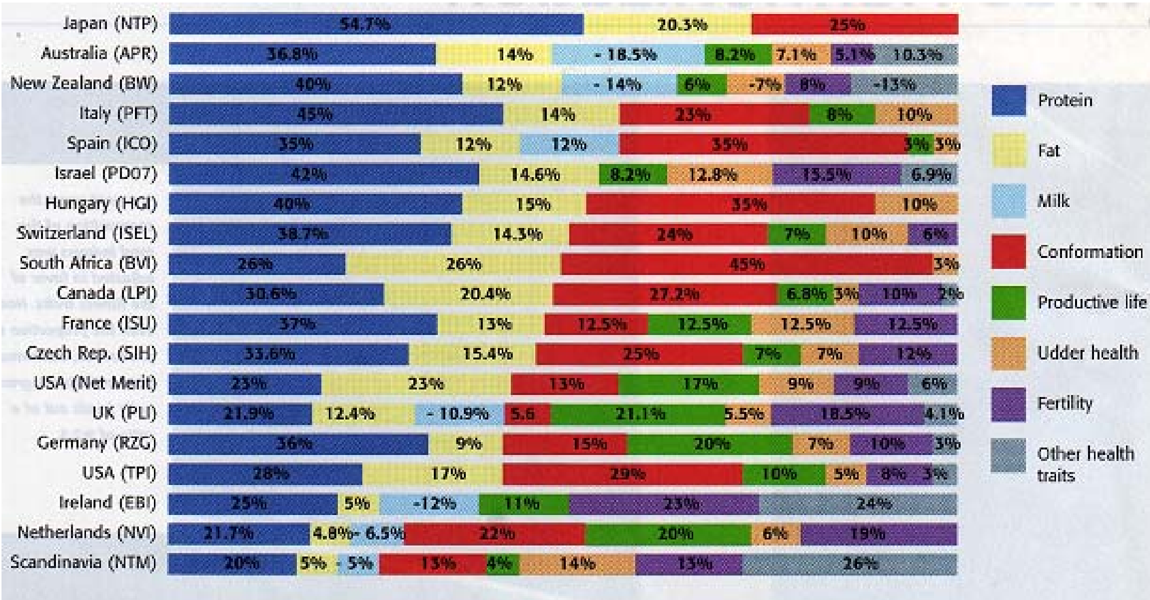
Source: Miglior 2004

However, the emphasis has evolved over the years. Producers around the world have recognised that high volumes of milk are not the sole basis for profitability, especially as costs of keeping a dairy herd rise. There is now an increased emphasis on healthy, long lasting cows and the national breeding indices indicate this change in focus (figure 2).

In the UK the PLI[3], reflects the industry's increased emphasis on health, fertility and longevity. It can be used within a particular breed to rank bulls for expected profitability of their daughters.

However, a number of farmers are looking at different and possibly quicker ways to change the genetics in their herds. For these farmers, the opportunity to look outside their own breed to identify breeds and bulls that can offer more immediate and significant results in breeding cows to suit their needs; crossbreeding is increasingly seen as an option.

Figure 2: Selection of various countries' total index systems 2009



Source: Holstein International June 2009

WHY CONSIDER CROSSBREEDING IN THE UK NOW?

For UK dairy farmers, and for much of the world, pure-breeding has been the dominant approach in their cattle breeding decisions.

The market demanded, and paid for more milk and the Holstein cow[4], better than any other breed supplied that volume of milk. UK dairy farmers grasped this and turned to selecting Holstein for their breeding decisions. In 1986, 85.8% of dairy

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[3] PLI or £PLI Profitable Lifetime Index: UK's ranking system including emphasis on Production, Health, Longevity, Fertility and Type Traits, Examples of other counties Indexes are included in the charts

[4] **Throughout the research, the majority of the comments reflect the situation with the International Holstein breed. Most of the trials done are crosses on Holstein. This should not be viewed as indicating that Holsteins are more problematic than other dairy breeds, but rather as a reflection of the world wide prevalence of the breed**

cows in the UK were Friesian (Dairy Facts and Figures 1986), but in 2008, 93% were Holstein. (http://www.whff.info/stats/statistics_WHFF_20090611a.htm)

This predominance of Holstein genetics has contributed to increasing levels of inbreeding and concerns associated with it (Kearney et al., 2004).

Inbreeding in dairy cattle has been linked to:

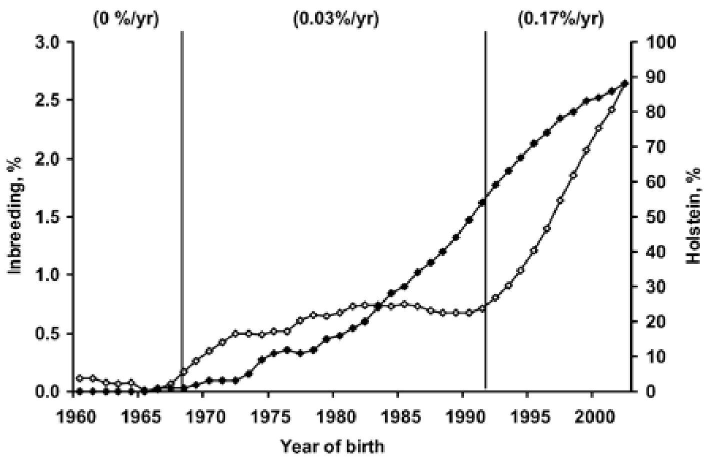
- Decreasing production (Miglior et al. 1995, Thompson et al. 2000, Smith et al. 1998)
- Negatively affecting reproductive traits including days to first service, straws per pregnancy, stillborn calves and others (Wall et al. 2003, Adamec et al. 2006)

In addition, increased inbreeding may lead to increased risk from lethal recessives as they become more frequent in the population (Kristensen T. N., Sørensen A. C. 2005).

Taken together, these conditions are not conducive to a sustainable breeding programme.

In the UK, inbreeding is also increasing, and at a faster rate (Wall et al. 2003.), than in the past. (Figure 3)

Figure 3: Increase in % Holstein in UK and increase in Inbreeding %



Key:
Average inbreeding coefficients ○
Percentage Holstein ●
Rates of inbreeding (in parentheses) for the UK dairy population - %

Wall et al. 2003 noted that, while inbreeding had particularly significant negative effects on fertility traits at higher levels (>10%); at current UK levels genetic gain for production would still outweigh any loss due to inbreeding. It should be noted that average UK Holstein inbreeding levels are still below the 6.25% often seen as a threshold in commercial dairy breeding decisions. However, inbreeding can reduce performance in traits not considered in UK selection indices in 2003, for example fertility, and therefore the effect of inbreeding on overall profitability will have to be considered rather than yield alone.

As well, research has identified a genetic link between increased production and deterioration in functional traits, including fertility (Rau et al., 1998, Veerkamp et al., 2001, MDC 1999, Wicks and Leaver 2004). This deterioration may be mitigated through changes in management. However, in reality, increasing herd size, the cost and lack of availability of good farm labour and narrow profit margins in the dairy industry have led to less time being spent with each animal. This has adversely affected functional traits and the economics of dairy farms.

