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CROSSBREEDING OF DAIRY CATTLE IN THE TROPICS

Crossbreeding cattle for milk production in the tropics: Achievements, challenges and opportunities

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Abstract

This paper reviews experiences with crossbreeding for milk production in the tropics. Data were compiled from 23 different studies evaluating performance of different grades of crossbred animals as well as local breeds. Relative performance of indigenous breeds compared with different grades of crossbreeds was calculated for 3 climatic zones. Traits considered were milk yield per lactation, age at first calving, services per conception, lifetime milk yield and total number of lactations completed. At 50% *Bos taurus* blood, lactation milk yields were 2.6, 2.4 and 2.2 times higher than those of local cattle in the Highland, Tropical Wet and Dry, and Semi-Arid climatic zones, respectively; lactation lengths increased by 1.2, 1.2 and 1.9 months in the above-mentioned climatic zones, respectively; there was a reduction in calving interval by 0.8 times and in age at first calving by 0.9 times. Similarly, crossbreds with 50% *Bos taurus* genes had 1.8 times higher lifetime milk yields and a 1.2 times higher number of total lactations. Although crossbreeding faces a number of challenges such as better infrastructure, higher demand for health care, there are many advantages of using it. These are higher production per animal, higher income for the families and provision of high-value food. It is therefore likely to continue to be an important livestock improvement tool in the Tropics in the future, where farmers can provide sufficient managment for maintaining animals with higher input requirements and access to the milk market can be secured.

Keywords: Cattle, crossbreeding, milk production, tropics

1. Introduction

Crossbreeding native cattle, often of *Bos indicus* type, with exotic *Bos taurus* cattle is now a widely used method of improving reproduction and production of cattle in the tropics (VanRaden and Sanders, 2003). Although indigenous cattle are well adapted to local production conditions, they are usually late-maturing, have poor growth rates and low milk yields (Syrstad, 1988).

Reports on crossbreeding in the tropics date back to 1875 (Gaur *et al.*, 2005), when Shorthorn bulls were crossed to native cows in India. Other reports (Buvanendran and Mahadevan, 1975) indicate that livestock improvement in the tropics using this method began more than 300 years ago when exotic cattle were introduced into what is today Sri Lanka. Results on the performance of such crosses in well-designed experiments have, however, only been available since 1930 and a great number of reports have been published since then. It has now become clear from studies carried out by Amble and Jain (1967); Mason (1974); Katpatal (1977); Kimenye (1978); Rege (1998); Demeke *et al.* (2004a) and Gaur *et al*. (2005) that where cattle management is good, the performance of crossbreds increases with the number of *Bos taurus* genes, and that the breeds that have 50% or 75% of these genes perform better than all other levels of exotic inheritance. Animals with these levels of *Bos taurus* blood calve earlier than the indigenous stock, produce more milk, and have longer lactations and shorter calving intervals. Crossbreeding is therefore a very attractive short-term livestock improvement tool, since improvements can be made in a population within a single generation. However, despite the impressive results and high demand for milk in the tropics, well-organized and successful crossbreeding programs remain few (McDowell *et al.*, 1996). For example, in India only 12% of its 187 million head of cattle are crossbreds (Ahlawat and Singh, 2005); similarly, in Bangladesh crossbred cattle account for only 2% of all milking cows (Miazi *et al.*, 2007). Reasons for this include: 1) lack of strategies and

policies to take advantages of crosses in most parts of the tropics (Rege, 1998); 2) gaps in knowledge as to what the appropriate levels of exotic inheritance should be for a particular production system (Kahi, 2002); 3) lack of in-depth analysis of the socio-economic and cultural values of livestock in the different production systems or production environments, which leads to wrong breeding objectives (Chagunda, 2002) and 4) small herd sizes that do not allow maintaining sufficiently large breeding stock for crossbreeding and often unknown exotic blood level.

This paper reviews the achievements that have been made in crossbreeding for milk production in the different climatic zones in the tropics, and discusses the challenges and opportunities for its use in the future.

2. Crossbreeding: the genetic background and types of crossbreeding

2.1 Genetic background

The genetic basis of crossbreeding can be broadly divided into two components: additive and non-additive. The additive component is due to the average effect of the strains involved (breeds or parental lines), weighted according to the level of each parental breed in the crossbred genotype. The non-additive component of crossbreeding is heterosis (Swan and Kinghorn, 1992). Heterosis is defined as the difference between the increase in crossbreeds' performance from the additive component based on the mean performance of the purebred parental lines. The levels of heterosis are presented as percentage values and can be used to calculate the expected performance of crossbred individuals (Bourdon, 2000). Heterosis is caused by dominance (interactions within loci) and epistasis (interactions between loci) effects of genes. The positive effects of dominance are the result of increased levels of heterozygosity, which allow an individual to react to environmental challenges in different ways (Swan and Kinghorn, 1992). Epistasis interactions can have a negative effect due to a breakdown of favourable

interactions between loci in purebred animals, which prior to crossbreeding developed by both natural and artificial selection within breeds (Roso *et al*., 2005). These effects have been observed in crossbreeding studies for milk production in the tropics. Syrstad (1989) reviews results obtained from F1 and F2 *Bos indicus* and *Bos taurus* crosses for milk production. In his article, a deterioration in performance due to the breakdown of epistatic gene effects was found to occur between the F1 and F2 for all traits studied (age at first calving, calving interval, milk yields and lactation lengths).

2.2 Types of crossbreeding

Crossbreeding can be grouped into three types. They are: grading up, rotational crossing or criss-crossing, and formation of synthetic or composite populations (Cunningham and Syrstad, 1987).

2.2.1 Grading up

This is a common crossbreeding strategy employed in most parts of the tropics. Usually an indigenous female animal is mated with an exotic male. The first cross generation (F1) performs very well in productive and reproductive traits: it has higher milk yields, shorter calving intervals and the animals calve at a younger age than the indigenous stock. Further upgrading, however, usually leads to mixed results (McDowell, 1985; Rege, 1998). These results are due a reduction in heterozygosity as the generations proceed (Cunningham and Syrstad, 1987). Although the average performance of the F1 usually exceeds that of the indigenous breeds in milk yields, performance of the crossbreds can be variable. This could be due to the large variation in the environmental conditions that exist in the tropics, and a result of the two genotypes involved (Cunningham, 1981; McDowell, 1985; Dhara *et al*., 2006).

2.2.2 Rotational crossing

Rotational crossing is used or widely advocated in different parts of the tropics as a strategy to maintain high levels of heterozygosity, and at same time achieve specific proportions of the domestic and exotic strains (Cunningham, 1981; Gregory and Trail, 1981). Madalena (1981) describes four forms of this method. In the first, two bulls (one exotic, one indigenous) are used in alternate generations; the exotic bull is bred to the indigenous cow, then the indigenous bull is bred to the resulting crossbred cows, and so on. Within a few generations, the system stabilizes at two types of grades (2/3 and 1/3), which co-exist on one farm at the same time. The second form also involves two breeds: one exotic and one indigenous bull. In this system, the indigenous bulls are only mated to cows with more than 75% exotic blood. This leads to a herd that is composed of three co-existing grades (3/7, 5/7 and 6/7). In other words, the exotic bull is used on two generations and followed by an indigenous bull for one generation. The third form is similar to the first one, but instead of an indigenous bull, a crossbred bull is used. In the fourth form, three breeds are used: two exotic bulls and one indigenous bull. In the first stage, the exotic breed is mated with the indigenous breed to produce the F1 population. This new breed is mated to the second exotic breed to produce offspring with 75% exotic genes. To complete the cycle, these are mated to the local breed to produce offspring with 37.5% exotic genes.

Rotational crossbreeding also has some limitations. First, in the two-breed rotational system the genes contributed by the two breeds fluctuate between 1/3 and 2/3 between generations. This makes it difficult to harmonize adaptability and performance characteristics to appropriately match the management level or the prevailing natural environment. Second, regular crossbreeding as described in the previous section is expensive to maintain.

2.2.3 Synthetic breeds

Synthetic breeds are made up of two or more component breeds, and are designed to benefit from hybrid vigour without crossing with other breeds (Bourdon, 2000). Synthetic breeds can be formed in many ways. Cunningham and Syrstad (1987) describe two methods: The simplest form involves two parental breeds which are crossed to produce the F1 generation. Selected F1 individuals are then *inter se* mated to produce the F2 generation. This process is repeated in subsequent generations. Figure 1 shows a summary of the crossbreeding program that is followed in the development of the Australian Milking Zebu (AMZ), a Sahiwal:Jersey synthetic**.** There are also other methods of forming synthetic breeds. A program using three breeds, for instance, could produce a synthetic with 25% local genes (*Bos indicus*), 25% from one of the *Bos taurus* breeds and 50% *Bos taurus* genes from a second exotic animal.

3 Materials and Methods

The relative performance of different grades of crosses with the indigenous genotypes from different climatic zones (CZs) in the tropics was compared. The data used in the study were obtained from published records for different parts of the tropics, and grouped into CZs according to the classification used by World Book (2009). Data were compiled from several studies on crossbreeding for dairy production in the tropics (the complete data set is provided in Supplementary Tables 1, 2 and 3). From these, a subset of studies was extracted that evaluated the performance of different grades of crossbreeds in comparison with local breeds (*Bos indicus*). Reports that did not have local breeds in their design were excluded. At the end of the process, 23 studies were obtained, as can be seen in Table 1. Data were further clustered into three production environment groups according to whether the study was conducted on stations or on farms, and according to the climatic zone in which the study was undertaken. Studies undertaken on large

commercial farms are marked on-farm 1, and studies conducted on small-scale farms on-farm 2. The final data set comprised data obtained from three CZs: Highlands (H), Tropical Wet and Dry (TWD), and Semi-Arid (SA). Due to the small differences between the Tropical Wet and Dry climatic zones, and because of the small amount of data obtained from the Tropical Wet zone, the data from these two zones were merged into one Tropical Wet and Dry zone. Traits compared in the study were milk yield per lactation (MYL), lactation length (LL), calving interval (CI), age at first calving (AFC), services per conception (SPC), lifetime milk yield (LMY) and total number of lactations completed (TLC). Some of the studies used did not evaluate all these traits; in that case only the traits reported were considered. Relative performance of the different grade crosses was compared with that of local breeds by dividing the least squares mean (LSM) of a given trait in the different cattle grades by the LSM of the same trait in the local breeds. Finally, means and standard deviations of the relative performance ratios for the different grade crosses for a given CZ were computed. The ratios obtained for every study under analysis are given in Supplementary Tables 4 and 5.

Most available crossbreeding studies are based on single lactation records, and therefore do not account for lifetime productivity of cows, which is an important measure of overall profitability of dairy cattle (Matharu and Gill, 1981). For the purpose of this paper, reports on lifetime milk production (LMY) and lactations completed (LC) were compiled (Supplementary Table 4) for indigenous cattle and the different grades of crosses. Unlike for the other traits, results from the different CZs were analysed together due to the low number of available studies.

4 Results

4.1 Grading up

In all CZs, crossbreds had higher milk yields, increased lactation length, shorter calving intervals and lower age at first calving compared with the local breeds (Tables 2 and 3). In the Highland CZ, it was observed that the mean MYL for cows with 50% *Bos taurus* genes was 2.6 times higher than that of the indigenous cows. Cows at the next level of exotic inheritance with 75% *Bos taurus* genes showed a similar performance, with a MYL 2.7 times higher than that of local cows. In the Tropical Wet and Dry CZ, increasing the percentage of *Bos taurus* genes beyond 75% resulted in lower milk yields than that observed in the 50% crosses. The F2 in this CZ performed significantly lower than the F1. In the Semi-Arid region, MYL increased by 2.2 times at the 50% *Bos taurus* level. In all CZs, all crossbreds with the exception of the 25% cross in the Tropical Wet and Dry CZ had longer lactation lengths. The overall range of change for MYL was between 1.1 and 4.5. In the Tropical Wet and Dry CZ, and in the Semi-Arid CZ, the F2 had lower MYL as compared with the 50%.. With the exception of the Semi-Arid CZ, where lactation length increased by 1.87, mean LL ranged between 1 and 1.3 times in all the other CZ.

There were also some unexpected results: for example, milk yield per lactation of the F2 in the Highlands zone was higher than that of the F1. This observation is in contrast with findings from other studies (Syrstad, 1989; Rege 1998), and could be due to the small amount of data used, and the fact that no correction was made for the different breed combinations used in the different studies. The widest mean range (1.4 to 4.5) for relative performance was observed in MYL for the F1 and 75% crosses in the Highlands. This could be the result of the large differences in management between farms, or due to the different *Bos taurus* and *Bos indicus* breeds used in the various crossbreeding programs providing the data. For example, in the Highlands of Ethiopia a lactation milk yield of 529 litres was observed for Boran cattle, as compared with the 809 litres obtained from the Arsi breed in the same area (Demeke *et al*., 2004b; Kiwuwa *et al*., 1983). Holstein-Friesian crosses had the highest relative performance for MYL, followed

by Jersey and Ayrshire crosses. Similar effects of *Bos taurus* blood on performance (MYL, AFC) have been reported in other earlier studies. Cunningham and Syrstad (1987) compared production traits in different projects in which two or more *Bos taurus* breeds were used simultaneously. The study included Holstein Friesians, Brown Swiss and Jersey cows. Jersey crosses were the youngest and Brown Swiss crosses the oldest at first calving, both differing significantly from Friesian crosses. Friesian crosses had the highest and Jersey crosses the lowest milk yields, and the differences between them were significant.

Crossbred animals with 50% *Bos taurus* genes had between 1.4 to 2.6 times higher LMY and 1.2 times more LC than the indigenous cattle. An increase in LMY and LC among crossbreds is also reported by Singh (2005), who reviewed lifetime parameters on two and three-breed crosses from different studies conducted on government and research farms in various parts of India involving several local and exotic breeds. Holstein-Friesian crosses of 50% to 62.5% *Bos taurus* genes had higher LMY and more LC than those above these levels of crossing (75% or 87.5%). These results were confirmed by a later study carried out by Goshu (2005), who compared lifetime performance of different grades of crosses of Holstein Friesians with Ethiopian Boran cattle under an intensive grazing system with supplementation at Chefa farm in Ethiopia. The level of crossing significantly affected herd life and LMY. The 50% and 75% *Bos taurus* crossbreeds had significantly higher LMY and longer herd life than animals with higher levels of exotic inheritance (87.5% or 93.7%).

To enable proper overall comparison of the different genotypes, some studies on upgrading have focused on economic performance in different production environments. Madalena *et al.* (1990) undertook a study involving 65 commercial co-operative farms in the states of Minas Gerais, São Paulo, Rio de Janeiro and Espírito Santo, and two research centres (Santa Monica and USEPA São Carlos) in Brazil. Six red and white

Holstein-Friesian (HF) x Guzera crosses (25, 50, 62.5, 75 and 87.5 % crosses and pure HF) kept under two types of management systems were compared, one with high and the other with low-level management and inputs. The F1 had a longer herd life, and better productive and reproductive performance than the other groups, and therefore yielded higher profits. The superiority of the F1 over all HF backcrosses was more pronounced at low levels of management.

In a more recent study, Haile *et al*. (2007) conducted an economic comparison of Ethiopian Boran animals and their crosses of 50, 75 and 87.5% Holstein-Friesian inheritance, which were all reared in an intensive, stall-feeding system in the Central Highlands of Ethiopia. The study covers one calendar year (2003) and collected its data from cattle kept on the Debre Zeit Research Station in Ethiopia. Returns per day and per cow were calculated from dung and milk production. Results showed that the cost of producing one litre of milk was significantly higher for the Ethiopian Borans than for the crosses. The 87.5% crosses returned a significantly higher profit per day per cow and profit per year per cow than the 50% crosses. The crosses of 75%, however, did not yield a significantly higher profit per day per cow and profit per year per cow than the 50% or 87.5% crosses. It was concluded that intensive dairy production with indigenous tropical breeds is not economically viable.

Variations in economic performance between crosses of different breeds have also been observed. Hemalatha *et al.* (2003) compiled reports in which Friesian crosses, Jersey crosses and local cattle kept in different parts of India were compared. These reports showed that the crossbreds produced higher profits per kilogram of milk produced than the indigenous zebu animals. It was also observed, however, that maintenance costs were highest for Friesian crosses, followed by Jersey crosses, and lowest for local cattle. The economic impact of crossbred cows in smallholder farming systems has been demonstrated in a number of studies. Some of these studies (Patil and Udo, 1997;

Bhowmik *et al*., 2006; Policy Note, 2007) reported that in areas where crossbred animals can be maintained, farmers incorporating them into their production systems had higher household incomes than those with pure indigenous breeds.

4.2 Rotational crossbreeding

One well-documented rotational crossbreeding program is the one conducted at Kilifi Plantations in the humid lowlands of Kenya. The rotational crossbreeding program on this farm dates back as far as 1939. Gregory and Trail (1981) analyzed data from two groups of cattle produced on this farm in a two-breed continuous rotational crossbreeding system. Group 1 was comprised of 67% Sahiwal and 33% Ayrshire genes, while group 2 consisted of 67% Ayrshire and 33% Sahiwal genes. The records analyzed were collected between 1972 and 1978. With regard to milk production, group 2 (463 observations) performed significantly better than group 1 in the following traits: age at first calving (1,019 vs 1,042 days), lactation milk yield (2,843 vs 2,662kg) and annual lactation yield (2,616 vs 2,503kg), but had significantly longer calving intervals (398 vs 390 days) than group 1. In a follow-up study, Thorpe *et al.* (1994) analyzed lifetime performance of the two groups and of the cross between them (interbreeds). LMY was 48% higher for group 2 (67% Ayrshire and 33% Sahiwal genes group) than for group 1. The interbreeds yielded 34% less than the average rotational cross (groups 1 and 2). This decline is thought to be due to recombination loss, which results from the breakdown of favourable epistatic interactions between genes in different loci.

