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Case study: Phenotypic and Economic Effect of Crossbreeding in a Swedish Red and White Dairy Cattle Herd

Fallstudie: Fenotypisk och ekonomisk effekt av korsningsavel i en SRB-besättning

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Sammanfattning

Lönsam mjölkproduktion är något som alltid strävas efter. Mjölkproduktionen i industrialiserade länder kämpar med problem så som ökad inavel, minskad fertilitet samtidigt som marknadens krav på producenten ökar. Detta påverkar lönsamheten hos producenten och det är därför av stort intresse att undersöka möjliga lösningar på dessa problem. Korsningsavel samt renrasavel är två föreslagna lösningar. Många studier finns som jämför effekten av korsningsavel med rensrasavel för Holstein Friesian kor men få för andra raser. Från ett svenskt perspektiv är därför även den till antalet näst största rasen, Svensk röd och vit boskap (SRB) av intresse.

Egenskaperna som undersökts i denna studie var kg mjölk, kg fett, kg protein, kornas överlevnad (livslängd), somatiskaceller i mjölken, antal insemineringar per befruktning, mankhöjd samt levandevikt. Genom att använda information från litteratur samt från intervjuer så sattes två olika program för korsningsavel ihop för en SRB besättning. Båda dessa korsningsprogram baserades på roterande treraskorsning i hela besättningen. Det första med raserna SRB, Holstein Friesian och Montbéliarde (kallad ProCross) och det andra med raserna SRB, Jersey och Montbéliarde (kallad SJM korsning). Därefter genomfördes simuleringar av 30 års korsningsavel samt renrasavel för SRB så att de fenotypiska och ekonomiska effekterna för SRB rasen och de två korsningsprogrammen kunde jämföras.

Resultaten från denna studie ger en skattning av den kombinerade genetiska förtjänsten för de använda raserna i ProCross och SJM systemen. Däremot kan andra egenskaper som inte är inkluderade i denna studie påverka detta resultat både positivt och negativt. Från ett SRB perspektiv så var renrasavel konkurrenskraftigt jämfört med de två testade korsningsprogrammen. SJM korsningarna gav med dagens prissättning den bästa förtjänsten av de två korsningsprogrammen. Det föreslås dessutom att en kombination av SJM kor med en renrasig SRB kärna kan öka den totala lönsamheten i en besättning ännu mer. För att verifiera detta och hitta den mest lönsamma kombinationen så krävs fler studier på olika kombinationer av raser samt uppdelning av besättningen.

Nyckelord: korsningsavel, heterosis, fallstudie, mjölkkor, SRB, Holstein, Montbéliarde, Jersey.

Abstract

Profitable dairy production is always strived for. In recent years, dairy production in developed countries struggle with genetic problems like increasing inbreeding, reduced fertility and at the same time increasing market demands for competitiveness. This affects the profitability in dairy production and therefore it is of interest investigate possible solutions for these problems. Crossbreeding or pure-breeding is two suggested solutions. Many studies have compared crossbreeding effects with pure-breeding for Holstein Friesian cattle. However, from a Swedish perspective the second most common breed Swedish Red dairy cattle, is of interest as well.

Traits investigated were, kg milk, kg fat, kg protein, cow survival, somatic cell count, conception rate, height at withers and live weight. By using information from literature and interviews two different crossbreeding schemes were created for a Swedish Red dairy cattle herd. For these two schemes three-breed rotational crossbreeding was the basis. The first included the breeds Swedish Red dairy cattle, Holstein Friesian and Montbéliarde (named ProCross) and the second the breeds Swedish Red dairy cattle, Jersey and Montbéliarde (named SJM cross). Simulations of 30 years of crossbreeding or pure-breeding were then done so that the phenotypic and economic effect for the Swedish Red dairy cattle breed could be compared.