In the UK, reproductive performance has declined over the last 20 years. Calving interval has increased, heat detection has become more difficult and increased services per conception are reported. While Defra, in 2003, claimed that decreased longevity has added significantly to the cost of milk production in the UK; DairyCo reports that the average number of lactations per cow has in fact been increasing (DairyCo: Factors Affecting Milk Supply 2009). However, the same report states that producers cite a concern about longevity in their herds as to one of the reasons for changing their breeding policy.

Sustainability is of increasing concern in the UK dairy industry. Rapidly decreasing numbers of dairy farmers and falling milk production makes sustainability a relevant and timely issue. The sustainability of the UK dairy production industry is dependent on a number of factors:

1. Financial returns to all sectors of the dairy chain
2. Economic and political policies affecting the market
3. Environmental impact
4. Ability to meet consumer demands
5. Concerns about “ethical” food production
6. Ability of the industry to meet the personal needs of the producer
7. A sustainable breeding programme

In terms of a breeding programme, the goals must meet the demands of all in order to provide an opportunity for a sustainable future.

Public perception of so-called “ethical” issues in dairy production is a relatively new phenomenon. Today many consumers are concerned about the environmental and animal welfare issues associated with the food they consume, including dairy products. A recent airing of the TV programme *Countryfile* (BBC1 May 10, 2009) raised concerns about animal welfare in UK dairy farming and in particular the role of the Holstein and stimulated calls to dairy processors and vendors asking about the cows that provide the milk they processed/sold.

A relevant question in this situation is “do we have to change our system to suit the cow or can we change the cow to suit the system?” In 2001 Simm et al. discussed the possibility of UK dairy farming evolving into three distinct sectors; high input/high output (intensive use of purchased feedstuffs), extensive systems (maximising home grown forages) and specialty markets such as organic dairy farming (Pryce et al.,2001). Various studies have shown that all breeds do not perform the same under different conditions (Bryant et al 2007, Philipsson et al., 2007). Therefore there is an opportunity to utilise alternative breeds better suited to different environments in order to improve performance.

Under these circumstances of increased health, production, management problems and welfare issues, farmers are looking for options in their breeding programmes. Crossbreeding is one option to address these concerns because, for some traits, the differences between breeds are much greater than differences within one breed plus there are extra benefits to be gained from heterosis[5] (Caraviello 2004).

THE CROSSBREEDING THEORY

The contribution of crossbreeding in a dairy breeding programme is based on three main pathways (Swan and Kinghorn 1992):

- Increased genetic resources
- Heterosis
- Complementarity

Increased Genetic Resources

One of the major foundations for genetic improvement is the size of genetic pool from which selection is made. The larger and better the pool from which parents are selected the greater the opportunity for improvement.

When following a pure-breeding programme, the breeder is restricted to selecting from within their own breed. However crossbreeding makes available a wider variety of breeds. This may include those that:

- Have put emphasis on different traits
- Have emphasized varying traits for extended periods of time
- And/or those that have a better base for this trait, as compared to the base purebred in the herd.

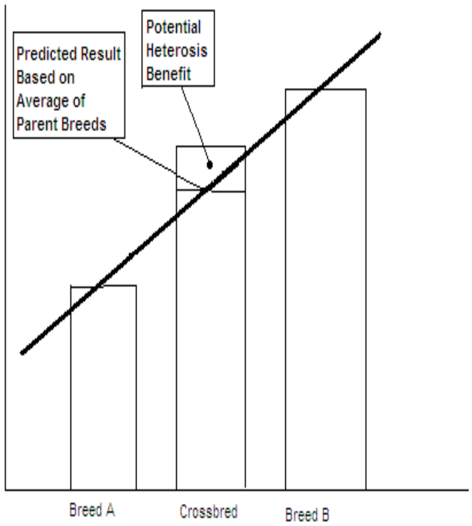
Heterosis/Hybrid Vigour

G. H. Shull first described heterosis in 1914 (Shull, 1948). It is defined as the increased performance of crossbred animals compared with the average of their pure-bred parent populations (Figure 4). This effect of heterosis is the result of changes in the genetic effects of dominance and epistasis (interaction between genes at different locations) (Swan and Kinghorn 1992). These effects are not transferred to subsequent generations.

[5] HETEROSOS or HYBRID VIGOUR: favourable gene effect in a crossbred offspring due to dominance

Dominance in crossbreeding is effected through the result of gene interaction within the loci. The effect from dominance most likely results from superior genes being more dominant and masking the effect of inferior genes. Generally it is assumed that because heterozygosity[6] and dominance are positively related, the effect of heterosis can be estimated.

Figure 4: Illustration of heterosis and complementarity



On the whole, those animals with more heterozygous loci will have better performance than those with more homozygous pairs (Swan and Kinghorn 1992). Pure-breed populations tend to have more homozygosity[7] due, in part, to selection.

As seen in the table 1 below, estimates of heterosis levels vary according to the trait considered.

Table 1: Guidelines for Danish producers on expected F1[8] heterosis

	Expected heterosis %
Production traits	≈ 3
Fertility	≈ 10
Calving ease (direct)	-10 to 15
Still birth (direct)	-5 to 10
Calving ease (maternal)	10 to 15
Still birth (maternal)	5 to 10
Longevity	10 to 15
Total merit	≥10

Sørensen et al., 2008

[6] HETEROZYGOSITY: genetic situation whereby, the genetic information found at a specific location on one chromosome differs from that found at the same location
on the second member of a chromosome pair
[7] HOMOZYGOTE: An animal having the same alleles for a gene. Typically symptomatic of purebreds.
[8] F1: the first cross as a result of 2 pure-breeds

Parent breeds, models used, environment, breeding programme and other factors, all affect the heterosis expressed.

While the dominance effect is within loci, the second genetic aspect of heterosis, epistasis, is between loci. Epistasis is difficult to quantify, however, if it is important it will tend to have a negative effect on the level of heterosis. This is due to recombination of genes, which are fixed, in a pure-bred animal.

In evaluating the “net effect” of crossbreeding the result is usually the sum of dominance (in general positive) and the recombination (in general negative).

A few key points about heterosis:

1. Heterosis is often described as the reverse of inbreeding
2. The effect of heterosis may be positive or negative
3. The total effect of heterosis is difficult to predict
4. Useful heterosis is where the performance of the offspring is higher than either of the parent populations for the trait being considered

Complementarity

The theory of complementarity in breeding is simply finding breeds that complement each other in achieving set breeding objectives. Complementarity is an additive genetic effect, the benefits will be transmitted to future generations, whereas heterosis is non-additive and the benefit is only observed in the resulting crossbred. Therefore it is simpler to predict the effect of complementarity.

In selecting breeds with greater genetic levels for desired traits more rapid improvement maybe achieved. For example, the Jersey breed is noted for high butterfat. Therefore using Jersey genetics in a crossbreeding programme with Holsteins is expected to produce a considerable improvement in butterfat percentage in one cross.

There is a substantial additive genetic variation between breeds for traits such as health, reproduction and production so complementarity is a significant aspect of the improvement that maybe obtained through crossbreeding.