Later, two more breeds (Brown Swiss and Holstein Friesians) were introduced into the breeding program. Mackinnon *et al*. (1996) analyzed data from a three-breed rotation program comprised of Brown Swiss, Ayrshire and Sahiwal cattle in various combinations. The data contained 8,447 observations. Lactation milk yield (MYL) for the herd was 3,268kg, and the LL and CI were 322 days and 398 days, respectively. The improvement

in performance of the three-breed crosses as compared with the two-breed crosses was attributed to the large amount of heterosis from crossing Sahiwal and the two *Bos taurus* genomes. In a more recent study (Kahi *et al*., 2000), performance of the herd was analyzed after the introduction of Holstein Friesians. The data set contained 25 crossbreed combinations of Holstein Friesian, Ayrshire, Brown Swiss and Sahiwal cattle. Overall herd MYL, CI and LL were 3,446kg, 402 days and 326 days, respectively. Crosses with 50% Holstein Friesian genes had significantly higher MYL, longer LL and shorter CI than those with 50% Brown Swiss genes. It was concluded that, since farm management had not changed, the improvement in MYL for the herd relative to the earlier study (Mackinnon *et al*., 1996) was due to the introduction of the Holstein Friesians.

4.3 Formation of synthetic populations

Several attempts have been made to form synthetic groups; Hayman (1974); Katyega (1987); Gaur *et al*. (2005); Singh (2005); Cerutti *et al.* (2006) give accounts of 13 synthetic breeds at varying levels of development from different parts of the tropics. McDowell (1985) compared data of five of these groups and found that performance of each group was superior to that of the native breeds. Table 5 shows a summary of some of the traits that were compared. For comparison, performance of the native breeds used is indicated in the same table. It should be noted that the figures given for the native breeds were selected from a few studies only to enable quick comparison. Performances of the same native breeds observed in different studies are summarized in supplementary Table 1.

The Australian Friesian Sahiwal (AFS) is one of the successful synthetic breeds: the 50:50 Sahiwal:Friesian is a well-documented synthetic developed by the government of

Queensland, Australia, from 1960 until 1994, when the program was sold to a private company. The program is now under the management of the AFS Association of Australia, which continues breed development, genetic management and progeny testing for AFS Bulls (Meat and Livestock Australia, 2006). The AFS was bred for milk letdown, tick resistance and milk yield. Under extensive grazing on tropical pastures, the AFS averaged 2,556 litres of milk and 105kg of fat, which compares favourably with the Holstein-Friesian performance of 2,291 litres of milk and 82kg of fat (Alexander, 1986). Another equally successful synthetic is the Girolando, a 62.5:37.5 Holstein-Friesian:Gir synthetic developed in Brazil. The Girolando produces 80% of the milk in Brazil and is characterised by an average of 3,600kg of milk with 4% fat content, and has a calving interval of 410 days (Girolando – Associação Brasileira Dos Criadores de Girolando, 2005). In some parts of the tropics, where synthetic breeds have been successfully developed and reared by farmers, major increments in overall milk yields have been recorded. For instance, the Sunandini cattle has contributed greatly to the dairy economy of Kerala State in India. It is a synthetic breed developed by crossing nondescript local cows of Kerala State with Jersey, Brown Swiss and Holstein Friesian cows. It is estimated that through the active involvement of farmers in the breeding program, milk production increased from 0.164 million tonnes in 1966 to 19.3 million tonnes in 1993 (Chacko, 2005).

4.4 Breeding strategies of smallholder farmers

A study of Ethiopian smallholder farmers keeping crossbreds has shown that farmers make informed decisions about the blood level they keep on their farm. Above 85% of all respondents (n=62) prefer crossbred cows with an exotic blood level between 50 and 75%. Main reasons for their preference are good level of income, adaptation of animals to environment and acceptable management level. A similar number of farmers (80%)

also prefer their bulls/AI semen between 50 and 75% of exotic blood. But 47% of farmers prefer their bulls/AI semen to have even more than 75% exotic blood. The percentages do not sum up to 100%, because farmers were allowed to give more than one exotic blood level group. They like having a choice of more than one blood levels to be able to use higher grade bulls/AI for mating with local and low grade crossbred cows and lower grade bulls/AI for mating with high grade crossbred cows (Roschinsky et al., 2012). Madalena *et al*. (2012) also report that farmers with smaller herd sizes use bulls from different breeds in an often disorganized way in order to sustain their crossbred herds.

Most farmers (88.7%) would advice other farmers to start with crossbreeding given proper management and accessible markets.

5 Challenges

In spite of the great potential of crossbreeding as a livestock improvement method, it has not led to a wide-spread increase in milk production in the tropics (Bayemi *et al*., 2005). Due to several challenges, crossbreeding has yet to be successfully and sustainably adopted and practised in the region (Rege, 1998; Kumar *et al*., 2003; Miazi *et al*., 2007). These include: (1) limitations of crossbreeding methods; (2) production environment and production system, and (3) intermittent funding of programs and lack of appropriate policies and (4) lack of or limited involvement of farmers in the design of the interventions.

5.1 Limitations of crossbreeding methods

The many impressive results of grading up on record were mostly achieved at research stations and commercial farms, where the level of management and nutrition of stock is good (e.g. Thorpe *et al*., 1994; Katpatal, 1977; Tadesse and Dessie, 2003; Demeke *et al*., 2004a; Tadesse *et al*., 2006). The smallholder sector in the tropics, which constitutes the majority of farmers, is at times unable to raise the levels of management and nutrition

in line with the requirements of the new genotypes (Kahi, 2002). This often leads to low productivity and high mortality among the animals (Chagunda, 2002; Philipsson *et al*., 2006).

Although results from rotational crossbreeding have shown a marked improvement in animal productivity, this improvement method can only be used on large-scale operations, where management is good. The programs associated with it are not practical for small-scale farmers, whose herd sizes may not justify keeping more than one bull. In the two-breed rotation system, there is great variability in genotypic composition from generation to generation, depending on the sire breed used. This is not practical for small-scale operations (Trail and Gregory, 1981; Syrstad, 1989, Madalena *et al.*, 2012). The most widely-reported success, the Kilifi Plantation rotation program (Mackinnon *et al.*, 1996; Kahi *et al.*, 2000), has never been expanded beyond the single ranch program or replicated elsewhere. Thus, this program has had only limited impact as a source of improved genetics to the wider dairy farming community in the hot and humid coastal region of Kenya.

The development of synthetic populations has its drawbacks, too. First, it takes many years to develop a synthetic population, during which the production environment could change. Second, the development can be expensive. For example, the development of the Australian Friesian Sahiwal started in the 1960s and the costs amounted to $30 million Australian dollars. The breeding program was later sold off to a private company, which has continued commercial development since 1994 (Meat and Livestock Australia, 2006; Chambers, 2006). During the development period of the AFS, there were drastic changes in Australia's infrastructure. As a result, milk production systems changed and the synthetic could not compete with breeds like Holstein Friesian or Jersey under the new intensive production systems. It is now estimated that only 250 purebred AFS cattle remain in Australia, but exports of AFS cattle continues to many tropical countries

including Mexico, Brunei, Thailand, India and Malaysia (Chambers, 2006). However, as will be later discussed in Section 6, the innovative combination of emerging assisted reproductive technologies, genomics and dense single nucleotide polymorphism (SNP) marker technologies can significantly speed up the development of synthetics.

5.2 Production environment and production system

Poor infrastructure and market access are major obstacles to the successful implementation of crossbreeding programs, especially in rural areas with lower agricultural potential. In addition, pricing policies for milk in some countries are often poor. Prices paid to the farmers are low and cannot support the purchase of feeds or investment in the necessary infrastructure, all of which are necessary to make the production system economically viable (McDowell, 1985). The failure to recognize the different needs of different production systems has also affected the success rate of crossbreeding programs. In many tropical countries, past, and, in some cases, ongoing crossbreeding programs have often been based on a one-genotype-combination-fits-all premise, with Holstein Friesians being the preferred improver breed even in the hot and humid tropics and under production systems such as stall feeding (zero grazing), where other breeds might be better suited (King *et al.*, 2006). Such genotype-production-system mismatches that ignore the important genotype-by-environment interaction effects, are partly responsible for the largely disappointing and poor performance of crossbred cattle in the tropics and their often insignificant impact (McDowell, 1985; King *et al.*, 2006; Philipsson *et al.*, 2006). The assumption that production systems can easily be changed and adapted to fit the needs of crossbred animals seems in many circumstances wrong. In these cases the genetic improvement of local breeds should be considered a more realistic approach.

The choice of *Bos taurus* breeds and the level of crossing for different production systems should not only be based on the genetic potential for milk yield, but also on farmers' ability to follow adequate husbandry practices as well as on the available healthcare services and markets. In addition, the availability of adequate, good quality feeds and water needs to be taken into account, too. Increasing the genetic potential of the animals alone is not enough, the above factors must be considered as well for the full beneficial heterotic effects to be realized (Ansell, 1985; Chantalakhana, 1998).

5.3 Intermittent funding of programs and lack of appropriate policies

A well-planned crossbreeding program requires adequate funding (Kumar *et al.*, 2003). However, funds in the required amount are not always available, which has caused the interruption of many programs (Shem and Mdoe, 2003; Cardoso and Vercesi Filho, 2006; Shem, 2007). In addition, a lack of supportive national breeding policies and appropriate strategies has contributed greatly to the failure of many programs. Rege (1998) and Chantalakhana (1998) observed that there is hardly a country in the tropics that has developed appropriate policies to take advantage of crossbreeding. This issue is of major concern to both farmers and technical personnel who are constantly seeking answers on how to maintain the appropriate level of crossing or determine which level of crossing is appropriate for a given production environment (Chantalakhana, 1998; Ansell, 1985). The lack of proper guidelines has led to undesirable consequences, especially at smallholder units where indigenous breeds are upgraded to higher exotic grades without following a defined crossbreeding program (Kahi, 2002).

5.4 Participation of farmers

Ownership of farmers of any breeding program, either for improving local breeds or crossbreeding with exotic breeds, is a crucial point for the success for any livestock

improvement intervention. Farmers have to have the right to express their opinion and should be involved in decision making processes. This can ensure that new procedures like data recording can be easily implemented, and that animals that better fit to the management of the individual farmers are bred.

6. Opportunities

Certain advantages exist to assist in addressing the challenges discussed in the previous section. These include: (1) availability of a large base population of indigenous tropical cattle; (2) advancements in assisted reproductive technologies; (3) availability of alternative recording methods, and (4) advances in genomic technology. Well-planned programs using all or a combination of the existing advantages may lead to a large number of productive crossbred animals in the tropics. In this section, the potential and impact of the advantages given above are discussed.

6.1 Availability of large base populations

A considerable number of cattle are found in the tropics. It is estimated that of the 1.4 billion cattle in the world, more than 2/3 are found in the tropics (Wint and Robinson, 2007). Most of these are indigenous cattle and belong to the zebu type. The zebu can be classified into a number of sub-groups according to external traits, such as size, origin or utility. It has been proposed that improvement in tropical cattle should be made by selective breeding within the *Bos indicus* race. This has however been shown to be a slow way to meet the fast growing need for production (Ansell, 1985). The large number of existing animals with unique qualities provide an opportunity to make rapid improvements over a short period, if breeding programs that crossbreed large numbers of animals with *Bos taurus* milk breeds can be successfully implemented.

6.2 Assisted reproductive technologies

Recent developments in assisted reproductive technologies provide an opportunity for rapid multiplication of crossbred populations. Assisted reproductive technologies (ART) are defined as techniques that manipulate reproductive-related events and/or structures to achieve pregnancy with the final goal of producing healthy offspring in bovine females (Velazquez, 2008). ART began with the development of artificial insemination (AI) about 50 years ago. Widespread use of AI has been greatly enhanced by the possibility to freeze semen. In well-structured crossbreeding programs in the tropics, AI has the potential of increasing the rate at which genetic change happens in the local population by increasing the reproductive rates of the bulls (Cunnigham, 1999). Through AI it has been possible to transfer exotic genes to the tropics through imported semen. In some parts of the tropics, the persistent use of AI has yielded impressive results. In India, a well-planned crossbreeding program resulted in the formation of the Sunandini synthetic breed. By 1993, Sunandini cattle had contributed greatly to the increase in milk production in Kerala State, India (Chacko, 2005).

A successful example for the use of AI for crossbreeding in the tropics is the dairy husbandry program of the non-governmental organisation (NGO) BAIF Development Research Foundation in India. Established in the 1970s in Maharashtra, India, with support from various international development agencies and the government of India, BAIF has built up a successful AI program. BAIF's program has served over 4.4 million families by establishing over 3500 cattle development centers across most states of India. The centers provide doorstep AI services to farmers accompanied by training and support concerning all aspects of dairy cattle farming (BAIF 2011b). Farmers buy high quality semen collected at BAIFs own bull station which houses 300 bulls of various exotic and indigenous breeds (BAIF, 2011a). The joint efforts of an NGO, the

government of India, private sponsors and farmers benefitting from and recognizing the value of this ART have led to a successful, sustainable crossbreeding program.

Following the success of AI, other methods of recovering, storing and implanting embryos, for instance Multiple Ovulation and Embryo Transfer (MOET), were developed. This opened up new possibilities for genetic improvement. It has been shown in some studies (e.g. Mapletoft and Hasler, 2005) that well-organized MOET programs can result in increased selection intensity and reduced generation intervals, which eventually lead to higher genetic gains. It is for example estimated that if nucleus herds are established and heifers subjected to juvenile MOET (before first breeding), genetic gains twice those obtained through traditional progeny testing programs can be achieved. Since the middle of the 1990s, another important technique has been developed: ovum pick-up followed by *in vitro* embryo production (OPU-IVP). In this method, oocytes are harvested from females and fertilized *in vitro* (Van der Werf and Marshal, 2003; Cunningham, 1999). Through OPU-IVP, reproductive rates in females can be increased. For example, if two OPU-IVP sessions are carried out per week, up to 150 embryos and 70 calves per donor can be produced every year. There are two benefits for crossbreeding programs: The number of females required in the program is significantly reduced, and it is possible to multiply the number of animals with the required qualities rapidly (Cunningham, 1999). If sexed semen is used for *in vitro* fertilization, the sex of the offspring can be predetermined. This opens up additional opportunities for repeatedly and rapidly producing crossbreds of specific breed combinations and preferred sex (Wheeler *et al*., 2006). It has also been proposed (Rutledge, 2001) that OPU-IVP be used widely as a method for continuous production of F1s by using oocysts from spent dairy cows and semen from adapted breeds. In this method, lactation in F1 cows can be initiated by transfer of F1 *invitro* produced embryos. This strategy eliminates the loss of the heterosis effect and increases the phenotypic variation that results when F1 cattle are bred to

either a purebred or crossbred sire (Hansen, 2006). Wide-scale use of the technologies mentioned above (MOET, OPU-IVP and AI) is, however, not possible in the tropics at the moment due to the high costs involved, the poor infrastructure in many countries and the shortage of technical personnel (Kahi *et al*., 2000). Madalena *et al. (2012)* report that there is one large cooperative in Brazil that offers to members F1 heifers pregnant with F1 or other female embryos.

6.3 Alternative recording methods

It has been pointed out (Cunningham, 1981) that any crossbreeding program adopted for a population requires at some point in the program an indigenous selection operation. A serious constraint on this is that performance records are not readily available in the tropics. The sort of extensive milk recording programs which support dairy breeding in the temperate regions are virtually non-existent in the tropics (Syrstad and Ruane, 1998; Kahi *et al.*, 2000; Kosgey *et al*., 2005). The reasons for this have been outlined by different authors (Ansell 1985; Islam *et al.*, 2002; Singh 2005) and include: small herd sizes, scattered herds, poor communication, low level of farmer education, lack of incentives for farmers to record data, poor facilities for collecting and processing data and great diversity in feeding and management regimes. Mason and Buvanendran (1982) argue that recording systems in the tropics do not have to be as elaborate as in the temperate regions. They propose the following approaches, which are simpler, cheaper and easier to adopt for the farmers, but would still allow progeny testing to be done: (1) bi-monthly recording: In this system, the recorder visits the farm every alternate month and records the milk yield obtained during a 24-hour period; (2) AM-PM sampling: In this method, the morning milk is weighed one month, and the evening milk the next month. It maintains monthly visits but is cheaper; (3) sampling at particular stages of

lactation: Sampling during early, mid or late lactation. This system is difficult to adopt for herds calving all year, since the cows will always be at different stages of lactation.