The results give an estimate of the combined total merit for the breeds used in ProCross and SJM. However, other traits not included in this study might affect the result differently. From an SRB perspective pure-breeding is competitive to these two tested crossbreeding schemes. With current market prices, the SJM cross gave the best profit of the two crossbreed scenarios. It is suggested that combining SJM crosses with a purebred nucleus might increase the overall herd profit even more. To verify this and find the most profitable combination more studies on different breed and herd group combinations are needed.

Keywords: Crossbreeding, heterosis, case study, dairy cattle, SRB, Holstein, Montbéliarde, Jersey.

Table of contents

Abbreviations

AI	Artificial insemination
BV	Breeding value
CR	Conception rate, percentage of mating's that result in conception
ECM	Energy corrected milk
HF	Holstein Friesian, dairy cattle breed
LW	Live Weight
Mb	Montbéliarde, dairy cattle breed
NRDC	Nordic Red Dairy cattle
NTM	Nordic total merit, index value used for breeding evaluation in Sweden, Norway and Denmark
ProCross	Crossbreeding scheme 1, rotational crossbreeding with the breeds SRB, HF and Mb
SCC	Somatic cell count
SJM cross	Crossbreeding scheme 2, rotational crossbreeding with the breeds SRB, Jersey and Mb
SRB	Swedish Red and White dairy cattle

1 Introduction

Livestock populations have for been managed and altered genetically by humans to increase their suitability for production of food, raw materials, traction and labor etc. During the last centuries, these genetic alterations have become more successful due to introduction of modern breeding programs and techniques. These breeds are, when comparing with traditional breeds, considered to give products more suitable for modern requirements, but also animals that produce more effectively and at a lower cost (Simm *et al.*, 2000). The combination of improved genetics, feeding and management has over the past 40 years led to a doubling in milk yield per dairy cow (*Bos taurus)* in most industrialized countries. In 2008, the milk production from Sweden´s two most common dairy cattle breeds, Holstein Friesian (HF) and Swedish red dairy cattle (SRB), made Sweden the European country with the highest milk yield. With national averages of 9 718 kg energy corrected milk (ECM)/lactation in the HF and 9 164 kg ECM/lactation for SRB (Rodriguez-Martinez *et al.* 2008). At present the Swedish averages are even higher and in 2015 Swedish HF produced on average 10 239 kg ECM/lactation and SRB 9529 kg ECM/lactation (Växa Sverige, 2016a). Despite the average production/cow being large the profitability in Swedish dairy production is uncertain. This uncertainty is reinforced by the variable milk price and increased proportion of imported milk to Sweden, which increases the competition with other countries. Partly as a result, the number of dairy cows has decreased with 13% during 2006-2015 in Sweden (Lingheimer *et al.*, 2016).

The overall genetic gain in milk production is estimated to 1.5% per year, however, at the same time there is a constant global decline in dairy herds average reproductive performance. This reproductive decline is biggest in breeds of high genetic potential for milk production as the HF (Rodriguez-Martinez *et al.* 2008). The decline explained partly by to the unfavorable genetic correlation between reproduction traits and milk production (Berglund, 2008). Increased inbreeding is another growing problem in common dairy cattle breeds, as the HF. This increases the risk of inbreeding depression (reduced biological fitness due to inbreeding) which is likely to also affect animal fertility and other health traits negatively (Hansen *et al.*, 2005; Sørensen *et al.*, 2005). Therefore, the need for dairy cows that are more efficient, healthy and robust is apparent for a sustainable production. Genetic improvement by selection is one way to achieve this. (Simm *et al.*, 2000). Crossbreeding is another option which might help to improve inbreeding problems at farm level as it results in the opposite of inbreeding; increased heterozygosity (Hansen *et al.*, 2005). Profitability might also be improved by systematic crossbreeding using breeds that are economically similar. Meaning that all breeds used in the crossing-system should have high levels of total genetic merit (McAllister, 2002; Sørensen, 2007; Sørensen *et al.*, 2008).