The effect of additive genetic merit achieved by using appropriate parent breeds may well be more significant than the effect of heterosis for that trait (Cassel 2007). In fact, complementarity can contribute economic benefits to a herd breeding programme even in the absence of heterosis (Montgomerie 2002).

The level of complementarity for a particular cross of breeds is a simple average of the value for a particular trait (Figure 4). This average may not be greater than that of a parental breed for any individual trait. Additional research has concluded that breed complementarity contributes to the increased farm profit that results from crossbreeding.

Research in New Zealand (Lopez-Villalobos and Garrick 2002) has highlighted the contribution of complementarity in improved profitability and complementarity has added to the popularity of crossbreeding in New Zealand (Pyman et al., 2005).

RESEARCH REVIEW

Production and health traits

The potential benefits to reproduction and health is a key aspect of crossbreeding. Warwick and Legates, 1979) stated "Almost without exception, crossbred animals have exhibited greater reproductive fitness than the parent breeds" (VanRaden and Miller, 2006).

Two critical aspects of dairy farm profitability are reproductive performance and production. Rincon et al. 1982 concludes that crossbreeding can improve yield and reproduction beyond that of pure-breeding.

Various trials around the world have gone on to prove the validity of his conclusion.

Tools are available to make progress in these vital traits within individual breeds and pure-breeding can result in improvement. However, results will be attained more slowly, perhaps MUCH (Cassel's emphasis) more slowly depending on contribution of breed complementarity and heterosis (Cassel, 2007) when compared to a well planned crossbreeding programme.

In one of the foundation trials on crossbreeding, Touchberry (1992) referred to a long-term experiment in Illinois involving Holsteins and Guernseys, during the early 1950's, that demonstrated heterosis in production of between 5% and 8% inseminations per pregnancy at 12.8% and days open of 9.4%. Further trials in various countries of the world have returned similar results. To a large extent, these results have been confirmed in subsequent trials.

Dechow et al. 2007 reported on a US trial involving over 3,400 cows and 6,500 lactations. The experiment compared pure Holstein, pure Brown Swiss, Brown Swiss x Holstein ((BH) and Brown Swiss x BH (backcross). BH had significantly fewer days open (12.3 days) than pure Holstein or pure BS (Appendix 1). This was at similar milk yields to the pure Holstein but higher protein and fat (Appendix 2). Heterosis estimates for days open were approximately 7.3%. This is in the same direction, but somewhat lower, than most other work (Brandt et al., 1974, McDowell and McDaniel 1968). The authors concluded that BS was a suitable cross for Holsteins.

This report highlights the need for additional research to be done on subsequent crosses (where do we go after the first cross?) While there is evidence of minor loss in production in the B(BH) backcross, this is not consistent with other research.

This study is in line with other research. Holsteins have been bred with an emphasis on milk yield and to date no other dairy breed or cross breed has consistently surpassed their milk production.

In terms of fat and protein, the picture is less clear, with some crosses matching or exceeding the yield of pure Holsteins. (Van Raden and Sanders 2003, Bryant 2007, Weller 2006, Dechow et al., 2007, Freyer et al., 2008). This has been the case under various systems of feed and management. However, it is difficult to quantify the actual difference in yield as this is a factor of the breeds involved, the conditions, the cycle in the crossbreeding rotation and various other factors.

Montgomerie 2002 reported on the New Zealand experiences with crossbreeding and indicated production and health trait heterosis in line with current research. He went on to refer to production of the "next generation". The F1 Holstein x Jersey animals were backcrossed to Holstein or Jersey (Appendix 3).

Montgomerie refers to this data giving "New Zealand farmers' confidence in systematic (planned) rotational crossbreeding".

As a result of crossbreeding Jersey sires on Holsteins at the University of Minnesota, Heins et al., 2008a (Appendix 4) questioned the suitability of Jersey cross Holsteins in a "confinement" management system as often seen in the Northern Hemisphere.

Research indicates that as a general rule, heterosis is greater for fitness traits than for production traits (McAllister 2002, Brandt et al. 1974, McDowell and McDaniel 1968), Sørensen et al., 2008 reported fitness heterosis in the range of 11.6% to exceeding 30% for varying traits. Yet VanRaden and Sanders 2003 reported low results for fitness, in the range of 0.7% to 1.2%.

Heterosis estimates may differ depending on the trait considered. Mastitis is of considerable economic cost to the industry. Mastitis resistance can be improved genetically and therefore is a useful tool in complementary matings. However, research is varied in terms of the effect of heterosis in addressing mastitis resistance. Van Raden and Sanders 2003 indicated no significant effect from heterosis on mastitis or somatic cell counts (SCC). However, Dechow et al., 2007 showed variable results and results from SAC (Brotherstone et al., 2004) indicate useful heterosis for SCC.

Much of the recent interest in crossbreeding has been stimulated by a crossbreeding project based at seven large commercial dairies in California. This commercial project has become the source of numerous published research papers by Heins, Hansen and Seykora. The trial was initiated by seven larger dairy farms that were looking to improve health and reproduction traits (Heins 2007). It was based on using semen from Montbéliarde, Normande, Scandinavian Red breeds on Holstein cows. Scandinavian Red was used to designate Swedish Red and Norwegian Red breeds collectively due to similar ancestry and exchange of sires of sons.

While this trial does not report on the heterosis effect (pure-bred animals of each breed are necessary in order to have a base for comparison), it does report significant, actual results achieved with various combinations.

Results were in line with other research, which indicates approximately two to three weeks fewer "days open" for crossbreds than pure-breds (Heins 2007 Appendix 5,6). However, the report also highlights the statistically lower production of all the crossbreed combinations vs. pure Holsteins. Yield results were in line with other work. Pure Holsteins surpassed the crossbreds for milk yield and virtually all the components. Only the Scandinavian Red had fat yield similar to the Holsteins.

A number of crossbreeding trials are currently being carried out in Germany, with similar goals to the California trial identifying new approaches to breeding dairy cattle that can meet the demands for high yielding, healthy, fertile cows that are easy to manage (Freyer et al., 2008).

A trial comparing Brown Swiss x Holstein to Holstein reports similar milk volumes but fat and protein contents were significantly greater for the crossbreds (Freyer et al. 2008 Appendix 7). The BS x H crossbreds also exhibited improved fertility and health traits (Appendix 8). However it was reported that the crossbreds ate significantly more than the pure Holsteins indicating a poorer feed efficiency as yields were similar.

Another German trial comparing Jersey x Holstein to pure Jerseys and pure Holsteins reports similar fat and protein yields between crossbreds and pure Holsteins. However, the crossbreds had a significantly better performance for all fertility traits and calving ease and fewer calf losses. The pure Holsteins had lower SCC but somewhat poorer feed efficiency (Freyer et al.2008).

In reporting on an ongoing crossbreeding trial in Germany, Swalve et al 2007 refer to pure Holsteins (380), Swedish Red x Holsteins (110) and Brown Swiss x Holsteins (96) (Appendix 9). In the first lactation on this organic farm the SR x Hol were significantly better than the pure Holsteins and the BS x Hol for milk yield. Both the crosses were better than pure Holsteins for fat and protein percentage. In terms of reproductive performance the trial results were similar to those demonstrated by Heins et al. 2007 - no significant difference in days to first service however significantly lower inseminations per pregnancy for the crossbreds (**Appendix 10**).