Another approach that could be employed to reduce sampling costs is to contract selected herds in a given region to produce the desired crossbreeds. In this approach, detailed recording would only take place for the contracted herds. Farmers could be familiarized with these recording systems through community-based organizations for general improvement of livestock (CBOGIL), which have been established by several groups of farmers. Kahi *et al.* (2000) define CBOGIL as organizations owned by farmers in a community with the objective of improving livestock production through use of animal genetic resources. Other authors (Sölkner et al., 1998, Wurzinger et al., 2008) refer to this livestock improvement approach as village breeding programs. CBOGIL ensure effective participation of the local communities and other stakeholders, which can lead to the establishment of successful recording systems and breeding programs, either for pure or crossbreeding programs (Kahi et al., 2000).

6.4 Genomic technology: current and future opportunities

Recent development in molecular genetics and the powerful new tool genomic selection are profoundly changing dairy cattle breeding in developed countries. Genomic selection refers to selection decisions based on genomic estimated breeding values (GEBV) or genomic breeding values (Hayes *et al.*, 2009). GEBV are the sum of the effects of dense genetic markers or the haplotypes of these markers across the genome (Hayes *et al*., 2009). Genomic selection is now becoming feasible because of the availability of large numbers of single nucleotide polymorphism (SNP) markers. In the case of crossbreeding, purebreds can be selected for performance of crossbreds by estimating the effects of SNPs on crossbred performance using phenotypes and SNP genotypes evaluated on crossbreds, and applying the results estimates to SNP genotypes obtained

on pure breeds (Dekkers, 2007). This is a major achievement because *Bos taurus* breeds used in most crossbreeding programs in the tropics are selected in the temperate regions under different management conditions. Due to genetic differences between purebreds and crossbreds, and the environmental differences between the two production systems, the performance of purebred parents is not a good predictor for that of their crossbred descendants. This development now makes it possible to identify purebreed parents whose descendants will perform best as crossbreds. Other benefits of genomic selection for crossbreeding include: (1) it does not require pedigree information on crossbreds; (2) once estimates of the SNP effects have been made, the genotype and phenotypic data can be used for several generations, and (3) it reduces the rate of inbreeding (Ibáñez-Escriche *et al.*, 2009).

The availability of large numbers of SNP makers has other benefits as well. It is, for example, possible to use certain techniques to accurately determine the breed composition of crossbred animals without prior pedigree information. This is important because recording systems in the tropics are rare, and as a result many crossbred populations exist whose breed compositions are unknown. Determining the breed composition of an animal enables inclusion of animals of unknown genotypes into breeding programs and allows farmers to find out the accurate breed composition of the animals they wish to buy or sell.

The use of genomic technology in combination with ART opens up new possibilities of speeding up the formation of synthetic breed populations by taking advantage of reduced generation intervals and thereby multiplying the animals of the required breed combination (e.g. synthetic breeds) faster than is currently possible. The costs of these new technologies must, however, come down before they can be used on a wide scale.

7 General discussion

Results from over 60 years of research confirm that crossbreeding is the fastest way to improve milk production, but not necessarily to long-lasting genetic improvement of livestock, with the excpetion of the formation of synthetic breeds.. However, results obtained at the various research centres have not been widely transferred to the farming community. This review has provided some reasons for this failure and proposed solutions for overcoming the still widespread problems. Results from a study point to the fact that the milk production performance of the F1 could be close to being the optimum, but other factors like reproductive performance also need to be considered to give recommendations on the right combination of exotic inheritance for a particular production system. Maintaining the suitable breed inheritance through grading up and rotational breeding still remains a challenge. Implementing the proposal of continuous production of F1s (Rutledge, 2001) as described in Section 6.2. can only be guaranteed if technical and financial issues limiting the use of ART are addressed. Another way to acquire animals of the required breed combination could be through special contracts with rotational breeders who supply smallholder farmers at an agreed price. The impact of such a move, however, would be limited, since there are only a few large-scale rotational breeders in the tropics. What is more, this approach cannot guard against genetic variation when offspring are mated to animals of different breed composition. It appears, therefore, that maintaining the suitable breed combination from generation to generation will be best achieved through developing synthetic breeds for the different production environments. This approach ensures the creation of a self-replacing population. It also ensures that the farmers deal with one kind of animal, which makes management easier, especially in harsh production environments. The combination of ART with advanced molecular genetics plus the availability of simple recording schemes provide great opportunities for developing and multiplying synthetic breeds at a much faster rate than in previously conducted breeding programs. Success of this kind of

program requires farmer involvement already at the development stage and long-term financial commitment of governments and funding bodies in the tropics. Innovative ways should be found to help deal with the high costs associated with ART and the use of genomic technology. The newly developed methods could, for example, initially be targeted at farmers that have established a community-based breeding program in which recording and breeding information is shared. This approach also enables efficient use of technical personnel and equipment, since it is available in a single place.

More, and more exhaustive studies on the various merits of indigenous tropical genotypes still need to be undertaken. The findings of these studies will help determine which combinations of exotic and indigenous breeds to use, and the level of exotic blood to maintain in the new genotypes. The conservation of indigenous breeds should not only not be ignored but become part of national breeding programs, since this group of animals possesses qualities that make them a valuable resource for present and future generations.

8 Conclusion

Crossbreeding remains an attractive option for livestock improvement in the tropics because of the quick results that can be obtained by its use and the potential benefits it has for farmers. Nevertheless careful assessment should be made on whether or not appropriate intervention strategies need to be put in place for each individual case. The required infrastructure for improved management and market access have to be secured. In most cases, the F1 crosses perform better than other genotypes, but the continuous production of F1s and animals of required genetic combinations for the different production environment still remains a big challenge. Production and multiplication of synthetic breeds is perhaps a solution to this problem. The success of any strategy followed to improve results obtained from crossbreeding depends greatly on

long-term financial commitment of governments, active involvement of the beneficiary farming communities in the design as well as operationalization of the breeding programs, and on the successful combination of advances in ART and molecular genetics in breeding programs.

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Table 1 Summary of data from 23 different studies used in the analysis

No	*Bos indicus*	*Bos taurus*	Climatic zone	Country	Location	Production environment	Source
1	Boran	Holstein-Friesian	Highlands	Ethiopia	Holeta station	On Station	Demeke et al., 2004a
	Boran	Jersey	Highlands	Ethiopia	Holeta station	On Station	Demeke et al., 2004a
	Boran	Holstein-Friesian	Highlands	Ethiopia	Holeta station	On Station	Demeke et al., 2004b
	Boran	Jersey	Highlands	Ethiopia	Holeta station	On Station	Demeke et al, 2004b
2	Arsi	Holstein-Friesian	Highlands	Ethiopia	Aresela region	On Station	Kiwuwa et al., 1983
	Arsi	Jersey	Highlands	Ethiopia	Aresela region	On Station	Kiwuwa et al., 1983
	Zebu	Holstein-Friesian	Highlands	Ethiopia	Aresela region	On Station	Kiwuwa et al., 1983
3	Barca	Holstein-Friesian	Highlands	Ethiopia	Aresela region	On Station	Tadesse and Dessie., 2003
4	Sahiwal	Ayrshire	Highlands	Kenya	Nanyuki	On-Farm1	Gregory and Trail, 1981
	Sahiwal_S	Ayrshire	Highlands	Kenya	Nanyuki	On-Farm1	Gregory and Trail, 1981
5	Sahiwal	Ayrshire	Highlands	Kenya	Ngong	On Station	Kimenye, 1978
	Sahiwal_S	Ayrshire	Highlands	Kenya	Ngong	On Station	Kimenye,1978
6	White Fulani	Holstein-Friesian	Tropical WD	Nigeria	Vom	On Station	Knudsen and Soheal, 1970
7	White Fulani	Holstein-Friesian	Tropical WD	Nigeria	Vom	On Station	Soheal, 1984
8	White Fulani	Holstein-Friesian	Tropical WD	Nigeria	Vom	On-Farm1	Olutogun et al 2006
9	Sahiwal	Holstein-Friesian	Tropical WD	India	Ambala	On Station	Amble et al., 1967
	Sahiwal	Holstein-Friesian	Tropical WD	India	Meerut	On Station	Amble et al., 1967
10	Sahiwal	Brown Swiss	Semi Arid	India	Karnal OS	On Station	Bala and Nagarcenkar,1981
	Deshi	Holstein-Friesian	Tropical WD	India	Haringhata	On Station	Bala and Nagarcenkar,1981
	Hariana	Holstein-Friesian	Tropical WD	India	Haringhata	On Station	Bala and Nagarcenkar,1981
	Hariana	Brown Swiss	Tropical WD	India	Haringhata	On Station	Bala and Nagarcenkar,1981
11	Deshi	Jersey	Tropical WD	Srilanka	Karagoda -Uyan.	On Station	Buvanendean et al., 1974
12	Sinhala	Holstein-Friesian	Tropical WD	Srilanka	Karagoda -Uyan.	On Station	Wijerante 1970
13	Sindi	Jersey	Tropical WD	Srilanka	Undugoda	On Station	Buvanendran and Mahadevan, 1975
	Sihala	Holstein-Friesian	Tropical WD	Srilanka	Karagoda-Uyangoda	On Station	Buvanendran and Mahadevan, 1975
14	Criollo	Jersey	Tropical WD	Costa Rica	Turrialba	On Station	Alba and Kennedy, 1985
15	Local	Jersey	Tropical WD	India	Chalakudy	On Station	Katpatal, 1977
	Local	Jersey	Tropical WD	India	Vikas Nagar	On Station	Katpatal, 1977
	Local	Jersey	Tropical WD	India	Visakhapatnam	On Station	Katpatal, 1977
16	Local	Holstein-Friesian	Tropical WD	Bangladesh	Comilla	On Farm 2	Miazi et al.,2007
	Local	Jersey	Tropical WD	Bangladesh	Comilla	On farm 2	Miazi et al., 2007
	Local	Holstein-Friesian	Tropical WD	Bangladesh	Khulna	On farm 2	Ashraf et al., 2000
17	Local	Holstein-Friesian	Tropical WD	Bangladesh	Dhaka	On Station	Majid et al 1996
18	Local	Jersey	Tropical WD	Bangladesh	Dhaka	On Station	Majid et al., 1996
	Sahiwal	Holstein-Friesian	Tropical WD	Bangladesh	Dhaka	On station	Majid et al., 1996
	Local	Jersey	Tropical WD	Bangladesh	Dhaka	On Station	Rahman et al., 2007
19	Local	Holstein-Friesian	Tropical WD	Bangladesh	Dhaka	On Station	Rahman et al., 2007
	Local	Holstein-Friesian	Tropical WD	Bangladesh	Barisal/Patuakahli	On Station	Al-Amin and Nahar, 2007
20	Sahiwal	Holstein-Friesian	Semi Arid	Pakistan	Bahadurnagar	On Station	McDowell et al., 1996
21	Sahiwal	Holstein-Friesian		India		On-Farm1	Matharu and Gill, 1981
22	Ratini	Red Dane	Semi Arid	India	Bikaner	On Farm1	Singh, 2005
23	Ongole	Jersey		India	Visakhapatnam	On Farm1	Singh, 2005

abbreviations: Tropical WD = Tropical Wet and Dry

Table 2 Relative performance of breed groups (F1 ¼ exotic; F1½ exotic; F1 ¾ exotic; F2) in two selected production traits in different climatic zones.

	Milk yield per lactation				Lactation length			
Climatic zone	**Breed group**				**Breed group**			
	1/4	**1/2**	**3/4**	**F2**	**1/4**	**1/2**	**3/4**	**F2**
Highlands (n=10)								
Mean	n.a.*	2.6	2.7	3.4	1.2	1.2	1.3	n.a.
S.D.	n.a.	1	1	0.4	0.2	0.2	0.2	n.a.
Range	n.a.	1.4 - 4.5	1.8 - 4.5	3 - 3.6	1 - 1.3	1 - 1.5	1.2 - 1.5	n.a.
Tropical wet & dry (n=27)								
Mean	1.7	2.4	1.8	1.9	1	1.2	1.1	1.1
S.D.	0.4	0.8	0.6	0.6	0.01	0.2	0.1	0.1
Range	1.1 - 2	1.2 - 3.9	1.4 -2.8	1.2 -2.9	1.05 - 1.07	1 - 1.7	0.9 - 1.3	1 - 1.3
Semi arid (n=4)								
Mean	1.4	2.2	1.5	1.4	n.a.	1.9	n.a.	n.a.
S.D.	0.5	0.4	0.5	0.5	n.a.	0.6	n.a.	n.a.
Range	1.1-1.7	1.8 -2.6	n.a.	1.2 -1.5	n.a.	1.2 -2	n.a.	n.a.

*n.a = not available

Table 3 Relative performance of breed groups (F1 ¼ exotic; F1½ exotic; F1 ¾ exotic; F2) in three selected reproduction traits in different climatic zones.

	Calving Interval				Age at first calving			Service/conception	
	Breed group				Breed group			Breed group	
Climate zone	**1/4**	**1/2**	**3/4**	**F2**	**1/2**	**3/4**	**F2**	**1/2**	**F2**
Highlands (n=7)									
Mean	n.a.*	0.9	1	0.9	0.8	0.8	0.9	0.8	0.89
S.D.	n.a.	0.1	0.1	0.01	0.01	0.01	0.01	0.1	0.1
Range	n.a.	0.8 -1	0.9 - 1	0.91 - 0.92	0.8 - 1	0.8 - 0.9	0.92 - 0.93	0.7 - 0.8	0.8 - 0.9
Tropical wet & dry (n=16)									
Mean	n.a.	0.92	1	1	0.8	0.9	0.9	1	n.a.
S.D.	n.a.	0.1	0.2	0.1	0.1	0.1	0.01	0.17	n.a.
Range	n.a.	0.8 - 1	0.8 -1.3	0.9 - 1.1	0.6 - 1	0.8 - 1	0.84 - 0.85	0.8 - 1.2	n.a.
Semi arid (n=4)									
Mean	n.a.	0.9	1.01	1	0.83	0.7	0.8	n.a.	n.a.
S.D.	n.a.	0.01	0.06	n.a.	0.1	0.03	0.02	n.a.	n.a.
Range	n.a.	n.a.	0.9 -1.0	n.a.	0.7 -0.9	0.7-0.8	0.8-0.84	n.a.	n.a.

*n.a = not available

Table 4 Relative performance of F1 with 50% exotic blood level in life time production traits summarized across all studies (n=6) in which these traits have been assessed.

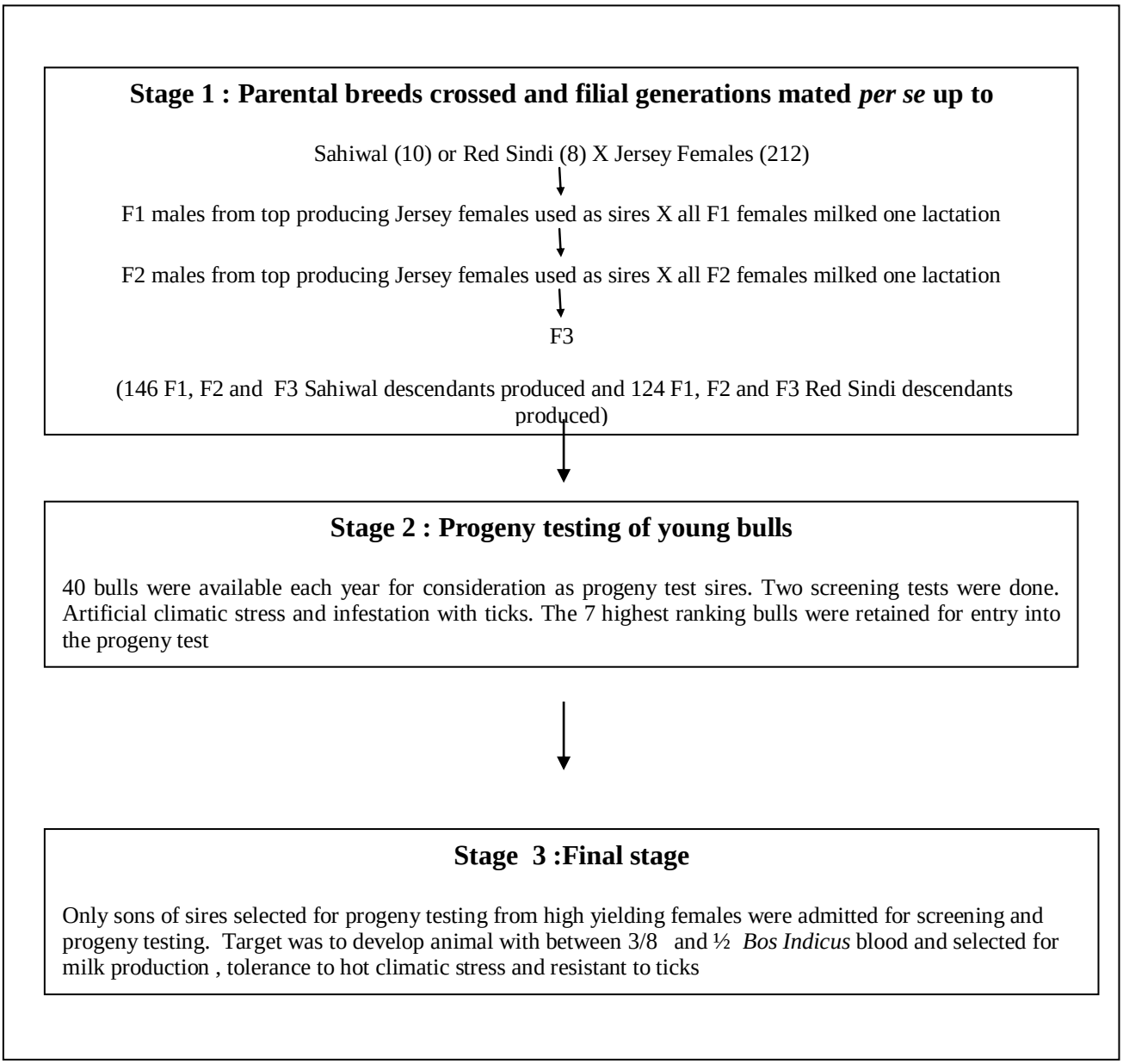
	Life time milk yield (n=6)	Total lactations completed (n=6)
Value	**F1 (50%)**	**F1 (50%)**
Mean	1.8	1.2
SD	0.5	0.03
Range	1.4 - 2.6	1.21-1.26