Many recent studies on dairy cattle crossbreeding in intensive production systems have been done in the U.S. (Heins *et al.*, 2012; Buckley *et al.*, 2014; Hazel *et al.*, 2016) and some in Denmark (Sørensen *et al.*, 2008). These studies are mainly comparing crossbred´s production and traits from a HF perspective. For other breeds like the SRB the economic and phenotypic effects are less studied. The most recent study on crossbreeding in Sweden was a Master thesis investigating breed effects and heterosis in Swedish HF and SRB (Jönsson, 2015). To increase the knowledge and possibilities to improve profitability of Swedish dairy production, it is of interest to further investigate how crossbreeding would affect the performance of dairy herds in Sweden.

The aim of this study was to investigate phenotypic and economic effects of two crossbreeding programs in comparison to pure breeding. Literature on crossbreeding will be summarized and used as a basis for a case study on crossbreeding. The case study will be performed by using information from the purebred SRB research herd at the Swedish University of Agricultural Sciences (SLU), Röbäcksdalen, and will investigate possible effects of crossbreeding at herd level.

2 Literature Review

2.1 Animal breeding

Animal breeding is generally divided into three different main strategies to achieve improvements of the progeny; between breed or strain selection, where one breed or strain is substituted for another. Within-breed or strain selection, where the best parents are selected within the breed or strain. Crossbreeding, where parents of two or more breeds or strains are mated. There are different genetic effects utilized in the three strategies where the within-breed selection utilizes the additive genetic effects, and crossbreeding utilizes both heterosis and additive genetic effects (Simm *et al.*, 2000). This paper will focus on the differences between genetic improvement in dairy cattle by crossbreeding and within-breed selection.

To understand breeding of dairy cattle it is necessary to know how breeding and breeding programs work in general. According to Oldenbroek and Van der Waaij (2014) the basis of animal breeding is that the parents' traits are reflected in their progeny. This is possible due to that traits are more or less heritable and that on average 50 % of the genes are coming from each of the parents. Simply stated, animal breeding means that animals with desired traits are selected and the best ones are used in breeding programs as parents. This enables genetic improvement in the progeny compared to previous generations for the selected traits. These traits, when measured as performance or appearance can also be referred to as phenotypes. These phenotypes are dependent on genotypes or both genotypes and environment. Long term breeding is planned in breeding programs and this generally includes seven different steps (Oldenbroek & van der Waaij, 2014). These seven steps are illustrated in Figure 1.

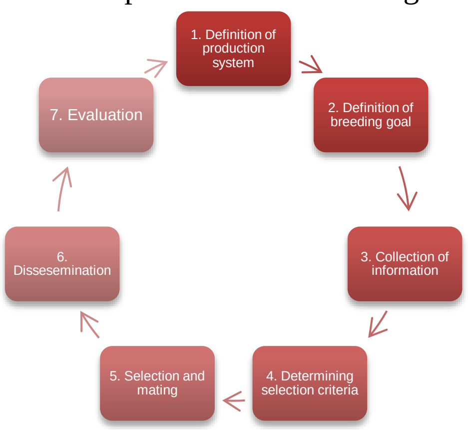

Figure 1. Seven general steps included in a breeding program.

Oldenbroek & van der Waaij (2014) has described the seven general steps in a breeding program. The first step, includes an analysis of the production system. This means that how and why the animals are kept should be described. Step one is relevant for the breeding program when deciding on which traits that are of importance for the targeted animals. Secondly, the breeding goal should be defined. This includes deciding which traits that should be improved in forthcoming generations. Thirdly, information regarding the traits included and pedigree data need to be collected. Today, DNA analysis (genomic testing) can also be used to aid this. Fourth, determining the selection criteria includes estimation of the animals breeding value (BV). This can be done with the use of a statistical model that includes pedigree information and are based on a genetic model. Also, DNA information on the animals can be used for this BV estimation (genomic selection). This BV gives an indication of the animals BV in connection to the breeding goal. For the fifth step, selection and mating, the BV is necessary to be able to select which animals that are superior and should be used for breeding. BV that are above average will then improve the traits in the breeding goal. Sixth, includes how the dissemination of the genes from the superior animals throughout the whole population should be done. This process depends on the breeding structure where different species have different structures. Dairy cattle breeding utilizes artificial reproduction techniques, in particular artificial inseminations (AI), to manage this. Finally, evaluated of the breeding program should be done on a regular basis. Evaluation includes analyzing the breeding goal traits, if goals have been achieved in the traits, if next generation animals are better, or if there are unwanted side effects. Also, the relatedness among the animals need to be analyzed and how the genetic diversity is affected in the population. These steps are then repeated and if needed after evaluation definitions and other steps in the breeding program will be changed (Oldenbroek & van der Waaij, 2014).