CALVING EASE AND CALVES

There are two main aspects to calving ease; direct calving ease – the ease of birth of offspring of a sire and maternal calving ease – the ease with which the daughter of a particular bull will deliver her offspring. When the sire is a different breed to the cow being mated then heterosis for CE is observed.

As in all cases, there are two areas to consider in terms of crossbreeding effects; heterosis and complementary impact.

For calving ease the Sørensen et al., 2008 trial indicated substantial negative heterosis for direct calving ease on heifers (indicating that the crossbred calves could be difficult for their dams to deliver).

Interestingly, this result of negative heterosis is not observed in actual results reported from the California trial (Heins 2007 Appendix 11, 12, 13). Scandinavian Red x Holstein, Brown Swiss x Holstein and Montbéliarde x Holstein, all demonstrated a lower incidence of direct calving difficulties and stillbirths than pure Holsteins. The BS crosses were significantly better for direct calving ease and SR significantly better for direct calving ease and stillbirths. As heterosis was not recorded in this trial, the reason for this improvement is unclear. Maltecca et al., 2006 reported less calving difficulties and improved calf health in crossbred calves (Jersey/Holstein sires x Holstein dams). The conclusion of this trial was that the introduction of Jersey genetics could lead to less calving problems (direct) and improvements in calf health.

In a trial comparing Montbéliarde and pure Holstein sires crossed on pure Holstein cows and Jersey x Holstein cows, Heins et al. 2009 reported on calving ease. While the Montbéliarde sired calves that had a longer gestation period than the Holstein sired calves (283.2 vs. 278.4 days) they had no more (statistically significant) calving difficulties. Substantial beneficial heterosis for maternal calving ease has been demonstrated in various trials (Hansen et al., 2004, Sørensen et al., 2008).

Dickinson and Touchberry 1961 demonstrated significant survivability of calves from birth to calving. In a trial comparing pure Holsteins and Guernseys and their crosses they reported 23.1% of the pure-breds dying vs. 11.1% of the crossbreeds. The survivability benefit to crossbreeds extended over three generations.

Sørensen et al., 2008 was able to evaluate heterosis for diseases. The trial considered enteritis, pneumonia, mortality and “other diseases” for calves and reported heterosis a significant positive factor for enteritis, pneumonia and mortality. Frequencies of enteritis and mortality in crossbreds were less than half of the pure-breed populations.

Results from cows were not as great, but still showed heterosis for metabolic and feet/leg problems.

SURVIVABILITY

Heins 2007 (Appendix 14) also looks at the increased longevity of crossbreds in the California trial. All crossbred combinations had a higher level of survivability. Van Raden and Sanders 2003 demonstrates positive trends in heterosis for longevity.

Studies under varying conditions (Denmark Sørensen et al., 2008 and New Zealand Harris et al. 2000) also agree in high levels of heterosis for longevity.
The trial of Dickinson and Touchberry 1961 (Appendix 15) demonstrated 35.4% of the pure-bred cows having to leave the milking herd vs. 15.4% of the crossbreds. This trial went on six lactations. The researchers refer to a more relevant figure as being

the number of cows that survive to the end of two lactations. In this trial 50% more of the crossbreds survived to the end of the second lactation. The authors conclude that, for the "average commercial dairyman" there would seem to be a real place for the healthier, longer lived crossbreds.

Touchberry 1992 indicated that a significant portion of the additional income from crossbreds was obtained as a result additional animals being voluntarily sold due to increased longevity and shorter calving interval.

Swalve et al. 2007 (Appendix 16) also referred to significantly higher survivability in the Swedish Red x Holstein crosses vs. pure Holsteins, however, the Brown Swiss x Holsteins had losses similar to the pure Holsteins.

INTERACTION OF GENETICS AND ENVIRONMENT ("HORSES FOR COURSES")

As stated earlier, not all breeds perform the same under different conditions. Therefore, it is important to consider the conditions under which the trial was conducted.

An Australian research project was conducted to look at production and reproduction results under a seasonal calving regime in south east Australia. 1,300 Holstein and crossbred cows (Holstein/Jersey) were evaluated over a single lactation (Pyman et al., 2005) Despite the Holsteins producing 2.1 kg/cow more milk there was no significant difference between the two groups for fat and protein yield. However, the crossbreds were 10% better (42% vs. 52%) for first service conception and 14% (68% vs. 54%) better on six week in-calf rate.

When considering the "right" cow for a particular environment Dechow et al., 2007 concluded in a US experiment, that crossbreeding will allow dairy producers to pick the right genetics for their farm management conditions.

A trial in Ireland under a different set of conditions determined similar results (Walsh et al., 2008). Four different dairy breeds (Holstein-Friesian, Montbéliarde, Normandie and Norwegian Red; and two crossbreeds, Montbéliarde x Holstein-Friesian and Normandie x Holstein-Friesian) were evaluated to look at the effect of the different breeds and crosses under high an low concentrate feeding on a grass based seasonal calving system. It concluded that other breeds and their crossbred combinations were more suitable than pure Holstein Friesian under a seasonal based system.

ORGANIC PRODUCTION

The interaction of different environments and conditions and genetics has been investigated in relation to organic milk production. While stressing that selection must still include milk yield Pryce et al., 2001 submitted that rising health and fertility problems maybe of more significance to organic dairy farmers as opposed to conventional. This is a result of the cost of the disease being higher in organic operations. In this case, the higher levels of disease resistance and reproductive performance could be of more financial benefit as well. Crossbreeding also offers organic farmers the opportunity to practise complementary matings in order to improve performance for these important traits.

A survey was done of Dutch organic dairy farmers to determine their breeding goals and avenues to achieve these (Nauta et al., 2006). Their goals identified were robust, long living cows, with good udder health and fertility. To achieve these, 51% of organic farmers in the survey selected crossbreeding. Of the farmers choosing pure breeds, 29% used Holstein, 10% other breeds, 7% Dutch breeds, 3% Jersey.

The interaction of genetics and environment suggests that there may be potential for a different type of crossbred cow under systems of low concentrate, high forage. (Weller 2006). This system of maximising use of forage would be typical of many organic farms.

However, Brotherstone et al., 2004 report on a model looking at the suitability of crossbred and pure-bred cows. Using assumptions and accounting for data on milk production, SCC, calving interval and survival they found that the Holstein was most profitable for organic production.

A large experiment is being conducted on an organic dairy farm in Germany involving pure Holsteins (380), Swedish Red (SR) x Holstein (110) and Brown Swiss (BS) x Holstein (96). The trial considered milk volume, fat and protein production, SCC, survivability and reproductive performance. The SR display significant advantages over the other two breed groups for all traits other than protein yield (no significant difference) and SCC (SR cross poorest). This trial is ongoing.

SUSTAINABILITY

The current trend of decreasing reproductive performance and deteriorating health traits is not sustainable genetically or financially. Effectively this is compromising the health of the animals. Crossbreeding, with the positive effects of heterosis and complementarity may be used to help alleviate this.