Table 5 Description of origin and composition of selected synthetic breeds and overview of performance parameters of selected synthetic and indigenous breeds

	Description of synthetic breed				
	Jamaica Hope	**Pitanguei-Ras**	**Australian Milking Zebu**	**Karan -Swiss**	**Sibovey**
Origin	Jamica	Brazil	Australia	India	Cuba
Composition	Jersey x Sahiwal	Red Poll x Zebu	Jersey x Sahiwal/Red Sindi	Brown Swiss x Sahiwal/Red Sindi	Holstein x Zebu
Performance of sythetic breeds					
AFC (months)	34.5	34.7	31	36.3	31.3
MYL (kg)	2930	2780	1987	2519	2897
DIM	282	281	244	324	298
CI (days)	439	414	422	415	405
Performance of the indigenous breeds used in establishment of synthetic breeds above					
	Sahiwal[2]	**Red Sindi**	**Zebu[5]**		
AFC (months)	37.4	40.5[3]			
MYL (kg)	1891	1270[4]	929		
DIM	305		303		
CI (days)	392	535[3]	451		

Source: [1]McDowell (1984), [2]Amble and Jain (1967), [3]Stonaker (1953), [4]Acharya (1970), [5]Kiwuwa et al. (1983)

Figure 1: Summary of the breeding program used to develop the Australian Milking Zebu



Source: Developed from Hayman, 1974

Supplementary Table 1: A summary of the data assembled: Production traits

No.	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	Milk Yield	An. Milk pd	Lact L.	Source
1	Africa	Cameroon	Wakwa station	T. Wet		Holstein Friesian (HF)	HF	2626 (171.8)	2391 (200.6)	247 (18.8)	Tawah et al., 1999
2	Africa	Cameroon	Wakwa station	T. Wet	Gudali (G)	Holstein Friesian (HF)	1/2HF 1/2G	1554 (96.1)	1555 (104.8)	261 (10.5)	Tawah et al., 1999
3	Africa	Cameroon	Wakwa station	T. Wet	Gudali (G)	Holstein Friesian (HF)	3/4HF 1/4G	1041 (229.5)	1266 (239.2)	251 (25.2)	Tawah et al., 1999
4	Africa	Cameroon	Wakwa station	T. Wet	Gudali (G)	Montebeliard(M)	1/2 M 1/2 G	1095 (115.6)	1165 (126.0)	214 (12.7)	Tawah et al., 1999
5	Africa	Cameroon	Wakwa station	T. Wet	Gudali (G)	Montebeliard(M)	3/4 M 1/4G	1226 (238.4)	1447 (237.7)	259 (26.1)	Tawah et al., 1999
6	Africa	Cameroon	Wakwa station	T. Wet	Gudali (G)	Montebeliard(M)	F2	1040 (111.9)	1217 (131.9)	237 (12.2)	Tawah et al., 1999
7	Africa	Ethiopia	Holeta station	Highland	Boran (Br)		Boran	529 (65)	514 (61)	193 (6)	Demeke et al., 2004a /2004b
8	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Holstein Friesian (HF)	1/2HF 1/2Br	2355 (71)	2057 (57)	348 (6)	Demeke et al., 2004a /2004b
9	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Holstein Friesian (HF)	F2	1928 (108)	1740 (94)	308 (9)	Demeke et al., 2004a /2004b
10	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Holstein Friesian (HF)	5/8HF 3/8Br	2187 (203)	2091 (99.5)	351(17)	Demeke et al., 2004a /2004b
11	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Holstein Friesian (HF)	3/4HF 1/4Br	2528 (141)	2093 (88.1)	331(12)	Demeke et al., 2004a /2004b
12	Africa	Ethiopia	Holeta station	Highland		Holstein Friesian (HF)	HF	3319 (55)	2879 (45)	346(4)	Demeke et al., 2004a /2004b
13	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Jersey (J)	1/2J 1/2Br	2092 (75)	1861 (60)	343 (6)	Demeke et al., 2004a /2004b
14	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Jersey (J)	F2	1613 (107)	1480 (94)	304 (9)	Demeke et al., 2004a /2004b
15	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Jersey (J)	3/4J 1/4Br	1956 (133)	1758 (89.5)	337(11)	Demeke et al., 2004a /2004b
16	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	HF / J	1/4F:1/4J:1/2Br	1790 (143)	1752 (98)	325 (13)	Demeke et al., 2004a /2004b
17	Africa	Ethiopia	Arsi region	Highland	Arsi (Ar)		Ar	809 (233)*	689(149)*	272 (233)*	Kiwuwa et al., 1983
18	Africa	Ethiopia	Arsi region	Highland	Zebu (Z)		Z	929 (104)*	770(90)*	303 (104)*	Kiwuwa et al., 1983
19	Africa	Ethiopia	Arsi region	Highland	Arsi (Ar)	Jersey (J)	1/2J 1/2 Ar	1741 (115)*	1534 (91)*	334 (115)	Kiwuwa et al., 1983
20	Africa	Ethiopia	Arsi region	Highland	Arsi (Ar)	Holstein Friesian (HF)	1/2F 1/2Ar	1977 (392)*	1704 (304)*	356 (392)	Kiwuwa et al., 1983
21	Africa	Ethiopia	Arsi region	Highland	Zebu (Z)	Holstein Friesian (HF)	1/2F 1/2Z	2352 (220)*	1913 (185)*	378 (220)	Kiwuwa et al., 1983
22	Africa	Ethiopia	Arsi region	Highland	Arsi (Ar)	Holstein Friesian (HF)	3/4F 1/4Ar	2374 (98)*	2043 (64)*	408 (98)*	Kiwuwa et al., 1983
23	Africa	Ethiopia	Arsi region	Highland	Zebu (Z)	Holstein Friesian (HF)	3/4F 1/4Z	2356 (53)*	1930 (41)*	378 (53)*	Kiwuwa et al., 1983

Abbreviations

( ) = Standard error , **( )*** = number of records observed in the study, **Climatic Z**= Climatic Zone, **An Milk pd**= Annual milk production , **Lact L**.= lactation length **Genetic grp**= genetic group **1/4HF H.Mgt** = 25% Exotic Inheritance on High management production system **1/4HF L.Mgt =** 25% Exotic Inheritance on a low management system **Highland =** Highlands climatic zone, **T. Wet** = Tropical Wet climatic zone, **T.wet /dry** = Tropical wet and dry
Holstein Friesian(A)*= Study in which Ayrshire bulls used initially used but later replaced by Holstein Friesian bulls, ****** = Weighetd means of first and second lactation.

Explanatory notes : Milk yield and An. Milk pd. are in kilograms except where l is indicated for litres. Lact L. is in days

Table 1: Continued

No.	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	Milk Yield	An. Milk pd	Lact L.	Source
24	Africa	Ethiopia	Debre Zeit Centre	Highland	Barca (B)		Barca	672 (196)	674 (224)	279 (24)	Tadesse and Dessie, 2003
25	Africa	Ethiopia	Debre Zeit Centre	Highland	Barca	Holstein Friesian (HF)	1/2F 1/2B	2316 (98)	2042 (106)	326(11)	Tadesse and Dessie, 2003
26	Africa	Ethiopia	Debre Zeit Centre	Highland	Boran (Br)	Holstein Friesian (HF)	1/2Br 1/2F	2088 (118)	1887 (136)	328 (13)	Tadesse and Dessie, 2003
27	Africa	Ethiopia	Debre Zeit Centre	Highland	Barca	Holstein Friesian (HF)	1/4B 3/4F	2373 (105)	1953 (111)	360 (12)	Tadesse and Dessie, 2003
28	Africa	Ethiopia	Debre Zeit Centre	Highland	Boran (Br)	Holstein Friesian (HF)	1/4Br 3/4 F	2336 (96)	1975 (106)	358 (11)	Tadesse and Dessie, 2003
29	Africa	Ethiopia	Debre Zeit Centre	Highland	Barca	Holstein Friesian (HF)	7/8 F 1/8 B	2189 (183)	1558 (239)	351 (22)	Tadesse and Dessie, 2003
30	Africa	Ethiopia	Debre Zeit Centre	Highland	Boran (Br)	Holstein Friesian (HF)	7/8Br 1/8 F	1915 (163)	1501 (173)	341 (20)	Tadesse and Dessie, 2003
31	Africa	Ethiopia	Debre Zeit Centre	Highland		Holstein Friesian (HF)	HF	3183 (111)	2679 (120)	362 (13)	Tadesse and Dessie, 2003
32	Africa	Kenya	Mariakani Centre	S. Arid	Sahiwal(S)	Ayrshire(A)	75%S 25%A	1234 (46)	1251 (51)	274 (6)	Thorpe et al., 1994
33	Africa	Kenya	Mariakani Centre	S. Arid	Sahiwal(S)	Ayrshire(A)	1/2A 1/2S	1537 (50)	1458 (54)	284 (7)	Thorpe et al., 1994
34	Africa	Kenya	Mariakani Centre	S. Arid	Sahiwal(S)	Holstein Friesian (HF)	1/2F 1/2S	1611 (69)	1465 (72)	290 (10)	Thorpe et al., 1994
35	Africa	Kenya	Mariakani Centre	S. Arid	Sahiwal(S)	Ayrshire(A)	75%A 25%S	1638 (51)	1423 (52)	299 (7)	Thorpe et al., 1994
36	Africa	Kenya	Kilifi Plantations	S. Arid	Sahiwal(S)	Ayrshire(A)	2/3S 1/3A	2662 (39)	2503 (32)		Thorpe et al., 1994
37	Africa	Kenya	Kilifi Plantations	S. Arid	Sahiwal(S)	Ayrshire(A)	2/3A 1/3S	2843 (50)	2616 (42)		Thorpe et al., 1994
38	Africa	Kenya	Nanyuki	Highland	Sahiwal(S)	Ayrshire(A)	3/4A 1/4S	1674(138)		197(17)	Trial and Gregory, 1981
39	Africa	Kenya	Nanyuki	Highland	Sahiwal(S)	Ayrshire(A)	1/2A 1/2S	1952 (193)		220(24)	Trial and Gregory, 1981
40	Africa	Kenya	Nanyuki	Highland	Sahiwal(S)	Ayrshire(A)	1/2S 1/2A	1417 (266)		186 (33)	Trial and Gregory, 1981
41	Africa	Kenya	Nanyuki	Highland	Sahiwal(S)	Ayrshire(A)	3/4 S 1/4 A	1464 (141)		191 (18)	Trial and Gregory, 1981
42	Africa	Kenya	Nanyuki	Highland	Sahiwal(S)		Sahiwal	956 (261)		143 (33)	Trial and Gregory, 1981
43	Africa	Kenya	Machakos	S.Arid	Sahiwal(S)			486 (148)		109 (19)	Kimenye ,1978
44	Africa	Kenya	Machakos	S.Arid	Sahiwal(S)	Ayrshire(A)	1/2S1/2A	1276 (184)		224 (24)	Kimenye ,1978
45	Africa	Kenya	Machakos	S.Arid	Sahiwal(S)	Ayrshire(A)	1/2A 1/2S	1163 (276)		263 (36)	Kimenye ,1978
46	Africa	Kenya	Machakos	S.Arid		Ayrshire(A)	Aryshire	1888 (137)		292 (18)	Kimenye ,1978

Table 1: Continued

No.	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	Milk Yield	An. Milk pd	Lact L.	Source
47	Africa	Kenya	Ngong	Highland	Sahiwal(S)			1177(159)		242 (15)	Kimenye ,1978
48	Africa	Kenya	Ngong	Highland	Sahiwal(S)	Ayrshire(A)	3/4S 1/4A	1857 (216)		253 (20)	Kimenye ,1978
49	Africa	Kenya	Ngong	Highland	Sahiwal(S)	Ayrshire(A)	1/2S 1/2A	1710 (126)		250 (12)	Kimenye ,1978
50	Africa	Kenya	Ngong	Highland	Sahiwal(S)	Ayrshire(A)	1/2A 1/2S	1940 (115)		265 (11)	Kimenye ,1978
51	Africa	Kenya	Ngong	Highland	Sahiwal(S)	Ayrshire(A)	3/4A 1/4S	2381 (192)		303(18)	Kimenye ,1978
52	Africa	Kenya	Ngong	Highland		Ayrshire(A)	Aryshire	2185 (112)		280 (10)	Kimenye ,1978
53	Africa	Nigeria	Vom	T.Wet/dry	White Fulani(WF)		WF	772.6 (263.03)		174.19 (49)	Olutogun et al., 2006
54	Africa	Nigeria	Vom	T.Wet/dry	White Fulani(WF)	Holstein Friesian (HF)	1/2HF 1/2WF	4095.3(278.1)		288.97 (34)	Olutogun et al., 2006
55	Africa	Nigeria	Vom	T.Wet/dry		Holstein Friesian (HF)	HF	6588.67(384.5)		284.43 (20)	Olutogun et al., 2006
56	Africa	Nigeria*	Shika	T.wet/dry	White Fulani(WF)	Holstein Friesian (HF)	1/2HF 1/2FU	1684 (287)*		243.7 (289)	Buvanedran et al., 1981
57	Africa	Nigeria	Shika	T.wet/dry	White Fulani(WF)	Holstein Friesian (HF)	3/4HF 1/4 Fu	1850 (143)*		263 (143)	Buvanedran et al., 1981
58	Africa	Nigeria*	Shika	T.wet/dry	White Fulani(WF)	Holstein Friesian (HF)	7/8 HF 1/8 FU	2051 (32)*		286 (33)	Buvanedran et al., 1981
59	Africa	Nigeria	Vom	T.wet/dry	White Fulani(WF)		Fulani	837 (17)			Knudsen and Sohael, 1970
60	Africa	Nigeria	Vom	T.wet/dry	White Fulani(WF)	Holstein Friesian (HF)	1/2HF 1/2 WF	1690 (35)			Knudsen and Sohael, 1970
61	Africa	Nigeria	Vom	T.wet/dry	White Fulani(WF)	Holstein Friesian (HF)	3/4 HF - Bull	1625 (103)			Knudsen and Sohael, 1970
62	Africa	Nigeria	Vom	T.wet/dry	White Fulani(WF)	Holstein Friesian (HF)	3/4HF semen I	2318 (130)			Knudsen and Sohael, 1970
63	Africa	Nigeria*	Vom	T.wet/dry	White Fulani(WF)		W. Fulani	834 (64)*		246(64)*	Sohael, 1984
64	Africa	Nigeria	Vom	T.wet/dry	White Fulani(WF)	Holstein Friesian (HF)	1/2HF 1/2WF	1692 (71)*		271 (71)*	Sohael, 1984
65	Africa	Nigeria	Vom	T.wet/dry		Holstein Friesian (HF)	HF	2538 (44)*		304 (44)*	Sohael, 1984
66	Africa	Nigeria*	Vom	T.wet/dry		Holstein Friesian (HF)	HF	3286 (50)*		282 (50)*	Sohael, 1984
67	Asia	Bangladesh	Comilla	T.wet	Local (L)			2.26/day (0.19)L		235,4 (6.95))	Miazi et al., 2007
68	Asia	Bangladesh	Comilla	T.wet	Local (L)	Sahiwal(S)	1/2S 1/2L	4.9/day (0.95)L		234 (24)	Miazi et al., 2007
69	Asia	Bangladesh	Comilla	T.wet	Local (L)	Holstein Friesian (HF)	HF	6.0/day (1)L		270 (0)	Miazi et al., 2007