2.2 Dairy cattle breeding in short

For within-breed selection in dairy cattle, several countries have used milk yield as the primary selection trait, as well as breeding goal, due to its economic importance (McAllister *et al.*, 1994; Miglior *et al.,* 2005). In contrast, the Nordic countries, such as Sweden, has traditionally differed from other countries by also including recording and evaluation of a broader range of functional and reproduction traits in breeding (Berglund, 2008). Functional traits refer to characters that increase the production efficiency by reduced cost of inputs instead of increased outputs (Groen *et al.*, 1997). However, in recent years the dairy breeding in other countries has shifted towards the same direction, with higher proportion of functional and reproduction traits in focus for more balanced breeding (Miglior *et al.*, 2005).

In livestock production, genetic improvement by crossbreeding is today commonly used at production herd level to increase profit in species like pigs and poultry (Sørensen, 2007; Sørensen *et al.*, 2008; Buckley *et al.*, 2014;). Also in dairy cattle, systematic crossbreeding is considered to enable increased profit, if the right combination of breeds is used (McAllister, 2002; Sørensen, 2007; Sørensen *et al.*, 2008). Nevertheless, in dairy cattle crossbreeding is less common compared to within-breed selection. However, the interest in crossbreeding for dairy production is increasing (Hansen *et al.*, 2005; Sørensen, 2007; Sørensen *et al.*, 2008; Buckley *et al.*, 2014). In the Nordic countries, Sweden, Finland and Denmark, the three most common dairy cattle breeds are HF, Nordic red breeds and Jersey (Nordic Cattle Genetic Evaluation, 2017a). In Sweden, the Swedish HF consists of 54 % and the SRB of 38 % of the recorded cow population. However as mentioned, the proportion of crossbred dairy cows is small and in 2015 the proportions of AI for crossbreeds were for Swedish Holstein 9 % and for SRB 16 % (Växa Sverige, 2016a).

In Swedish breeding, inclusion of genes from other countries HF and of Finnish Ayrshire as well as the Norwegian Red are done on a regular basis for the Swedish HF and SRB populations (Ericson *et al.*, 1988). Today the SRB as well as the previously mentioned red breeds are part of the Nordic Red Dairy Cattle (NRDC) and the breeding evaluation is done in cooperation with the Nordic countries Denmark and Finland in the organization Nordic Cattle Genetic Evaluation (NAV). The same applies for the HF and the Jersey populations where all breeding evaluation in Sweden, Finland and Denmark is done by NAV (Viking Genetics, 2016; Växa Sverige, 2016b; Växa Sverige, 2016c; Nordic Cattle Genetic Evaluation, 2017a). For the Nordic breeding evaluation in NAV the Nordic total merit index (NTM) is used to aid the selection of breeding animals. The NTM is created to describe a cows' genetic potential for good economic results. Several traits are included in this index and these are; Yield, Live weight gain, Fertility, Calving ability (direct and maternal), Udder health, General health, Claw health, Temperament, Longevity, Udder conformation, Milkability, Feet and leg conformation. These traits are then weighted against each other so that high NTM cows should give the best economic benefits for the farmer (Nordic Cattle Genetic Evaluation, 2017b). Another tool to select breeding animals is genomic testing (Växa Sverige, 2017b). This is based on DNA sampling and enables higher accuracy in the estimated breeding value as well as selection of breeding animals earlier in life. However, genomic selection is also dependent of continued data recording for the selection traits (Jonas and De Koning, 2015).