Today, sustainability in dairy cattle breeding must account for animal welfare as well. The significant heterosis effect for many of the health and reproductive traits can be used to help address these concerns through a planned crossbreeding programme.

On a larger scale, predicative modelling has indicated that improving fertility can have a major effect on reducing greenhouse gas emissions from dairy enterprises (Defra).

Crossbreeding has been interpreted as inbreeding depression in reverse, so a systematically planned crossbreeding programme may effectively dispel the negative effects of inbreeding on sustainability.

PROFITABILITY

A key element in evaluating any breeding programme is profitability. In a trial in the USA, Touchberry 1992 (Appendix 17) reported that in terms of income/cow/lactation, crossbreds exceeded purebreds by 14.9% and income/cow/year by 11.4%. Further research has gone on to confirm that crossbreds can improve profitability under different systems (N.Z. Lopez-Villalobos et al., 2000 Appendix 18, Canada McAllister 1994 Appendix 19, USA Van Raden and Sanders 2003). It is important to consider the overall environment of dairy production, including milk payment terms in determining the possible benefits of crossbreeding.

In a large trial evaluating purebred and crossbreds in the USA, Van Raden and Sanders 2003 (Appendix 20) concluded profitability of BS x Holstein and Jersey x Holstein exceeded pure Holsteins in two of three pricing systems (net merit and cheese pricing) The Holsteins exceeded all others in fluid milk merit pricing .

A further trial in the US compared Holsteins and Jersey/Holstein crossbreds (Anderson et al., 2007) concluded the Jersey cross animals demonstrated benefits in milk composition, reproductive performance, some health disorders and cull rate. Together these benefits offset the lower milk yield of the crossbreeds and led to greater economic performance.

HOW TO BREED THE CROSSBRED

The need to plan and execute a breeding programme in order to succeed with crossbreeding has been stressed in numerous papers (Kahi et al 2000, Dechow et al., 2007, Sørensen et al., 2008). A systematic, considered approach is necessary for success.

An important part of this planning is determining how many, and which breeds to use in a crossbreeding programme. Maximising the effect of heterosis is one consideration. A two way rotational cross, results in 67% of the maximum hybrid vigour available in the F1, three way equates to 86% and a four way rotation brings 93% of F1 hybrid vigour. Heterosis evolves through generations based on the crossbreeding programme followed. Table 2 illustrates the level of heterosis that will be available in different populations following various breeding programmes. The choice of breeding programme and breeds is made less apparent due to the fact there have been no long-term experiments evaluating different systems other than in New Zealand (Swalve 2007).

Table 2: Heterosis through generations

Generation	2 breeds	3 breeds (%)	4 breeds
1	100	100	100
2	50	100	100
3	75	75	100
4	63	88	88
5	69	88	94
6	66	84	94
7	67	86	94
8	67	86	93

According to Cassel 2007, a key benefit of the two way cross is simplicity however the system offers the least heterosis of the rotational options. A further concern of the two way cross may be the considerable additive effect variation between generations. For example the implications of possible size variation in a two way cross involving Holstein and Jersey.

A three way cross contributes additional heterosis and lessens the pure paternal effect on a mating. However, it is important to ensure that significant breeding goals are not compromised in order to include a third breed in the rotation.

The research looking at each system is not consistent in the conclusions drawn. Various researchers advocate the two way cross (McAllister 2002, Steine and Larsgard 2005 and Lopez-Villalobos et al., 2000). Others (Hansen 2006, Heins 2007, Kring 2007, Sørensen 2007) a three way crossbreeding system.

However the research is in agreement that the selection or the breeds and sires within the breeds are critical to giving the foundation for success in crossbreeding (Cassel and McAllister 2008, Weigel 2006). In selecting the breeds and sires, it is important to consider how much of the benefit obtained from crossbreeding is the result of heterosis and how much due to complementary breed (Sørensen et al 2008).

The literature supports the use of a crossbreeding programme based on breeds that are genetically distant in order to maximise heterosis (Mäki-Tanila, 2007, Touchberry 1992, Dechow 2007). Boichard et al 1993, Wall et al., 2005 demonstrate lower levels of observed heterosis due to unfavourable recombination loss in crossing European Black and Whites based on Friesian breed, with North American Holsteins indicating the need for genetic distance in order to maximise heterosis. Also Sørensen et al. 2008 suggests care be used regarding the use of individual bulls within breed that may contain some percentage of Holstein genes.

No research literature was found that supports the use of crossbred bulls in a breeding programme (Cassel and McAllister 2008). Swan and Kinghorn 1992 refer to crosses including one pure-bred parent may be superior as these crosses might have less recombination loss. Maltecca et al., 2006 could find no difference in fertility of crossbred Jersey/Holstein sires vs. pure Holstein sires in a US experiment. However the use of crossbred A.I. proven sires is suggested as an option in Australia (Turner 2006) and Montgomerie 2001 reports that 15% of the bulls born in 2001 and selected by NZ A.I. units were crossbred.

MANAGING CROSSBREDS

Surveys have been done in Australia (Turner 2006) and the USA (Weigel and Barlass 2003) of producers that had experience of crossbreeding. These results should just be seen as indicative of these farmers' attitudes as a result of their own experiences. However their experiences follow the trends reported in the research **Table 3**.

Table 3: Farmers' Attitudes to crossbreds

	Australia*	**USA****
Breeds	HF x Jersey	Jersey x Hol. And B.S. x Holstein
Advantages	higher components smaller size hybrid vigour improved fertility	higher components improved fertility calving ease longevity
Disadvantages	lower sale value smaller size lower milk yield	lower sale value inconsistent size

***Turner 2006, ** Weigel and Barlass 2003**

Little research has been reported regarding management of crossbred animals. Dechow et al 2007 refers to anecdotal evidence of difficulty in getting Brown Swiss calves to drink from buckets. Further Freyer 2008 reports that BS x Holstein calves were robust, calves that developed easily, however this author went on to report on the significantly slower milking speed of the Brown Swiss crossbreds.

Heins et al., 2008a referred to temperament in Jersey x Holsteins being an issue as well as variation of cow size as a result of this cross, in some management systems.

Robustness of crossbreds was also mentioned by Sørensen 2007 as the reason for their increased longevity.

OBSERVATIONS ON LITERATURE

It is important to evaluate the results of the various research based on factors that are relevant to the dairy industry in the UK and in particular to the individual dairy producer considering crossbreeding.

Research has been carried out under a wide variety of environmental, management, nutrition and payment methods. The variation in the conditions and genetics used in the different trials makes it very difficult to draw hard and fast conclusions as to which of the benefits, and at what level of those specific benefits; a particular individual may obtain.

Much of the financial benefit reported in the New Zealand trials is derived from increased stocking rates on pasture. A UK producer that is in a location in the country where it maybe possible to implement a similar system would find these trial results more significant than a producer whose cows are housed all year. However for a system that features more confinement and intensive production, results from Europe, the US and Canada are probably more significant. While the extent and source vary, results from all countries considered suggest increased profitability from crossbreeding.