Table 1: Continued

No.	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	Milk Yield	An. Milk pd	Lact L.	Source
70	Asia	Bangladesh	Comilla	T.wet	Local (L)	Jersey(J)	J	5.71/day (0.87)L		274 (3.74)	Miazi et al., 2007
71	Asia	Bangladesh	Khulna	T.wet	Local (L)		L	937 (183)		244.6 (10.1)	Ashraf et al., 2000
72	Asia	Bangladesh	Khulna	T.wet	Local (L)	Holstein Friesian (HF)	1/2F 1/2L	1633 (133)		271.4 (9.19)	Ashraf et al., 2000
73	Asia	Bangladesh	Khulna	T.wet	Local (L)	Sahiwal	1/2S 1/2L	1863 (141)		299.38 (9.74)	Ashraf et al., 2000
74	Asia	Bangladesh	Dhaka	T.wet	Local (L)		Local	653 (16.3))			Majid et al., 1996
75	Asia	Bangladesh	Dhaka	T.wet	Local (L)	Holstein Friesian (HF)	1/2HF 1/2L	1,956 (130.5)			Majid et al., 1996
76	Asia	Bangladesh	Dhaka	T.wet	Local (L)	Jersey(J)	1/2J 1/2L	1,743 (138.74)			Majid et al., 1996
77	Asia	Bangladesh	Dhaka	T.wet	Sahiwal(S)	Holstein Friesian (HF)	1/2S 1/2F	1,900 (95.1)			Majid et al., 1996
78	Asia	Bangladesh	Dhaka	T.wet	Sahiwal(S)		S	1,056 (84.69)			Majid et al., 1996
79	Asia	Bangladesh	Dhaka	T.wet	Local	Holstein Friesian (HF)	F2	1,897 (235.4)			Majid et al., 1996
80	Asia	Bangladesh	Dhaka	T.wet	Local	Jersey(J)	F2	1,543 (105.93)			Majid et al., 1996
81	Asia	Bangladesh	Barisal/Patuakahli	T.wet	Local		Local	845 (21.5)L		225.5 (6.1)	Al-Amin and Nahar, 2007
82	Asia	Bangladesh	Barisal/Patuakahli	T.wet	Local	Holstein Friesian (HF)	1/2HF 1/2L	1836.7 (18.2)L		339 (7.4)	Al-Amin and Nahar, 2007
83	Asia	Bangladesh	Dhaka	T.wet	Local		L	700 (39.9)		275.2 (7.9)	Rahman et al., 2007
84	Asia	Bangladesh	Dhaka	T.wet	Local	Holstein Friesian (HF)	1/2F 1/2L	1753.2 (90.31)		357.6 (4.9)	Rahman et al., 2007
85	Asia	Bangladesh	Dhaka	T.wet	Local	Jersey(J)	1/2J	1492.8 (48.3)		330.7 (7.3)	Rahman et al., 2007
86	Asia	India	Dalhousie	Highland		Holstein Friesian (A)*	3/4 HF	2324(107)		297 (8)	Amble and Jain, 1967
87	Asia	India	Dalhousie	Highland		Holstein Friesian (A)*	7/8 HF	2213(108)		303 (9)	Amble and Jain, 1967
88	Asia	India	Dalhousie	Highland		Holstein Friesian (A)*	15/16HF	2158 (131)		272 (14)	Amble and Jain, 1967
89	Asia	India	Kasauli	Highland		Holstein Friesian (A)*	1/2 HF	2771 (365)		355 (33)	Amble and Jain, 1967
90	Asia	India	Kasauli	Highland		Holstein Friesian (A)*	3/4HF	2601 (166)		335 (17)	Amble and Jain, 1967
91	Asia	India	Kasauli	Highland		Holstein Friesian (A)*	7/8HF	2582 (179)		324 (16)	Amble and Jain, 1967
92	Asia	India	Kasauli	Highland		Holstein Friesian (A)*	15/16HF	2199 (201)		287 (20)	Amble and Jain, 1967

Table 1: Continued

No.	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	Milk Yield	An. Milk pd	Lact L.	Source
93	Asia	India	Jullundur	S. Arid		Holstein Friesian (A)*	1/4HF	1770 (295)		325 (21)	Amble and Jain, 1967
94	Asia	India	Jullundur	S. Arid		Holstein Friesian (A)*	3/8HF	2448 (169)		300 (12)	Amble and Jain, 1967
95	Asia	India	Jullundur	S. Arid		Holstein Friesian (A)*	1/2HF	2203 (272)		282 (22)	Amble and Jain, 1967
96	Asia	India	Jullundur	S. Arid		Holstein Friesian (A)*	5/8HF	2762 (303)		295 (27)	Amble and Jain, 1967
97	Asia	India	Jullundur	S. Arid		Holstein Friesian (A)*	3/4HF	2584 (153)		319 (12)	Amble and Jain, 1967
98	Asia	India	Jullundur	S. Arid		Holstein Friesian (A)*	7/8HF	2200 (201)		275 (15)	Amble and Jain, 1967
99	Asia	India	Jullundur	S. Arid		Holstein Friesian (A)*	15/16HF	2308 (197)		299 (15)	Amble and Jain, 1967
100	Asia	India	Ambala	T. Wet	Sahiwal(S)		S	1891 (89)		305 (7)	Amble and Jain, 1967
101	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian (A)*	3/8HF	1766 (174)		255 (16)	Amble and Jain, 1967
102	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian (A)*	1/2HF	2346 (124)		276 (11)	Amble and Jain, 1967
103	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian (A)*	5/8HF	2692 (174)		281 (17)	Amble and Jain, 1967
104	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian (A)*	3/4HF	2194 (76)		285 (7)	Amble and Jain, 1967
105	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian (A)*	7/8HF	2096 (82)		296 (7)	Amble and Jain, 1967
106	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian (A)*	15/16HF	2012 (127)		299 (12)	Amble and Jain, 1967
107	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian (A)*	31/32HF	1832 (192)		263 (18)	Amble and Jain, 1967
108	Asia	India	Meerut	T. Wet	Sahiwal(S)		Sahiwal	1653 (139)		288 (8)	Amble and Jain, 1967
109	Asia	India	Meerut	T. Wet	Sahiwal(S)	Holstein Friesian (A)*	3/8HF	2480 (373)		374 (23)	Amble and Jain, 1967
110	Asia	India	Meerut	T. Wet	Sahiwal(S)	Holstein Friesian (A)*	1/2HF	2342 (373)		308 (23)	Amble and Jain, 1967
111	Asia	India	Meerut	T. Wet	Sahiwal(S)	Holstein Friesian (A)*	3/4HF	2716 (249)		316 (18)	Amble and Jain, 1967
112	Asia	India	Meerut	T. Wet	Sahiwal(S)	Holstein Friesian (A)*	7/8HF	2184 (334)		326 (24)	Amble and Jain, 1967
113	Asia	India	Lucknow	T. Wet		Holstein Friesian (A)*	1/2HF	2484 (302)		332 (17)	Amble and Jain, 1967

Table 1: Continued

No.	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	Milk Yield	An. Milk pd	Lact L.	Source
114	Asia	India	Lucknow	T. Wet		Holstein Friesian (A)*	5/8HF	2286 (166)		296 (12)	Amble and Jain, 1967
115	Asia	India	Lucknow	T. Wet		Holstein Friesian (A)*	3/4HF	2157 (201)		306 (16)	Amble and Jain, 1967
116	Asia	India	Jubbulpore	T. Wet		Holstein Friesian (A)*	1/4HF	1708 (309)		263 (19)	Amble and Jain, 1967
117	Asia	India	Jubbulpore	T. Wet		Holstein Friesian (A)*	3/8HF	2212 (198)		294 (10)	Amble and Jain, 1967
118	Asia	India	Jubbulpore	T. Wet		Holstein Friesian (A)*	1/2HF	2969 (176)		329 (13)	Amble and Jain, 1967
119	Asia	India	Jubbulpore	T. Wet		Holstein Friesian (A)*	5/8HF	2282 (246)		298 (18)	Amble and Jain, 1967
120	Asia	India	Jubbulpore	T. Wet		Holstein Friesian (A)*	3/4HF	2390 (134)		317 (9)	Amble and Jain, 1967
121	Asia	India	Jubbulpore	T. Wet		Holstein Friesian (A)*	7/8HF	2249 (158)		294 (10)	Amble and Jain, 1967
122	Asia	India	Jubbulpore	T. Wet		Holstein Friesian (A)*	15/16HF	2125 (206)		292 (14)	Amble and Jain, 1967
123	Asia	India	Kirkee	T.wet/dry		Holstein Friesian (A)*	1/4HF	1711 (314)		253 (20)	Amble and Jain, 1967
124	Asia	India	Kirkee	T.wet/dry		Holstein Friesian (A)*	3/8HF	1663 (186)		263 (12)	Amble and Jain, 1967
125	Asia	India	Kirkee	T.wet/dry		Holstein Friesian (A)*	1/2HF	2443 (202)		277 (12)	Amble and Jain, 1967
126	Asia	India	Kirkee	T.wet/dry		Holstein Friesian (A)*	5/8HF	2054 (240)		291 (15)	Amble and Jain, 1967
127	Asia	India	Kirkee	T.wet/dry		Holstein Friesian (A)*	3/4HF	2164 (108)		293 (7)	Amble and Jain, 1967
128	Asia	India	Kirkee	T.wet/dry		Holstein Friesian (A)*	7/8HF	2220 (130)		278 (8)	Amble and Jain, 1967
129	Asia	India	Kirkee	T.wet/dry		Holstein Friesian (A)*	15/16HF	1866 (240)		312 (15)	Amble and Jain, 1967
130	Asia	India	Secunderabad	T.wet/dry		Holstein Friesian (A)*	1/2HF	2750 (184)		308 (9)	Amble and Jain, 1967
131	Asia	India	Secunderabad	T.wet/dry		Holstein Friesian (A)*	3/4HF	2406 (133)		288 (8)	Amble and Jain, 1967
132	Asia	India	Secunderabad	T.wet/dry		Holstein Friesian (A)*	7/8HF	2399 (265)		299 910)	Amble and Jain, 1967
133	Asia	India	Karnal	S. Arid	Sahiwal(S)		Sahiwal	1704 (3.6)		285 (0.57)	Taneja and Chawla, 1978
134	Asia	India	Karnal	S. Arid	Sahiwal(S)	Brown Swiss(BS)	1/4BS 3/4S	3039 (304.3)		299 (27.3)	Taneja and Chawla, 1978
135	Asia	India	Karnal	S. Arid	Sahiwal(S)	Brown Swiss(BS)	1/2BS 1/2S	3160 (32)		331 (3.2)	Taneja and Chawla, 1978
136	Asia	India	Karnal	S. Arid	Sahiwal(S)	Brown Swiss(BS)	F2	2579 (74.08)		292 (7.12)	Taneja and Chawla, 1978
137	Asia	India	Karnal	S. Arid	Sahiwal(S)	Brown Swiss(BS)	3/4 BS 1/4S	2670 (78.5)		292 (7.6)	Taneja and Chawla, 1978

Table 1: Continued

No.	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	Milk Yield	An. Milk pd	Lact L.	Source
138	Asia	India	Karnal	S. Arid		Brown Swiss(BS)	BS	2355 (28.4)		401 (4.6)	Taneja and Chawla, 1978
139	Asia	India	Haringhata	T. Wet	Deshi (D)		D	334 (102)		283(17)	Bala and Nagarcenkar, 1981
140	Asia	India	Haringhata	T. Wet	Hariana(H)		H	791 (37)		311(18)	Bala and Nagarcenkar, 1981
141	Asia	India	Haringhata	T. Wet	Deshi (D)	(HF)	1/2F 1/2D	1321(68)		321(11)	Bala and Nagarcenkar, 1981
142	Asia	India	Haringhata	T. Wet	Deshi (D)	Jersey(J)	1/2J 1/2 D	1269(57)		327(9)	Bala and Nagarcenkar, 1981
143	Asia	India	Haringhata	T. Wet	Hariana(H)	Friesian	1/2F 1/2H	1926 (32)		341(5)	Bala and Nagarcenkar, 1981
144	Asia	India	Haringhata	T. Wet	Hariana(H)	B. Swiss(BS)	1/2BS 1/2H	1717 (47)		333(8)	Bala and Nagarcenkar, 1981
145	Asia	India	Haringhata	T. Wet	Hariana(H)	Jersey(J)	1/2J 1/2H	1610 (26)		326(4)	Bala and Nagarcenkar, 1981
146	Asia	India	Haringhata	T. Wet	Hariana(H)	Friesian	F/ H - F2	1293 (74)		334 (12)	Bala and Nagarcenkar, 1981
147	Asia	India	Haringhata	T. Wet	Hariana(H)	Jersey(J)	J/H - F2	1139 (60)		322 (10)	Bala and Nagarcenkar, 1981
148	Asia	India	Haringhata	T. Wet		Friesian	Friesian	2403 (97)		372 (16)	Bala and Nagarcenkar, 1981
149	Asia	India	Haringhata	T. Wet		Jersey(J)	Jersey	2012 (95)		349 (16)	Bala and Nagarcenkar, 1981
150	Asia	India	Chalakudy	T.wet	Local (L)		L	573 (0.24)			Katpatal, 1977
151	Asia	India	Chalakudy	T.wet	Local (L)	Jersey(J)	1/4J 3/4L	1159(23.6)			Katpatal, 1977
152	Asia	India	Chalakudy	T.wet	Local (L)	Jersey(J)	1/2J 1/2L	1411 (1.4)			Katpatal, 1977
153	Asia	India	Chalakudy	T.wet	Local (L)	Jersey(J)	3/4J 1/4L	1426 (5.3)			Katpatal, 1977
154	Asia	India	Chalakudy	T.wet	Local (L)	Jersey(J)	7/8J 1/8L	1796 (84.9)			Katpatal, 1977
155	Asia	India	Chalakudy	T.wet	Local (L)	Jersey(J)	F2	1601 (40.3)			Katpatal, 1977
156	Asia	India	Vikas Nagar	T.wet	Local (L)		L	492 (3.7)			Katpatal, 1977
157	Asia	India	Vikas Nagar	T.wet	Local (L)	Jersey(J)	1/2J 1/2L	1151 (11.9)			Katpatal, 1977
158	Asia	India	Vikas Nagar	T.wet	Local (L)	Jersey(J)	3/4J 1/4L	1102 (62.4)			Katpatal, 1977
159	Asia	India	Visakhapatnam	T.wet	Local (L)		L	699(5.1)			Katpatal, 1977
160	Asia	India	Visakhapatnam	T.wet	Local (L)	Jersey(J)	1/4J 3/4L	1216 (135)			Katpatal, 1977
161	Asia	India	Visakhapatnam	T.wet	Local (L)	Jersey(J)	1/2J 1/2L	1774 (12.9)			Katpatal, 1977
162	Asia	India	Visakhapatnam	T.wet	Local (L)	Jersey(J)	3/4J 1/4L	1999 (55.5)			Katpatal, 1977
163	Asia	Pakistan	Bahadurnagar	S.Arid	Sahiwal(S)		Sahiwal	1474 (1)			McDowell et al., 1996
164	Asia	Pakistan	Bahadurnagar	S.Arid	Sahiwal(S)	Holstein Friesian(HF)	1/4H 3/4S	1651 (20.4)			McDowell et al., 1996
165	Asia	Pakistan	Bahadurnagar	S.Arid	Sahiwal(S)	Holstein Friesian(HF)	1/2H 1/2S	2787 (2.9)			McDowell et al., 1996

Table 1: Continued

No.	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	Milk Yield	An. Milk pd	Lact L.	Source
166	Asia	Pakistan	Bahadurnagar	S.Arid	Sahiwal(S)	Holstein Friesian(HF)	3/4H 1/4S	2239 (13)			McDowell et al., 1996
167	Asia	Pakistan	Bahadurnagar	S.Arid	Sahiwal(S)	Holstein Friesian(HF)	F2	1820 (5.8)			McDowell et al., 1996
168	Asia	Sri Lanka	Karagoda -Uyan.	T. Wet	Sinhala (Sn)		Sn	570 (25)		224 (20)	Buvanendran and Mahadevan, 1975
169	Asia	Sri Lanka	Karagoda -Uyan.	T. Wet	Sinhala (Sn)	Holstein Friesian(HF)	1/2F 1/2S	1573 (29)		327 (6)	Buvanendran and Mahadevan, 1975
170	Asia	Sri Lanka	Karagoda -Uyan.	T. Wet	Sinhala (Sn)	Holstein Friesian(HF)	F2	987 (56)		302 (14)	Buvanendran and Mahadevan, 1975
171	Asia	Sri Lanka	Karagoda -Uyan.	T. Wet	Sinhala (Sn)	Jersey(J)	1/2J 1/2S	1215 (21)		313 (4)	Buvanendran and Mahadevan, 1975
172	Asia	Sri Lanka	Karagoda -Uyan.	T. Wet	Sinhala (Sn)	Jersey(J)	F2	809 (58)		272 (12)	Buvanendran and Mahadevan, 1975
173	Asia	Sri Lanka	Undugoda	T.wet	Sindhi (Si)	Jersey(J)	1/2J 1/2Si	1929		295	Buvanendran and Mahadevan, 1975
174	Asia	Sri Lanka	Undugoda	T. Wet	Sindhi (Si)	Jersey(J)	F2	1115 (22.7)		265 (5.4)	Buvanendran and Mahadevan, 1975
175	Asia	Sri Lanka	Undugoda	T. Wet	Sindhi (Si)	Jersey(J)	5/8J 3/8Si	884		265	Buvanendran and Mahadevan, 1975
176	Asia	Sri Lanka	Undugoda	T. Wet	Sindhi (Si)	Jersey(J)	3/4J 1/4Si	1700		317	Buvanendran and Mahadevan, 1975
177	S.America	Costa Rica	Turrialba	T.wet/dry	Criollo(cr)		Criollo	1202		207	Alba and Kennedy, 1985
178	S.America	Costa Rica	Turrialba	T.wet/dry	Criollo	Jersey(J)	1/4J 3/4Cr	1356		222	Alba and Kennedy, 1985
179	S.America	Costa Rica	Turrialba	T.wet/dry	Criollo	Jersey(J)	1/2J 1/2Cr	1859		286	Alba and Kennedy, 1985
180	S.America	Costa Rica	Turrialba	T.wet/dry	Criollo	Jersey(J)	3/4J 1/4Cr	1765		270	Alba and Kennedy, 1985
181	S.America	Costa Rica	Turrialba	T.wet/dry		Jersey(J)		1883		301	Alba and Kennedy, 1985
182	S.America	Brazil	Valenca	T.Wet		Holstein Friesian(HF)	Holestein				Madalena, 1981
183	S.America	Brazil	Valenca	T.Wet	Gir (Gi)	Holstein Friesian(HF)	1/2 HF 1/2Gi				Madalena, 1981
184	S.America	Brazil	Valenca	T.wet	Gir (Gi)		3/4HF 1/4Gi				Madalena, 1981
185	S.America	Brazil	Various		Guzera(Gu)		Guzera		1582 (47)		Madalena, 1981
186	S.America	Brazil	Various		Guzera(Gu)	Holstein Friesian(HF)	1/4HF 3/4Gu		1992 (44.3)		Madalena, 1981
187	S.America	Brazil	Various		Guzera(Gu)	Holstein Friesian(HF)	1/2H 1/2Gu		2527 (37)		Madalena, 1981