One area of significant importance in considering crossbreeding is milk payment method. A key benefit of many of the crossbred combinations is improved milk components. Therefore crossbreds may well yield increased income under a milk payment scheme that rewards higher components. Under a system that only pays based on milk volume care would have to be taken to select breeds, and bulls within breeds that could maintain milk volume.

The importance of having a planned or systematic crossbreeding programme is emphasized in much of the research. To a large extent this is simply because there is more variation and choice available in crossbreeding. Rather than simply choosing the best of one breed as in pure-breeding, crossbreeding involves the additional process of initially choosing the breed and then selecting bulls within those breeds. Establishing and carrying out a successful crossbreeding programme requires planning and organisation. More of this will be discussed in the section ‘Planning a Crossbreeding Programme’.

Crossbreeding offers significant benefits in health and reproduction traits. However it is important to remember that these traits are significantly affected by various environment and management actions. Crossbreeding is not a “magic pill” that will solve all problems in these areas. It is tool that does offer benefits and can be used to improve performance and outputs, particularly under systems that are not ideal.

Crossbreeding is based on exploiting the benefits of breed variety, heterosis (hybrid vigour) and complementarity. Many consider heterosis as the key benefit of crossbreeding. However this must be seen as a “bonus” on top of a well-planned programme. Quite likely the most significant improvement from crossbreeding, and certainly the longest lasting, is using a combination of breeds that meet the needs of an individual operation.

Analysing the direct calving ease research regarding cross breeding demonstrates the implications of heterosis vs. complementarity. While crossing Jersey on Holsteins will result in easier calvings this is a result of the selection of Jersey (very easy calving breed) not the result of crossbreeding per se. The implication is that it is as important to consider breed and sire selection in a crossbreeding programme as it is in a pure-breeding programme.

Little research was reported on management aspects of crossbreeding. While crossbreds are reported as robust, vigorous animals, little was said about the impact of crossbreeding on a farm management system. One area that has been mentioned by many in terms of crossbreeding is variety. The extent of this variety will be affected by the programme selected, the breeds utilised and the stage in development of a crossbreeding programme. For example, a programme involving a much smaller breed could have quite significant effects on the size of crosses and their relationship in the herd environment. The impact of this variety must be considered and planned for.

The value of animals sold was mentioned by producers involved with crossbreeding in different surveys. In some areas crossbred dairy animals are discriminated against, in other areas they are seen as a bonus. However one area of importance in the UK is compensation for disease culls. This was not referred to in any of the research. At the present time pedigree purebred dairy animals in the UK command some premium Table 4 and of course crossbreds cannot be pedigree.

Table 4 UK cattle compensation rates July 2009

Dairy Sector

Male		Female	
Age	**Compensation due (£/head)**	**Age**	**Compensation due (£/head)**
Up to 3 months	68	Up to 3 months	127
Over 3 months up to 6 months	172	Over 3 months up to 6 months	*
Over 6 months up to 12 months	321	Over 6 months up to 12 months	538
Over 12 months up to 16 months	557	Over 12 months up to 16 months	585
Over 16 months up to 20 months	599	Over 16 months up to 20 months	754
20 months and over	669	20 months and over	1,169
		Calved	1,327

Dairy Sector Pedigree

Male		Female	
Age	**Compensation due (£/head)**	**Age**	**Compensation due (£/head)**
Up to 2 months	*	Up to 2 months	516
Over 2 months up to 12 months	*	Over 2 months up to 10 months	*
Over 12 months up to 24 months	1,511	Over 10 months up to 18 months	1,383
Bull 24 months and over	*	Over 18 months not calved	1,696
		Calved under 36 months	1,895
		Calved 36 months and over	1,540

*Compensation to be determined using individual evaluations Defra website http://www.defra.gov.uk/news/2009/090701.htm accessed02/07/2009

ESTABLISHING A CROSSBREEDING PROGRAMME

The goal of any breeding programme is to provide the right type of animal to suit the needs of the producer. These needs must take into account the environmental, financial and management realities of the unit. A crossbreeding programme must do this as well. So the goal of a crossbreeding programme is not to maximise heterosis but rather to meet these needs as efficiently as possible.

In establishing a cross breeding programme and selecting breeds, there are a few key points to remember:

1. **Crossbreeding is a commitment**
2. **Make a plan**
   - How many breeds to use
     - o The weight of opinion falls on the side of three way cross
     - o Reasons for this include:
       - ▪ Maintaining hybrid vigour
       - ▪ Increased opportunity to avoid inbreeding
   - When to use them in rotation
   - Which animals in the herd to cross breed
     - A farmer does not have to commit the whole herd to cross breeding
3. **Breed selection (Appendix 21)**
   - Ensure breeds selected:
     - Are sampling a large number of bulls
     - Have a quality young sire testing programme
     - Are making genetic progress
   - Consider maximising heterosis through using breeds that are far apart genetically

- Consider impact of breed on variability of the herd

4. **Use breeds that are complementary to each other and herd goals**
   - E.g. if you are satisfied with milk yield in your herd but want increased components
5. **Select top bulls within each breed that meet herd goals and match the system**
   - Use A.I. sires
   - Natural service sires are an "unknown quantity" for production and health traits, just because the bull is a different breed doesn't mean the crossbred calves will be good
   - Bull selection is as important in cross breeding as in pure breeding

GAPS IN RESEARCH

In preparing this study gaps in current research on crossbreeding became apparent. These may well form the basis of future studies.

Management implications of crossbreeding

In general comments regarding management of crossbreds are positive:

- Healthy, vigorous calves
- Fast growing
- Fit in well with the herd
- Cows are referred to as "first in the parlour" and aggressive eaters.

However there are some concerns about managing a herd that may have different sized animals, implications on cubicles, animal behaviour etc.

In order to ensure that producers can make informed decisions and get the most out of their crossbreds these areas should be addressed.

Beef from crossbreds

Various breeds (Norwegian Red, Fleckvieh), include beefing quality testing in their young sire programmes. Others are breeds with more weight (Montbéliarde, Normande). These breeds, used in a dairy crossbreeding programme, could provide additional benefits to producer income and UK beef supplies.

Producers' opinions on crossbreeding and current UK results

Crossbreeding in dairy cattle is an emotive issue. Yet crossbreeding can be a useful tool in correcting decreasing health and reproductive performance in dairy cattle.

While producer surveys regarding crossbreeding, have been done in other countries no research was evident of such a survey having been done in the UK. A well-constructed survey could help assess the level of interest and participation in crossbreeding and help develop programmes to assist producers on making decisions and implementing crossbreeding.

Optimal crossing system

Two, three or four way crossing is an option in rotational crossbreeding. There are no clear-cut answers in terms of the "best" way (if such an answer exists). Various authors suggested the need for more research on this topic.

CONCLUSIONS

The potential gain, or loss, due to crossbreeding is dependent on various factors:

- Trait considered
- Breeds selected
- Level of hybrid vigour expressed for a trait
- Farm environment[9], management and nutrition
- Milk payment conditions

Research from Europe, the USA, Canada, Australia and New Zealand has shown that crossbreeding:

- Improves reproductive and health performance
- Improves components of milk
- Increases Survivability
- Eliminates inbreeding in the first cross
- Improves maternal calving ease
- Increases robustness
- Can result in an increase in overall profitability.