Table 1: Continued

No.	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	Milk Yield	An. Milk pd	Lact L.	Source
188	S.America	Brazil	Various		Guzera(Gu)	Holstein Friesian(HF)	3/4HF 1/4Gu		2435 (21.6)		Madalena, 1981
189	S.America	Brazil	Various		Guzera(Gu)	Holstein Friesian(HF)	7/8HF 1/8Gu		2336 (74.4))		Madalena, 1981
190	S.America	Brazil	Various			Holstein Friesian(HF)	HF		2332 (137)		Madalena, 1981
191	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	1/4HF H.Mgt	1368 (129)**		197 (11)	Madalena et al., 1990
192	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	1/4HF L.Mgt	1176 (108)**		255 (15)	Madalena et al., 1990
193	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	1/2HF H.Mgt	2674 (144)**		281(13)	Madalena et al.,1990
194	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	1/2HF L.Mgt	2569 (93)**		354 (13)	Madalena et al., 1990
195	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	5/8HF H.Mgt	1520 (160)		209 (14)	Madalena et al., 1990
196	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	5/8HF L.Mgt	1409 (120)		276 (17)	Madalena et al., 1990
197	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	3/4HF H.Mgt	2975 (156)		309 (13)	Madalena et al., 1990
198	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	3/4HF L.Mgt	2147 (107)		343 (15)	Madalena et al., 1990
199	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	7/8 HF H.Mgt	2857 (133)		284 (11)	Madalena et al., 1990
200	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	7/8 HF L.Mgt	1714 (118)		302 (17)	Madalena et al., 1990
201	S.America	Brazil	Various	T.wet		Holstein Friesian(HF)	HF H.Mgt	3275 (156)		308 (14)	Madalena et al., 1990
202	S.America	Brazil	Various	T.wet		Holstein Friesian(HF)	HF L.Mgt	1304 (121.2)		263 (11)	Madalena et al., 1990

Supplementary Table 2: A summary of the data assembled: Performance traits

No.	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	CI	DP (days)	Age FC	Spc	Source
1	Africa	Cameroon	Wakwa station	T. Wet		Holstein Friesian(HF)	HF	439(39.6)	130(1.3)			Tawah et al., 1999
2	Africa	Cameroon	Wakwa station	T. Wet	Gudali (G)	Holstein Friesian(HF)	1/2HF 1/2G	384 (20.5)	134(1.1)	39 (1.43)		Tawah et al., 1999
3	Africa	Cameroon	Wakwa station	T. Wet	Gudali (G)	Holstein Friesian(HF)	3/4HF 1/4G	400(42.2)	164(1.3)			Tawah et al., 1999
4	Africa	Cameroon	Wakwa station	T. Wet	Gudali (G)	Montebeliard(M)	1/2 M 1/2 G	387(24.8)	176(1.2)	39.9 (2.16)		Tawah et al., 1999
5	Africa	Cameroon	Wakwa station	T. Wet	Gudali (G)	Montebeliard(M)	3/4 M 1/4G	367(46.9)	108(1.4)			Tawah et al., 1999
6	Africa	Cameroon	Wakwa station	T. Wet	Gudali (G)	Montebeliard(M)	F2	373(25.8)	196(1.1)	45.5 (1.42)		Tawah et al., 1999
7	Africa	Ethiopia	Holeta station	Highland	Boran (Br)		Boran	473 (7)		42.5 (0.5)	1.71 (0.04)	Demeke et al., 2004a /2004b
8	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Holstein Friesian(HF)	1/2HF 1/2Br	417 (6)		36.0 (0.4)	1.49 (0.04)	Demeke et al., 2004a /2004b
9	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Holstein Friesian(HF)	F2	435 (10)		39.6 (0.6)	1.60 (0.06)	Demeke et al., 2004a /2004b
10	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Holstein Friesian(HF)	5/8HF 3/8Br	426 (18)		38.5 (1)	1.41 (0.11)	Demeke et al., 2004a /2004b
11	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Holstein Friesian(HF)	3/4HF 1/4Br	444 (13)		36.7 (0.7)	1.70 (0.09)	Demeke et al., 2004a /2004b
12	Africa	Ethiopia	Holeta station	Highland		Holstein Friesian(HF)	HF	459 (4)		37.3 (0.3)	1.73 (0.03)	Demeke et al., 2004a /2004b
13	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Jersey(J)	1/2J 1/2Br	408 (6)		35.4 (0.5)	1.31 (0.04)	Demeke et al., 2004a /2004b
14	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Jersey(J)	F2	430 (10)		39.2 (0.6)	1.44 (0.06)	Demeke et al., 2004a /2004b
15	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	Jersey(J)	3/4J 1/4Br	426 (11)		37.7 (0.7)	1.46 (0.08)	Demeke et al., 2004a /2004b
16	Africa	Ethiopia	Holeta station	Highland	Boran (Br)	HF / J	1/4F:1/4J:1/2Br	411 (14)		40.2 (0.8)	1.42 (0.09)	Demeke et al., 2004a /2004b
17	Africa	Ethiopia*	Arsi region	Highland	Arsi (Ar)		Ar	439 (202)*	165(152)*	34.4(62)*		Kiwuwa et al., 1983
18	Africa	Ethiopia	Arsi region	Highland	Zebu (Z)		Z	451 (94)*	154(92)*			Kiwuwa et al., 1983
19	Africa	Ethiopia	Arsi region	Highland	Arsi (Ar)	Jersey(J)	1/2J 1/2 Ar	403 (92)*	76(91)*	33.7(39)*		Kiwuwa et al., 1983
20	Africa	Ethiopia	Arsi region	Highland	Arsi (Ar)	Holstein Friesian(HF)	1/2F 1/2Ar	427 (306)*	81(305)*	33.9 (154)*		Kiwuwa et al., 1983
21	Africa	Ethiopia	Arsi region	Highland	Zebu (Z)	Holstein Friesian(HF)	1/2F 1/2Z	458(194)*	83(185)*	34.8 (60)*		Kiwuwa et al., 1983
22	Africa	Ethiopia	Arsi region	Highland	Arsi (Ar)	Holstein Friesian(HF)	3/4F 1/4Ar	464 (64)	70(64)*	33.7(66)*		Kiwuwa et al., 1983
23	Africa	Ethiopia*	Arsi region	Highland	Zebu (Z)	Holstein Friesian(HF)	3/4F 1/4Z	475 (44)*	90 (41)*	33.6(37)*		Kiwuwa et al., 1983

Abbreviations

( ) = Standard error , **( )*** = number of records observed in the study, **Climatic Z**= Climatic Zone, **CI** = calving Interval, **DP**= Dry period , **AgeFC**= age at first calving, **SPC**= services per conception, **Genetic grp**= genetic group **1/4HF H.Mgt** = 25% Exotic Inheritance on High management production system **1/4HF L.Mgt =** 25% Exotic Inheritance on a low management system **Highland =** Highlands climatic zone, **T. Wet** = Tropical Wet climatic zone, **T.wet /dry** = Tropical wet and dry **Holstein Friesian(A)*=** Study in which Ayrshire bulls used initially used but later replaced by Holstein Friesian bulls

Notes: CI is given in days except where M is indicated for months. **Age FC** is given in months except where D is indicated for days

Table 2: Continued

No.	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	CI	DP	Age FC	Spc	Source
24	Africa	Ethiopia	Debre Zeit Centre	Highland	Barca (B)		Barca	401 (24)				Tadesse and Dessie, 2003
25	Africa	Ethiopia	Debre Zeit Centre	Highland	Barca	Holstein Friesian(HF)	1/2F 1/2B	400 (14)				Tadesse and Dessie, 2003
26	Africa	Ethiopia	Debre Zeit Centre	Highland	Boran (Br)	Holstein Friesian(HF)	1/2Br 1/2F	426 (19)				Tadesse and Dessie, 2003
27	Africa	Ethiopia	Debre Zeit Centre	Highland	Barca	Holstein Friesian(HF)	1/4B 3/4F	448 (16)				Tadesse and Dessie, 2003
28	Africa	Ethiopia	Debre Zeit Centre	Highland	Boran (Br)	Holstein Friesian(HF)	1/4Br 3/4 F	436 (15)				Tadesse and Dessie, 2003
29	Africa	Ethiopia	Debre Zeit Centre	Highland	Barca	Holstein Friesian(HF)	7/8 F 1/8 B	498 (30)				Tadesse and Dessie, 2003
30	Africa	Ethiopia	Debre Zeit Centre	Highland	Boran (Br)	Holstein Friesian(HF)	7/8Br 1/8 F	464 (24)				Tadesse and Dessie, 2003
31	Africa	Ethiopia	Debre Zeit Centre	Highland		Holstein Friesian(HF)	HF	458 (16)				Tadesse and Dessie, 2003
32	Africa	Kenya	Mariakani Centre	S. Arid	Sahiwal(S)	Ayrshire(A)	75%S 25%A	416(12)		1042D (15)		Thorpe et al., 1994
33	Africa	Kenya	Mariakani Centre	S. Arid	Sahiwal(S)	Ayrshire(A)	1/2A 1/2S	449 (13)		979D (19)		Thorpe et al., 1994
34	Africa	Kenya	Mariakani Centre	S. Arid	Sahiwal(S)	Holstein Friesian(HF)	1/2F 1/2S	441 (17)		967D (24)		Thorpe et al., 1994
35	Africa	Kenya	Mariakani Centre	S. Arid	Sahiwal(S)	Ayrshire(A)	75%A 25%S	483 (12)		1005D (18)		Thorpe et al., 1994
36	Africa	Kenya	Kilifi Plantations	S. Arid	Sahiwal(S)	Ayrshire(A)	2/3S 1/3A	390 (3.6)		1042D (8.)		Thorpe et al., 1994
37	Africa	Kenya	Kilifi Plantations	S. Arid	Sahiwal(S)	Ayrshire(A)	2/3A 1/3S	398 (4.6)		1019D (6.5)		Thorpe et al., 1994
38	Africa	Kenya	Nanyuki	Highland	Sahiwal(S)	Ayrshire(A)	3/4A 1/4S	453(12.3)		1071D(10.4)		Trial and Gregory, 1981
39	Africa	Kenya	Nanyuki	Highland	Sahiwal(S)	Ayrshire(A)	1/2A 1/2S	445 (14.6)		1062D (15)		Trial and Gregory, 1981
40	Africa	Kenya	Nanyuki	Highland	Sahiwal(S)	Ayrshire(A)	1/2S 1/2A	386 (15.5)		1105D(18.9)		Trial and Gregory, 1981
41	Africa	Kenya	Nanyuki	Highland	Sahiwal(S)	Ayrshire(A)	3/4 S 1/4 A	396 (12.6)		1066D(12.3)		Trial and Gregory, 1981
42	Africa	Kenya	Nanyuki	Highland	Sahiwal(S)		Sahiwal	450 (14.3)		1116D(15.2)		Trial and Gregory, 1981
43	Africa	Kenya	Machakos	S.Arid	Sahiwal(S)					36,2 (1.4)		Kimenye ,1978
44	Africa	Kenya	Machakos	S.Arid	Sahiwal(S)	Ayrshire(A)	1/2S1/2A			30,9 (1.8)		Kimenye ,1978
45	Africa	Kenya	Machakos	S.Arid	Sahiwal(S)	Ayrshire(A)	1/2A 1/2S			27,7 (2.6)		Kimenye ,1978
46	Africa	Kenya	Machakos	S.Arid		Ayrshire(A)	Aryshire			33,6 (1.3)		Kimenye ,1978

Table 2: Continued

No	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	CI	DP	Age FC	Spc	Source
47	Africa	Kenya	Ngong	Highland	Sahiwal(S)					38,3 (1.1)		Kimenye ,1978
48	Africa	Kenya	Ngong	Highland	Sahiwal(S)	Ayrshire(A)	3/4S 1/4A			32,8 (1.5)		Kimenye ,1978
49	Africa	Kenya	Ngong	Highland	Sahiwal(S)	Ayrshire(A)	1/2S 1/2A			32,6 (0.9)		Kimenye ,1978
50	Africa	Kenya	Ngong	Highland	Sahiwal(S)	Ayrshire(A)	1/2A 1/2S			28,6 (0.8)		Kimenye ,1978
51	Africa	Kenya	Ngong	Highland	Sahiwal(S)	Ayrshire(A)	3/4A 1/4S			35,6 (1.3)		Kimenye ,1978
52	Africa	Kenya	Ngong	Highland		Ayrshire(A)	Aryshire			31,9 (0,8)		Kimenye ,1978
53	Africa	Nigeria*	Shika	T.wet/dry	White Fulani(WF)	Holstein Friesian(HF)	1/2HF 1/2FU	383 (234)		33.2 (73)		Buvanedran et al., 1981
54	Africa	Nigeria	Shika	T.wet/dry	White Fulani(WF)	Holstein Friesian(HF)	3/4HF 1/4 Fu	390 (108)		32.5 (52)		Buvanedran et al., 1981
55	Africa	Nigeria*	Shika	T.wet/dry	White Fulani(WF)	Holstein Friesian(HF)	7/8 HF 1/8 FU	393 (22)		31.2 (13)		Buvanedran et al., 1981
56	Africa	Nigeria*	Vom	T.wet/dry	White Fulani(WF)		W. Fulani	367(64)*		45.4 (64)*		Sohael, 1984
57	Africa	Nigeria	Vom	T.wet/dry	White Fulani(WF)	Holstein Friesian(HF)	1/2HF 1/2WF	358 (71)*		30.9 (71)*		Sohael, 1984
58	Africa	Nigeria	Vom	T.wet/dry		Holstein Friesian(HF)	HF	368 (44)*		28.7(44)		Sohael, 1984
59	Africa	Nigeria*	Vom	T.wet/dry		Holstein Friesian(HF)	HF	387(50)*		29.6 (50)*		Sohael, 1984
60	Asia	Bangladesh	Comilla	T.wet	Local (L)			15,4M (0.75)		37,6 (1.3)	1,32 (0.13)	Miazi et al., 2007
61	Asia	Bangladesh	Comilla	T.wet	Local (L)	Sahiwal(S)	1/2S 1/2L	15,3M (3)		28 (0)	1,5 (0.5)	Miazi et al., 2007
62	Asia	Bangladesh	Comilla	T.wet	Local (L)	Holstein Friesian(HF)	HF	14,2M (0.49)		32,6 (2.32)	1,6 (0.24)	Miazi et al., 2007
63	Asia	Bangladesh	Comilla	T.wet	Local (L)	Jersey(J)	J	14,08 M (0.62)		31,08 (1.75)	1,25 (0.13)	Miazi et al., 2007
64	Asia	Bangladesh	Khulna	T.wet	Local (L)		L				1,6 (0.18)	Ashraf et al., 2000
65	Asia	Bangladesh	Khulna	T.wet	Local (L)	Holstein Friesian(HF)	1/2F 1/2L				1,1(0.17)	Ashraf et al., 2000
66	Asia	Bangladesh	Khulna	T.wet	Local (L)	Sahiwal	1/2S 1/2L				1,08 (0.18)	Ashraf et al., 2000
67	Asia	Bangladesh	Barisal/Patuakahli	T.wet	Local		Local	415. (5)		1465D (59)	1.8 (0.14)	Al-Amin and Nahar, 2007
68	Asia	Bangladesh	Barisal/Patuakahli	T.wet	Local	Holstein Friesian(HF)	1/2HF 1/2L	452(6.6)		1029D(49)	1.5 (0.1)	Al-Amin and Nahar, 2007
69	Asia	Bangladesh	Dhaka	T.wet	Local		L	447.9 (14.5)				Rahman et al., 2007
70	Asia	Bangladesh	Dhaka	T.wet	Local	Holstein Friesian(HF)	1/2F 1/2L	468.7 (7.3)				Rahman et al., 2007

Table 2: Continued

No	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	CI	DP	Age FC	Spc	Source
71	Asia	Bangladesh	Dhaka	T.wet	Local	Jersey(J)	1/2J	451.4 (9.5)				Rahman et al., 2007
72	Asia	India	Dalhousie	Highland		Holstein Friesian(A)*	3/4 HF	389 (16)		35.2 (0.6)		Amble and Jain, 1967
73	Asia	India	Dalhousie	Highland		Holstein Friesian(A)*	7/8 HF	425 (21)		36.4 (0.7)		Amble and Jain, 1967
74	Asia	India	Dalhousie	Highland		Holstein Friesian(A)*	15/16HF	382 (31)		36 (1.1)		Amble and Jain, 1967
75	Asia	India	Kasauli	Highland		Holstein Friesian(A)*	1/2 HF	492 (45)		37 (6)		Amble and Jain, 1967
76	Asia	India	Kasauli	Highland		Holstein Friesian(A)*	3/4HF	461 (24)		36.8 (1)		Amble and Jain, 1967
77	Asia	India	Kasauli	Highland		Holstein Friesian(A)*	7/8HF	434 (24)		36.6 (0.9)		Amble and Jain, 1967
78	Asia	India	Kasauli	Highland		Holstein Friesian(A)*	15/16HF	387 (32)		36.6 (1.2)		Amble and Jain, 1967
79	Asia	India	Jullundur	S. Arid		Holstein Friesian(A)*	1/4HF	466 (60)		35.0 (1.5)		Amble and Jain, 1967
80	Asia	India	Jullundur	S. Arid		Holstein Friesian(A)*	3/8HF	442 (26)		35.7 (0.8)		Amble and Jain, 1967
81	Asia	India	Jullundur	S. Arid		Holstein Friesian(A)*	1/2HF	442 (46)		32.7 (1.5)		Amble and Jain, 1967
82	Asia	India	Jullundur	S. Arid		Holstein Friesian(A)*	5/8HF	377 (54)		35.3 (1.7)		Amble and Jain, 1967
83	Asia	India	Jullundur	S. Arid		Holstein Friesian(A)*	3/4HF	458 (27)		35.4 (0.8)		Amble and Jain, 1967
84	Asia	India	Jullundur	S. Arid		Holstein Friesian(A)*	7/8HF	478 (35)		34.8 (1.0)		Amble and Jain, 1967
85	Asia	India	Jullundur	S. Arid		Holstein Friesian(A)*	15/16HF	466 (35)		36.1 (1.0)		Amble and Jain, 1967
86	Asia	India	Ambala	T. Wet	Sahiwal(S)		S	392 (17)		37.4 (0.6)		Amble and Jain, 1967
87	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian(A)*	3/8HF	369 (35)		37 (1.4)		Amble and Jain, 1967
88	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian(A)*	1/2HF	407 (24)		37.4 (1.)		Amble and Jain, 1967
89	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian(A)*	5/8HF	414 (37)		35.9 (1.4)		Amble and Jain, 1967
90	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian(A)*	3/4HF	442 (14)		36.3 (0.6)		Amble and Jain, 1967
91	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian(A)*	7/8HF	472 (16)		36.8(0.6)		Amble and Jain, 1967
92	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian(A)*	15/16HF	438 (29)		37.9 (1)		Amble and Jain, 1967
93	Asia	India	Ambala	T. Wet	Sahiwal(S)	Holstein Friesian(A)*	31/32HF	463 (48)		36.8 (1.5)		Amble and Jain, 1967
94	Asia	India	Meerut	T. Wet	Sahiwal(S)		Sahiwal	450 (19)		39.2 (0.8)		Amble and Jain, 1967

Table 2: Continued

No	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	CI	DP	Age FC	Spc	Source
95	Asia	India	Meerut	T. Wet	Sahiwal(S)	Holstein Friesian(A)*	3/8HF	484 (52)		44.6 (2.2)		Amble and Jain, 1967
96	Asia	India	Meerut	T. Wet	Sahiwal(S)	Holstein Friesian(A)*	1/2HF	423 (57)		40 (2.2)		Amble and Jain, 1967
97	Asia	India	Meerut	T. Wet	Sahiwal(S)	Holstein Friesian(A)*	3/4HF	569 (40)		38.5 (1.4)		Amble and Jain, 1967
98	Asia	India	Meerut	T. Wet	Sahiwal(S)	Holstein Friesian(A)*	7/8HF	439 (46)		34.8 (1.8)		Amble and Jain, 1967
99	Asia	India	Lucknow	T. Wet		Holstein Friesian(A)*	1/2HF	399 (31)		38.3 (1.6)		Amble and Jain, 1967
100	Asia	India	Lucknow	T. Wet		Holstein Friesian(A)*	5/8HF	490 (20)		36.1 (1.1)		Amble and Jain, 1967
101	Asia	India	Lucknow	T. Wet		Holstein Friesian(A)*	3/4HF	500 (28)		38.2 (1.5)		Amble and Jain, 1967
102	Asia	India	Jubbulpore	T. Wet		Holstein Friesian(A)*	1/4HF	380 (41)		38.4 (1.6)		Amble and Jain, 1967
103	Asia	India	Jubbulpore	T. Wet		Holstein Friesian(A)*	3/8HF	426 (23)		38 (0.9)		Amble and Jain, 1967
104	Asia	India	Jubbulpore	T. Wet		Holstein Friesian(A)*	1/2HF	431 (22)		37 (1.1)		Amble and Jain, 1967
105	Asia	India	Jubbulpore	T. Wet		Holstein Friesian(A)*	5/8HF	410 (36)		39.1 (1.5)		Amble and Jain, 1967
106	Asia	India	Jubbulpore	T. Wet		Holstein Friesian(A)*	3/4HF	463 (17)		37.3 (0.7)		Amble and Jain, 1967
107	Asia	India	Jubbulpore	T. Wet		Holstein Friesian(A)*	7/8HF	444 (21)		39.1 (0.9)		Amble and Jain, 1967
108	Asia	India	Jubbulpore	T. Wet		Holstein Friesian(A)*	15/16HF	446 (27)		36.7 (1.1)		Amble and Jain, 1967
109	Asia	India	Kirkee	T.wet/dry		Holstein Friesian(A)*	1/4HF	406 (57)		39.2 (2.0)		Amble and Jain, 1967
110	Asia	India	Kirkee	T.wet/dry		Holstein Friesian(A)*	3/8HF	503 (36)		37.2 (1.2)		Amble and Jain, 1967
111	Asia	India	Kirkee	T.wet/dry		Holstein Friesian(A)*	1/2HF	449 (37)		32.9 (1.4)		Amble and Jain, 1967
112	Asia	India	Kirkee	T.wet/dry		Holstein Friesian(A)*	5/8HF	472 (44)		32.9 (1.6)		Amble and Jain, 1967
113	Asia	India	Kirkee	T.wet/dry		Holstein Friesian(A)*	3/4HF	516 (20)		34.2 (0.7)		Amble and Jain, 1967
114	Asia	India	Kirkee	T.wet/dry		Holstein Friesian(A)*	7/8HF	490 (25)		34.2 (0.8)		Amble and Jain, 1967
115	Asia	India	Kirkee	T.wet/dry		Holstein Friesian(A)*	15/16HF	532 (50)		38.7 (1.5)		Amble and Jain, 1967
116	Asia	India	Secunderabad	T.wet/dry		Holstein Friesian(A)*	1/2HF	411 (29)		34.2 (1.2)		Amble and Jain, 1967
117	Asia	India	Secunderabad	T.wet/dry		Holstein Friesian(A)*	3/4HF	415 (25)		34.6(1)		Amble and Jain, 1967
118	Asia	India	Secunderabad	T.wet/dry		Holstein Friesian(A)*	7/8HF	510 (38)		35.1 (1.3)		Amble and Jain, 1967

Table 2: Continued

No	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	CI	DP	Age FC	Spc	Source
119	Asia	India	Karnal	S. Arid	Sahiwal(S)		Sahiwal	458 (1.2)		1211D (2.5)		Taneja and Chawla, 1978
120	Asia	India	Karnal	S. Arid	Sahiwal(S)	Brown Swiss(BS)	1/4BS 3/4S	409 (45.4)		930D (30)		Taneja and Chawla, 1978
121	Asia	India	Karnal	S. Arid	Sahiwal(S)	Brown Swiss(BS)	1/2BS 1/2S	408 (4.24)		908D (7.2)		Taneja and Chawla, 1978
122	Asia	India	Karnal	S. Arid	Sahiwal(S)	Brown Swiss(BS)	F2	413 (12.2)		1020D (20.4)		Taneja and Chawla, 1978
123	Asia	India	Karnal	S. Arid	Sahiwal(S)	Brown Swiss(BS)	3/4 BS 1/4S	404 (12.8)		930D (20.1)		Taneja and Chawla, 1978
124	Asia	India	Karnal	S. Arid		Brown Swiss(BS)	BS	461 (81)		1077D (13)		Taneja and Chawla, 1978
125	Asia	India	Haringhata	T. Wet	Deshi (D)		D	535 (30)		47.9(1.9)		Bala and Nagarcenkar, 1981
126	Asia	India	Haringhata	T. Wet	Hariana(H)		H	570 (12)		51.6 (0.7)		Bala and Nagarcenkar, 1981
127	Asia	India	Haringhata	T. Wet	Deshi (D)	(HF)	1/2F 1/2D	431 (25)		36.8(1.3)		Bala and Nagarcenkar, 1981
128	Asia	India	Haringhata	T. Wet	Deshi (D)	Jersey(J)	1/2J 1/2 D	433 (18)		35.6 (1.1)		Bala and Nagarcenkar, 1981
129	Asia	India	Haringhata	T. Wet	Hariana(H)	Friesian	1/2F 1/2H	465 (10)		34 (0.6)		Bala and Nagarcenkar, 1981
130	Asia	India	Haringhata	T. Wet	Hariana(H)	B. Swiss(BS)	1/2BS 1/2H	449 (16)		36(0.9)		Bala and Nagarcenkar, 1981
131	Asia	India	Haringhata	T. Wet	Hariana(H)	Jersey(J)	1/2J 1/2H	443 (8)		32.7 (0.5)		Bala and Nagarcenkar, 1981
132	Asia	India	Haringhata	T. Wet	Hariana(H)	Friesian	F/ H - F2	592 (33)		42.2 (1.4)		Bala and Nagarcenkar, 1981
133	Asia	India	Haringhata	T. Wet	Hariana(H)	Jersey(J)	J/H - F2	491 (23)		41.7 (1.1)		Bala and Nagarcenkar, 1981
134	Asia	India	Haringhata	T. Wet		Friesian	Friesian	480 (36)		30.2 (1.8)		Bala and Nagarcenkar, 1981
135	Asia	India	Haringhata	T. Wet		Jersey(J)	Jersey	349 (16)		24.5 (1.)		Bala and Nagarcenkar, 1981
136	Asia	Pakistan	Bahadurnagar	S.Arid	Sahiwal(S)		Sahiwal	466 (0.3)	288 (0.19)	43,9 (0.03)	1.7	McDowell et al., 1996
137	Asia	Pakistan	Bahadurnagar	S.Arid	Sahiwal(S)	Holstein Friesian(HF)	1/4H 3/4S	456 (5.6)	241 (2.9)	34,7 (0.4)	4,5 (0.05)	McDowell et al., 1996
138	Asia	Pakistan	Bahadurnagar	S.Arid	Sahiwal(S)	Holstein Friesian(HF)	1/2H 1/2S	427 (0.44)	199 (0.2)	32,3 (0.3)	2,6 (0)	McDowell et al., 1996
139	Asia	Pakistan	Bahadurnagar	S.Arid	Sahiwal(S)	Holstein Friesian(HF)	3/4H 1/4S	461(2.6)	185 (1.07)	30,5 (0.17)	3,4 (0.1)	McDowell et al., 1996
140	Asia	Pakistan	Bahadurnagar	S.Arid	Sahiwal(S)	Holstein Friesian(HF)	F2	473 (1.5)	222 (0.7)	34,8 (0.1)	1,9 (0.006)	McDowell et al., 1996
141	Asia	Sri Lanka	Karagoda -Uyan.	T. Wet	Sinhala (Sn)		Sn	391 (5)		44.8 (0.5)		Buvanendran and Mahadevan, 1975
142	Asia	Sri Lanka	Karagoda -Uyan.	T. Wet	Sinhala (Sn)	Holstein Friesian(HF)	1/2F 1/2S	393 (7)		36.9 (0.6)		Buvanendran and Mahadevan, 1975

Table 2: Continued

No	Continent	Country	Location	Climatic Z	Local breed	Exotic breed	Genetic grp	CI	DP	Age FC	Spc	Source
143	Asia	Sri Lanka	Karagoda -Uyan.	T. Wet	Sinhala (Sn)	Holstein Friesian(HF)	F2	448 (24)		38.5 (1.6)		Buvanendran and Mahadevan, 1975
144	Asia	Sri Lanka	Karagoda -Uyan.	T. Wet	Sinhala (Sn)	Jersey(J)	1/2J 1/2S	370 (5)		38.5 (1.6)		Buvanendran and Mahadevan, 1975
145	Asia	Sri Lanka	Karagoda -Uyan.	T. Wet	Sinhala (Sn)	Jersey(J)	F2	412 (16)		38.3 (1.5)		Buvanendran and Mahadevan, 1975
146	Asia	Sri Lanka	Undugoda	T.wet	Sindhi (Si)	Jersey(J)	1/2J 1/2Si	368		33.7		Buvanendran and Mahadevan, 1975
147	Asia	Sri Lanka	Undugoda	T. Wet	Sindhi (Si)	Jersey(J)	F2	430 (8.7)		33.0 (0.6)		Buvanendran and Mahadevan, 1975
148	Asia	Sri Lanka	Undugoda	T. Wet	Sindhi (Si)	Jersey(J)	5/8J 3/8Si	373		36.3		Buvanendran and Mahadevan, 1975
149	Asia	Sri Lanka	Undugoda	T. Wet	Sindhi (Si)	Jersey(J)	3/4J 1/4Si	434		39.6		Buvanendran and Mahadevan, 1975
150	S.America	Brazil	Valenca	T.Wet		Holstein Friesian(HF)	Holestein	515 (22)		1368D (38)		Madalena, 1981
151	S.America	Brazil	Valenca	T.Wet	Gir (Gi)	Holstein Friesian(HF)	1/2 HF 1/2Gi	478 (143)		1202D (33)		Madalena, 1981
152	S.America	Brazil	Valenca	T.wet	Gir (Gi)		3/4HF 1/4Gi	519 (24)		1303D (36)		Madalena, 1981
153	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	1/4HF H.Mgt	388 (12)				Madalena et al., 1990
154	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	1/4HF L.Mgt	489 (20)				Madalena et al., 1990
155	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	1/2HF H.Mgt	401 (12)				Madalena et al., 1990
156	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	1/2HF L.Mgt	473 (16)				Madalena et al., 1990
157	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	5/8HF H.Mgt	363 (15)				Madalena et al., 1990
158	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	5/8HF L.Mgt	565 (24)				Madalena et al., 1990
159	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	3/4HF H.Mgt	396 (14)				Madalena et al., 1990
160	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	3/4HF L.Mgt	525 (20)				Madalena et al., 1990
161	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	7/8 HF H.Mgt	402 (12)				Madalena et al., 1990
162	S.America	Brazil	Various	T.wet	Guzera	Holstein Friesian(HF)	7/8 HF L.Mgt	546 (23)				Madalena et al., 1990
163	S.America	Brazil	Various	T.wet		Holstein Friesian(HF)	HF H.Mgt	422 (13)				Madalena et al., 1990
164	S.America	Brazil	Various	T.wet		Holstein Friesian(HF)	HF L.Mgt	559 (25)				Madalena et al., 1990

Supplementary Table 3: A summary of data assembled for the review . Life time milk yields (LTMY) and lactations completed