Improved survivability of crossbreds is an important benefit of crossbreeding. This offers the potential of increased heifer sales, more intensive culling of unsatisfactory cows and possibly the option of increased beef crossbreeding in the dairy herd to increase income.

Longer living cows require less replacements and this has been identified as an environmental benefit to crossbreeding. As well, the improved reproductive performance of crossbreds also has a positive impact on the environment.

In turn a lower replacement rate provides the opportunity for more of the dairy herd being bred to beef sires improving the yield and quality of domestic beef with less reliance on imports.

Available research indicates that crossbreeding may well have larger benefits to the UK dairy industry as a whole. The possibility of crossbreeding generating more robust cows could be a significant benefit in the age of animal welfare concerns. Animal welfare is not just a concern on moral grounds; it has financial implications as well.

For the processing industry crossbreeding provides the opportunity of increasing solids content of milk more dramatically through the use of high component breeds.

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[9] ENVIRONMENT: used in this sense refers to the physical conditions of the farm

The level of benefits achieved by any individual breeding programme is determined by the:

1. Programme implemented and maintained
2. The breeds selected
3. The difference between the breeds
4. The sires selected

Producers should choose their programmes and breeds carefully and use A.I. progeny tested sires that meet their goals.

Crossbreeding must be considered carefully and planned. Amongst the most common concerns expressed in the research are:

1. What type of breeding programme to most effectively maintain the benefits of crossbreeding? “Where to go after the first cross?”
2. Concerns about variation in animal size and impact in nutrition and housing
3. Loss of pedigree status and the impact of this
4. Potential loss of yield and implications

These, together with a lack of recent research in the UK indicate the need for additional research in the UK.

UK dairy producers are concerned about negative trends in their herds for survivability, reproduction and fitness traits and the impact of this on their profitability. The research demonstrates crossbreeding can contribute useful heterosis and complementarity benefits in these traits and that a well planned crossbreeding programme can play a role in addressing these concerns.

Appendix 1 US trial comparing reproductive results from Holstein, Brown Swiss and their crosses

Trait	Hol	BS x Hol	BS x (BS/Hol)	BS	USA
Number of records	1773	1321	85	805	Dechow et al.
Days Open	156	144*	153	156	
Hol = Holstein, BS = Brown Swiss					
* = statistically better than pure					

Appendix 2 US trial comparing Holstein, Brown Swiss and their crosses

Trait	Hol	BS	BSx(BS/H)	BS	USA
Number of cows	1773	132	85	805	Dechow et al. 2007
ME** Milk, lbs	24,747	24,520	22,295***	21,695***	
ME** fat, lbs	873	915	849	833	
ME** protein, lbs	725	772***	714	699***	
ME = Mature Equivalent *** = statistically different					

Appendix 3 New Zealand data illustrating production of NZ Holstein-Friesian, Jersey, Ayrshire and crossbreds

Trait		Hol-Frie.	Jersey	Cross breeds	Ayrshire	NZ
Number of cows		1,351,127	408,773	607,449	29,929	Montgomery 2002
Milk volume litres/cow/season	2000/2001 season	3912	2813	3519	3553	
Milk Solids kgs./cow/season	2000/2001 season	306	275	304	280	
Hol-Frie = Holstein-Friesian, Crossbreds = all crossbreds						

Appendix 4 US trial comparing Holsteins and Jersey x Holsteins in Northern US confinement systems

Trait	**Lactation**	**Hol**	**Jer. x Hol**	USA
Number of cows	**First**	73	76	Heins et al., 2008
Lactation yield lbs.		16,986	15,756	
Fat lbs.		610	605	
Protein lbs.		524	492	

Appendix 5 US Reproductive data from California trial

	Hol.	**Nor x Hol**	**Monte x Hol**	**Scan Red x Hol**	Heins 2007
Number	**360**	**235**	**478**	**315**	
Days Open 1st lact.	147	122	124	131	
note: all crossbreds significantly better than pure Holsteins					

Appendix 6 USA California Trail evaluating Holsteins and Normande, Montbéliarde and Scandinavian Red crossed on Holstein cows

Trait	**Lactation**	**Hol.**	**Nor x Hol**	**Monte x Hol**	**Scan Red x Hol**	USA
Number of cows	**First**	380	245	494	328	Heins 2007
Milk kgs. 305 days		9,891	8595	9202**	9309**	
Fat Kgs. 305 days		352	323**	337**	343	
Protein Kgs. 305 days		307	278**	292**	298*	
Number	**Second**	310	245	432	274	
Milk kgs. 305 days		11,965	9990**	10683**	10782**	
Fat Kgs. 305 days		427	375**	400**	404**	
Protein Kgs. 305 days		373	326**	342**	347**	

Hol = Holstein, Nor = Normande, Monte = Montbeliarde, Scan Red = Scandinavian Red ** significantly different from pure Holsteins

Appendix 7 Comparing Holstein and Brown Swiss x Holstein Production

Trait	**Lactation**	**Hol**	**BS x Hol**	Germany
Number of records	**First**	45	50	Freyer et al 2008
Daily Milk kgs.		30.6	30	
Fat %		3.97	4.16	
Protein %		3.52	3.67	
Trait	**Lactation**	Hol	BS x Hol	
Number of Records	**Second**	40	46	
Daily Milk kgs.		40.7	39.7	
Fat %		3.98	4.41	
Protein %		3.41	3.51	

Hol = Holstein, BS = Brown Swiss

Appendix 8 German Trial assessing Days Open and Inseminations/pregnancy for Holsteins and Brown Swiss x Holsteins

Trait	Lactation	Hol	BS x Hol	
Number		**45**	**50**	Germany Freyer et al 2008
Days Open	1st	106.8	89.1	
Inseminations/Pregnancy		2.00	1.84	
Number		40.00	46.00	
Days Open	2nd	128.2	120.4	
Inseminations/Pregnancy		2.23	1.93	

Appendix 9 German data reviewing Production of Holstein and Swedish Red x Holstein, Brown Swiss x Holstein on Organic farm

Trait 1st Lact. Prod.	Hol	Swed. Red x Hol.	BS x Hol	-	Germany Swalve et al. 2007
Number	380	110	96		
Milk Yield/day Kgs.	21.02	22.27	20.62		
Fat %	3.76	3.83	3.84		
Fat Yield/day Kgs.	0.78	0.83	0.79		
Protein %	3.18	3.26	3.31		
Protein Yield/day Kgs.	0.66	0.71	0.67		

Hol= Holstein, Swed. Red = Swedish Red, BS = Brown Swiss

Standard error Holsteins milk .27, fat % .02 fat yield .01, protein %.01, protein yield .01

Standard error Swed. Red x milk .46, fat % .04 fat yield .02, protein %.02, protein yield .01

Standard error BS x milk .53, fat % .04 fat yield .02, protein %.02, protein yield .02

Appendix 10 German Reproduction data from Organic Farm

Trait	Hol	Swed. Red x Hol.	BS x Hol	Germany Swalve et al. 2007
Number	380	110	96	
Days to First Service	no significant difference			
Inseminations/Pregnancy	2.28	1.76	1.77	
Hol= Holstein, Swed. Red = Swedish Red, BS = Brown Swiss				

Appendix 11 US California data of Sire Breed effect on 1st lactation Calving ease/stillbirths when used on Holsteins

Calving Difficulty and Stillbirths by Sire Breed on 1st lact. Holstein dams	Hol.	Montbéliarde	Brown Swiss	Scan. Red	Heins 2007
Number	371	158	209	855	
Calving Difficulty %	16.4%	11.6%	12.5%*	5.5%*	
Stillbirths	15.1%	12.7%	11.6%	7.7%*	
note: * significantly different from pure Holsteins					

Appendix 12 US California data of Sire Breed effect on Subsequent lactation Calving ease/stillbirths when used on Holsteins

Calving Difficulty and Stillbirths by Sire Breed on Holstein dams 2nd-5th lact.	Hol.	Normande	Montbéliarde	Brown Swiss	Scan. Red	Heins 2007
Number	303	326	2373	524	515	
Calving Difficulty %	8.4%	8.7%	5.4%	4.9%	2.1%*	
Stillbirths	12.7%	7.3%*	5%*	5.6%*	4.7%*	
note: * significantly different from pure Holsteins						

Appendix 13 US California data on calving ease/stillbirths based on breed of dam

Calving Difficulty and Stillbirths by Dam Breed with different sires 1st lact.	Hol.	Normande x	Montbéliarde x	Scan. Red x	Heins 2007
Number	676	262	370	264	
Calving Difficulty %	17.7%	11.6%*	7.2%*	3.7%*	
Stillbirths	14.0%	9.9%	6.2%	5.1%*	
note: * significantly different from pure Holsteins					

Appendix 14 US data from California looking at survivability of Pure and Crossbred cows in 1st lactation

	Hol.	Nor x Hol	Monte x Hol	Scan Red x Hol	Heins 2007
Number	380	245	494	328	
1st Lact. Survival to 305 days	83%	90%	93%	90%	
note: all crossbreds significantly better than pure Holsteins					

Appendix 15 US trial data reviewing survivability of Pure and Crossbred calves and cows

			Hol.	Hol x G	G x Hol	G	
							USA Dickinson and Touchberry 1961
Number			35	30	33	30	
% died (birth to calving)	**calves**	**1st gen.**	14.3	6.7	15.2	33.3	
			Hol.	3/4 Hol / 1/4 G	3/4 G / 1/2 H	G	
Number			58	53	48	24	
% died (birth to calving)	**calves 2nd gen.**		19.0	5.7	8.3	20.8	
			Hol.	**Hol x G**	**G x Hol**	**G**	
Number			29	25	27	19	
% Leaving herd to 6 lact.	**cows 1st gen**		31.0	16.0	14.8	42.1	

Survival and Calving

Appendix 16 German data from Organic dairy comparing survivability of Holsteins and Crossbreds

Trait	**Hol**	**Swed. Red x Hol.**	**BS x Hol**	
				Germany Swalve et al. 2007
Number	380	110	96	
Losses in 1st 365 days	16.8%	8.20%	18.10%	
Hol= Holstein, Swed. Red = Swedish Red, BS = Brown Swiss				

Appendix 17 Income per Cow comparing Crossbreds to Holsteins

Holstein/Guernsey	**Income/cow/lactation compared to Pure Holsteins**	**Crossbreds**	114.90%	USA Touchberry 1992
	Income/cow/year compared to Pure Holsteins	**Crossbreds**	111.40%	

Appendix 18 New Zealand model simulating Net Income per Hectare of Pure and Crossbreeds

Holstein/Jersey		Hol-Frie	Jersey	H-F x Jer	2 way Rotation H-f x J	NZ Villalobos et al., 2000
	Net Income Hectare $	$1487	$1590	$1639	$1633	

Appendix 19 Profitability of Holstein/Ayrshire crossbreds over numerous generations

Holstein/Ayrshire	Criteria	Breeds	Results	Canada McAllister et al., 1994
	Annualized discounted net returns	Holstein	$234.80	
		Hol x Ayr = G1	$292.50	
		Ayr x Hol	$210.80	
		H x G1 = G2	$304.50	
		A x G2 = G3	$219.40	
		H x G3 = G4	$301.50	
	(fluid pricing)	A x G4 = G5	$201.30	
		H x G5	$300.80	

Appendix 20 US Research on Profitability of various crossbreeds compared to Holsteins under various milk payment systems

Breed	Criteria	Results	Criteria	Results	Criteria	Results	USA
Holstein/Ayrshire	Net Merit $ Compared to Pure Holsteins	-58	Cheese Merit $ Compared to Pure Holsteins	-27	Fluid Merit $ Compared to Pure Holsteins	-201	Van Raden et al., 2003
Holstein/Brown Swiss		18		79		-241	
Holstein Guernsey		-184		-138		-395	
Holstein/Jersey		44		113		-269	
Holstein /Milking Shorthorn		-249		-223		-373	

Appendix 21 US Payment Systems

Trait	Net Merit $	Net Merit Cheese $	Net Merit Fluid $
Protein	23	28	0
Fat	23	18	23
Milk	0	-12	24
Productive Life	17	13	17
SCS	-9	-7	-9
Udder	6	5	6
Feet/Legs	3	3	3
Body Size	-4	-3	-4
Dtr Preg. Rate	9	7	8
Calving Ability	6	4	6

Appendix 22 Breed Attribute Chart

Breed	Milk Volume	Milk Components	Meat Production	Size	Feet/legs	Udder	Milking Speed	Still Birth	Fertility	Health	World Wide Population	Bulls Sampled per year	Comments
Holstein	+++++	++	++	++++	+++	++++	+++	++	++	++	25,000,000	4,000	
Jersey	++	+++++	+	+	++++	+++	++	+++	+++	++	1,200,000	630	consider size variation
Danish Red	+++	+++	+++	++++	++++	+++	++	+++	+++	+++	43,000		check individual sires for Holstein content. Sufficient genetic distance between "Scandinavian Breeds" for Hybrid Vigour?
Swedish Red	++++	+++	++	+++	+++	++	+++	++++	++++	++++	205,000	100	
Norwegian Red	+++	+++	++++	+++	+++	++	+++	++++	++++	++++	242,000	150	
Ayrshire	++++	+++	++	+++	+++	++	+++	+++	+++	+++	100,000	150	watch individual sires for Holstein content
Brown Swiss	++++	++++	++	+++	+++	+++	+++	++	+++	+++	7,000,000	800	
Friesian	+++	++++	++++	+++	+++	+++	+++	+++	+++	+++			Check individual sires for Holstein. Sufficient genetic distance from Holsteins for Hybrid Vigour?
Montbéliarde	+++	+++	++++	+++	+++	++	+++	++++	+++	+++	330,000	170	
Fleckvieh	+++	++++	++++	+++	+++	++	+++	+++	+++	+++	6,000,000	1200	
Normande	++	+++	+++	++	+++	++					300,000	160	

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