	Continent	Country	Locatation	Climatic Z	Local breed	Exotic Breed	Genetic grp	LTMY	Lactations	Source
1	Asia	India			Sahiwal(S)		Sahiwal	7710	4.3	Matharu and Gill , 1981
2	Asia	India			Sahiwal(S)	Holstein Friesian(HF)	1/2HF 1/2S	13375	5.2	Matharu and Gill , 1981
3	Asia	India			Sahiwal(S)	Holstein Friesian(HF)	62,5HF 37.5S	14390	5.3	Matharu and Gill , 1981
4	Asia	India			Sahiwal(S)	Holstein Friesian(HF)	3/4HF 1/4S	12120	4.8	Matharu and Gill , 1981
5	Asia	India	Visakhapatnam	T.wet	Ongole (O)		O	4567	4.2	Singh, 2005
6	Asia	India	Visakhapatnam	T.wet	Ongole (O)	Jersey(J)	1/2J 1/2O	6372		Singh, 2005
7	Asia	India	Bikaner	Semi Arid	Rathi (R)		R	5707	4	Singh, 2005
8	Asia	India	Bikaner	Semi Arid	Rathi (R)	Red Dane (RD)	1/2RD 1/2R	12108	5.04	Singh, 2005
9	Asia	Bangladesh	Dhaka	T.wet	Local(L)		L	3934 (402.2)		Majid et al., 1996
10	Asia	Bangladesh	Dhaka	T.wet	Local(L)	Holstein Friesian(HF)	1/2F 1/2L	7147 (2,268.8)		Majid et al., 1996
11	Asia	Bangladesh	Dhaka	T.wet	Local(L)	Jersey(J)	1/2J 1/2L	10,355 (2,509.2)		Majid et al., 1996
12	Asia	Bangladesh	Dhaka	T.wet	Local(L)	Holstein Friesian(HF)	F2 -1/2L 1/2HF	8969 (897.08)		Majid et al., 1996
13	Asia	Bangladesh	Dhaka	T.wet	Local(L)	Holstein Friesian(HF)	F2 -1/4L 3/4HF	11,756 (112)		Majid et al., 1996
14	Asia	Bangladesh	Dhaka	T.wet	Sahiwal(S)		S	5,891 (808.06)		Majid et al., 1996
15	Asia	Bangladesh	Dhaka	T.wet	Sahiwal(S)	Holstein Friesian(HF)	1/2HF 1/2S	8789 (2145.9)		Majid et al., 1996
16	Asia	Bangladesh	Dhaka	T.wet	Friesian		HF	11,134 (2916)		Majid et al., 1996
17	Africa	Kenya	Kilifi	Semi Arid	Sahiwal(S)	Ayrshire(A)	2/3A 1/3S r*	9376 (394)	3.38 (0.11)	Thorpe et al., 1994
18	Africa	Kenya	Kilifi	Semi Arid	Sahiwal(S)	Ayrshire(A)	2/3S 1/3A r*	6331 (468)	2.53 (0.35	Thorpe et al., 1994
19	Africa	Ethiopia	Cheffa	Highland	Boran (Br)	Holstein Friesian(HF)	1/2HF 1/2Br	14,342 (127)	5.02 (0.04)	Goshu, 2005
20	Africa	Ethiopia	Cheffa	Highland	Boran (Br)	Holstein Friesian(HF)	3/4HF 1/4Br	12,074 (90)	4.05(0.03)	Goshu, 2005
21	Africa	Ethiopia	Cheffa	Highland	Boran (Br)	Holstein Friesian(HF)	7/8HF 1/8Br	7891 (117)	2.64(0.03)	Goshu, 2005
22	Africa	Ethiopia	Cheffa	Highland	Boran (Br)	Holstein Friesian(HF)	15/16HF	7343 (206)	2.42(0.06)	Goshu, 2005

Key: r* =produced by rotational crossbreeding . Population stablized at 2/3 genes of the sire and 1/3 from breed of maternal grandsire
Notes : LTMY is given in Kilograms

Supplementary Table 4: A summary of relative performance of production traits (of the exotic and crossbred as compared to the indigenous breeds) calculated for the different climatic zones

No	Local B	Exotic B	Climatic Z	Country	Location	Prod Env	Milk Yield Per Lactation						Lactation Length						Source
							1/4	1/2	3/4	7/8	15 / 16	F2	1/4	1/2	3/4	7/8	15 / 16	F2	
1	Boran	Holstein Friesian	Highlands	Ethiopia	Holeta station	On Station		4.45	4.46			3.64							Demeke et al.,, 2004b
2	Boran	Jersey	Highlands	Ethiopia	Holeta station	On Station		3.95				3.05							Demeke et al.,, 2004b
3	Arsi	Holstein Friesian	Highlands	Ethiopia	Aresela region	On Station		2.44	2.93					1.3	1.5				Kiwuwa et al., 1983
4	Arsi	Jersey	Highlands	Ethiopia	Aresela region	On Station		2.15						1.22					Kiwuwa et al., 1983
5	Zebu	Holstein Friesian	Highlands	Ethiopia	Aresela region	On Station		2.53	2.5					1.25	1.25				Kiwuwa et al., 1983
6	Barca	Holstein Friesian	Highlands	Ethiopia	Aresela region	On Station		3.53	3.44	3.26			1.29	1.17		1.25			Tadesse and Dessie, 2003
7	Sahiwal	Ayrshire♂	Highlands	Kenya	Nanyuki**	On farm		2.04	1.75					1.53	1.37				Trail and Gregory ,1981
8	Sahiwal ♂	Ayrshire	Highlands	Kenya	Nanyuki**	On farm		1.65	2.02										Trail and Gregory ,1981
9	Sahiwal	Ayrshire♂	Highlands	Kenya	Ngong	On Station	1.5	1.6	2.02				1.045	1.09	1.15				Kimenye, 1978
10	Sahiwal ♂	Ayrshire	Highlands	Kenya	Ngong	On Station		1.4						1.03					Kimenye, 1978
						Mean	**1.5**	**2.57**	**2.73**	**3.26**		**3.35**	**1.17**	**1.23**	**1.32**	**1.25**			
						STDEV		**1.028**	**0.963**			**0.42**	**0.16**	**0.16**	**0.15**				
11	White Fulani	Holstein Friesian	T.wet/dry	Nigeria	Vom	On Station		2.05	1.97										Knudsen and Sohael, 1970
12	White Fulani	Holstein Friesian	T.wet/dry	Nigeria	Vom	On Station		2.02						1.1					Sohael, 1984
13	White Fulani	Holstein Friesian	T.wet/dry	Nigeria	Vom	On Station		5.3						1.65					Olutogun et al., 2006
14	Sahiwal	Holstein Friesian	T.wet/dry	India	Ambala	On Station		1.2	1.31	1.11	1.06			0.9	0.92	0.97	0.98		Amble and Jain, 1967
15	Sahiwal	Holstein Friesian	T.wet/dry	India	Meerut	On Station		1.41	1.64	1.32				1.07	1.09	1.13			Amble and Jain, 1967
16	Sahiwal	B.Swiss	T.wet/dry	India	Karnal OS	On Station	1.78	1.85	1.56			1.51	1.05	1.16	1.02			1.02	Bala and Nagarcenkar, 1981
17	Deshi	Holstein Friesian	T.wet/dry	India	Haringhata	On Station		3.9						1.13					Bala and Nagarcenkar, 1981
18	Deshi	Jersey	T.wet/dry	India	Haringhata	On Station		3.8						1.2					Bala and Nagarcenkar, 1981
19	Hariana	Holstein Friesian	T.wet/dry	india	Haringhata	On Station		2.43				1.63		1.09				1.07	Bala and Nagarcenkar, 1981
20	Hariana	B.Swiss	T.wet/dry	India	Haringhata	On Station		2.17						1.07					Bala and Nagarcenkar, 1981
21	Deshi	Jersey	T.wet/dry	Srilanka	Karagoda -Uyan.	On Station		2.03				1.43		1.05				1.03	B. and M .,1975*
22	Sinhala	Holstein Friesian	T.wet/dry	Srilanka	Karagoda -Uyan.	On Station		2.75				1.73		1.45				1.34	B. and M .,1975*

Key **Local B** = Local breed in the study **Exotic B**= Exotic breed in the study **Prod Env** = production environment
Ayrshire♂= breed of sire in the study is Ayrshire. **Sahiwal**♂ = breed of sire in the study is Sahiwal
Local* = Actual breed used in the study no given. local breed **B. and M .,1975* =** Buvanendran and Mahadevan ,1975

Table 4: continued

No	Local B	Exotic B	Climatic Z	Country	Location	Prod Env	Milk Yield Per Lactation						Lactation Length						Source
							1/4	1/2	3/4	7/8	15 / 16	F2	1/4	1/2	3/4	7/8	15 / 16	F2	
23	Sindi	Jersey	T.wet/dry	Srilanka	Undugoda	On Station		2.12	0.97			1.22		1.19	1.07			1.07	B. and M .,1975*
24	Jenubi	Holstein Friesian	T.wet/dry	Srilanka	Undugoda	On Station		1.58	1.8	1.6	1.5								B. and M .,1975*
25	Criollo	Jersey	T.wet/dry	Costa Rica	Turrialba	On Station	1.1	1.5	1.4				1.07	1.38	1.3				Alba and Kennedy, 1985
26	Local*	Jersey	T.wet/dry	India	Chalakudy	On Station	2.02	2.46	2.48	3.13		2.79							Katpatal ,1977
27	Local*	Jersey	T.wet/dry	India	Vikas Nagar	On Station		2.3	2.2										Katpatal ,1977
28	Local*	Jersey	T.wet/dry	India	Visakhapatnam	On Station	1.73	2.53	2.86										Katpatal, 1977
29	Local*	Sahiwal	T.wet/dry	Bangladesh	Comilla	on-farm		2.16						0.99					Miazi et al., 2007
30	Local*	Holstein Friesian	T.wet/dry	Bangladesh	Comilla	On farm		2.65						1.14					Miazi et al., 2007
31	Local*	Jersey	T.wet/dry	Bangladesh	Comilla	On farm		2.5						1.16					Miazi et al., 2007
32	Local*	Holstein Friesian	T.wet/dry	Bangladesh	Khulna	On farm		1.7						1.1					Ashraf et al., 2000
33	Local*	Holstein Friesian	T.wet/dry	Bangladesh	Dhaka	On Station		2.9				2.9							Majid et al., 1996
34	Local*	Jersey	T.wet/dry	Bangladesh	Dhaka	On Station		2.7				2.3							Majid et al., 1996
35	Sahiwal	Holstein Friesian	T.wet/dry	Bangladesh	Dhaka	Onstation		1.8											Majid et al., 1996
36	Local*	Jersey	T.wet/dry	Bangladesh	Dhaka	On Station		2.1						1.2					Rahman et al., 2007
37	Local*	Holstein Friesian	T.wet/dry	Bangladesh	Dhaka	On Station		2.5						1.2					Rahman et al., 2007
38	Local*	Holstein Friesian	T.wet/dry	Bangladesh	Barisal/Patuakahli	On Station		2.17						1.5					Al-Amin and Nahar, 2007
						Mean	**1.66**	**2.38**	**1.82**	**1.79**	**1.28**	**1.94**	**1.06**	**1.187**	**1.08**	**1.05**	**0.98**	**1.11**	
						STDEV	**0.39**	**0.84**	**0.57**	**0.92**	**0.31**	**0.64**	**0.01**	**0.18**	**0.14**	**0.11**		**0.13**	
39	Sahiwal ♂	Ayrshire	Semiarid	Kenya	Machakos	On Station		2.6						2.05					Kimenye, 1978
40	Sahiwal	Ayrshire♂	Semiarid	Kenya	Machakos	On Station		2.4						2.41					Kimenye, 1978
41	Sahiwal	Friesian	Semiarid	Pakistan	Bahadurnagar	On Station	1.1	1.80	1.5			1.2							McDowell et al., 1996
42	Sahiwal	B.Swiss	T.wet/dry	India	Karnal OS	On Station	1.78	1.85	1.56			1.51	1.05	1.16	1.02			1.02	Bala and Nagarcenkar, 1981
						Mean	**1.44**	**2.16**	**1.53**			**1.36**		**1.873**					
						STDEV	**0.48**	**0.53**	**0.48**			**0.481**		**0.64**					

Supplementary Table 5: A summary of relative performance of reproductive traits (of the exotic and crossbred as compared to the indigenous breeds) calculated for the different climatic zones

No	Local Br	Exotic Br	Climatic Z	Country	Location	Production Env	Calving Interval			Age at first calving			Services /Conception			Source
							1/2	3/4	F2	1/2	3/4	F2	1/4	1/2	F2	
1	Boran	Friesian	Highlands	Ethiopia	Holeta station	On Station	0.88	0.92	0.92	0.84	0.88	0.93		0.87	0.94	Demeke et al., 2004a
2	Boran	Jersey	Highlands	Ethiopia	Holeta station	On Station	0.86		0.91	0.82		0.92		0.77	0.84	Demeke et al., 2004a
3	Arsi	Friesian	Highlands	Ethiopia	Aresela region	On Station	0.97	1.08		0.98	0.90					Kiwuwa et al., 1983
4	Arsi	Jersey	Highlands	Ethiopia	Aresela region	On Station	0.90			0.97						Kiwuwa et al., 1983
5	Zebu	Friesian	Highlands	Ethiopia	Aresela region	On Station	1.02	0.94								Kiwuwa et al . 1983
6	Barca	Friesian	Highlands	Ethiopia	Aresela region	On Station	0.99									Tadesse et al., 2003
7	Sahiwal	Ayrshire♂	Highlands	Kenya	Nanyuki**	On farm	0.90	1.01		0.95	0.95					Trail and Gregory, 1981
8	Sahiwal ♂	Ayrshire	Highlands	Kenya	Nanyuki**	On farm				0.75	0.83					Trail and Gregory, 1981
9	Sahiwal	Ayrshire♂	Highlands	Kenya	Ngong	On Station				0.75	0.83					Kimenye, 1978
10	Sahiwal ♂	Ayrshire_D	Highlands	Kenya	Ngong	On Station				0.85						Kimenye, 1978
						Mean	**0.93**	**0.99**	**0.92**	**0.86**	**0.88**	**0.93**		**0.82**	**0.89**	
						STDEV	**0.06**	**0.07**	**0.01**	**0.09**	**0.05**	**0.01**		**0.07**	**0.07**	
11	White Fulani	Friesian	T.wet/dry	Nigeria	Vom	On Station	0.90			0.68						Soheal, 1984
12	Sahiwal	Friesian	T.wet/dry	India	Ambala	On Station	1.04	1.06		1.01						Amble and Jain, 1967
13	Sahiwal	Friesian	T.wet/dry	India	Meerut	On Station	0.94	1.33		1.02	0.98					Amble and Jain, 1967
14	Deshi	1/2 Friesian	T.wet/dry	India	Haringhata	On Station		0.80		0.76						Bala and Nagarcenkar, 1981
15	Deshi	1/2 Jesrey	T.wet/dry	India	Haringhata	On Station	0.80			0.76						Bala and Nagarcenkar, 1981
16	Hariana	Friesian	T.wet/dry	india	Haringhata	On Station	0.82									Bala and Nagarcenkar, 1981
17	Hariana	B.Swiss	T.wet/dry	India	Haringhata	On Station	0.78			0.78						Bala and Nagarcenkar, 1981
18	Deshi	Jersey	T.wet/dry	Srilanka	Karagoda - Uyan.	On Station	0.77		0.86	0.63						Buvanendran and Mahadevan, 1975
19	Sinhala	Friesian	T.wet/dry	Srilanka	Karagoda - Uyan.	On Station	1.00		1.14	0.82		0.85				Buvanendran and Mahadevan, 1975
20	Sindi	Jersey	T.wet/dry	Srilanka	Undugoda	On Station	0.86	0.88	1.08							Buvanendran and Mahadevan, 1975

Key **Local B** = Local breed in the study **Exotic B**= Exotic breed in the study **Prod Env** = production environment
Ayrshire♂= breed of sire in the study is Ayrshire. **Sahiwal**♂ = breed of sire in the study is Sahiwal
Local* = Actual breed used in the study no given. local breed

Table 5: continued

No	Local Br	Exotic Br	Climatic Z	Country	Location	Production Env	Calving Interval			Age at first calving			Services /Conception			Source
							1/2	3/4	F2	1/2	3/4	F2	1/4	1/2	F2	
21	Jenubi	Friesian	T.wet/dry	Srilanka	Undugoda	On Station				0.81	0.76					Buvanendran and Mahadevan, 1975
22	Local	Sahiwal	T.wet/dry	Bangladesh	Comilla	on-farm	0.99			0.74				1.13		Miazi et al., 2007
23	Local	Holstein	T.wet/dry	Bangladesh	Comilla	On farm	0.92			0.86				1.21		Miazi et al., 2007
24	Local	Jersey	T.wet/dry	Bangladesh	Comilla	On farm	0.91			0.82				0.94		Miazi et al., 2007
25	Local	Friesian	T.wet/dry	Bangladesh	Khulna	On farm	0.94									Ashraf et al., 2000
26	Local	Friesian	T.wet/dry	Bangladesh	Dhaka	On Station										Majid et al., 1996
27	Local	Jersey	T.wet/dry	Bangladesh	Dhaka	On Station										Majid et al., 1996
28	Sahiwal	Friesian	T.wet/dry	Bangladesh	Dhaka	Onstation										Majid et al., 1996
29	Local	Jersey	T.wet/dry	Bangladesh	Dhaka	On Station	1.00									Rahman et al., 2007
30	Local	Friesian	T.wet/dry	Bangladesh	Dhaka	On Station	1.04									Rahman et al., 2007
31	Local	Friesian	T.wet/dry	Bangladesh	Barisal/Patuakahli	On Station	1.08							0.83		Al-Amin and Nahar, 2007
						Mean	**0.92**	**1.02**	**1.03**	**0.81**	**0.87**	**0.85**		**1.03**		
						STDEV	**0.09**	**0.24**	**0.15**	**0.12**	**0.16**			**0.17**		
32	Sahiwal ♂	Ayrshire_D	Semiarid	Kenya	Machkos	On Station				0.85						Kimenye,1978
33	Sahiwal	Ayrshire ♂	Semiarid	Kenya	Machkos	On Station				0.92						Kimenye, 1978
34	Sahiwal	Friesian	Semiarid	pakistan	Bahadurnagar	On Station	0.90	1	1.01	0.73	0.70	0.80	2.60	1.50	1.10	McDowell et al., 1996
35	Sahiwal	B.Swiss	Semiarid	India	Karnal	On Station	0.89	0.88	0.90	0.77	0.75	0.84				Bala and Nagarcenkar, 1981
							0.90	**1**	**1.01**	**0.83**	**0.70**	**0.80**	**2.60**	**1.50**		
						STDEV	**0.01**		**0.06**	**0.10**	**0.03**	**0.02**				

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