2.3 Additive genetic effect

In selective breeding and crossbreeding, both additive gene effects and heterosis are utilized. These are described further in the two following parts.

Within-breed selection is generally done to increase the average level of additive genetic merit, also called BV, in an animal population. The additive gene effect is based on interactions between genes, dominance and epistatic effects excluded, that contribute to the phenotype. The gene effect is termed additive when the heterozygous animals are intermediate to the homozygous animals. Furthermore, the additive genetic variance is the combined additive gene effects causing variation in one trait or BV (Simm *et al.*, 2000).

2.4 Heterosis effect

In crossbreeding, the crossed breeds have different additive genetic levels. When crossing these, new combinations of additive gene effects are created, resulting in offspring with for example better profitability (Falconer & Mackay, 1996). A function of the difference between the crossbreed progeny and the average purebred progeny is the definition of heterosis. The amount of heterosis, depends on how big the difference is in allele frequencies, at loci where dominance effects exists, between the two breeds. The heterosis effect is due to changes in dominance, epistasis and increased heterozygosity (Van Vleck *et al.*, 1987; Simm *et al.*, 2000). Another way to consider the heterosis effect is as a bonus in performance on top of the crossed individuals´ gene effects, where the best result is gained when top AI sires are used. Furthermore, to maintain the competitiveness in crossbreed populations it is essential to continue the genetic improvement in the pure breeds. Otherwise the phenotypic level of future crossbreds will stop improving (Hansen et al., 2005).

Measurement of heterosis, is done either in trait units or as a percentage of the mid parent mean. The non-additive gene action that causes the heterosis also increases the difficulty in predicting the effect of the crossing, as some crosses give large heterosis effects and some don´t. In cases where the effect is large the breeds crossed are said to have a good combining ability (Simm *et al.*, 2000). Heterosis for dairy cattle is shown to be present in economically important traits such as milk production and conception rate. The bonus of heterosis is thought to be largest for longevity and functional traits compared with production traits (Sørensen et al., 2008).

2.5 Reproduction methods

At some point all livestock production systems needs to replace their production stock. Purebred dairy cattle herds can easily produce their replacement heifers by mating animals of the same breed. In crossbreed herds a first-generation cross is called F1 and is produced by mating two purebred animals of different breeds. For optimum heterosis effects all animals in the herd should be F1. Producing your own replacement stock can thus be more difficult in a crossbred herd (Lopez-Villalobos *et al.*, 2000). Usage of F1 animals at herd level in dairy cattle production has earlier been difficult due to cattle's low reproduction rate and long generation interval. Nowadays, sexed semen is a tool that can change this situation (Sørensen *et al.*, 2008). Sexed semen enables the farmer to choose the gender of the progeny. For example, to ensure that the selected cow gets a heifer calf that can be used for replacement or a bull calf from the elite dam for progeny testing. This lowers the required females for production of replacement heifers as the sex ratio is altered (Hohenboken, 1999). Sexed semen sorted for heifer calves is called x-vik and when sorted for bull calves it is called y-vik.

Furthermore, combining sexed semen with crossbreeding enables that herds can have a pure-bred nucleus that produce both production F1 animals and pure-bred animals for the nucleus as a higher percentage of the progeny will be heifers. Progeny from the F1 animals are then only used for meat production. To increase the profit from these, beef semen can be used on the F1 animals (Hohenboken, 1999; Sørensen *et al.,* 2008).

2.6 Aims with crossbreeding

Crossbreeding can be used for different reasons, some general reasons for crossbreeding has been summarized by Simm *et al.*, (2000). Firstly, crossbreeding can be used in production systems to improve the overall efficiency of the system. This is done by crossing two animals with high genetic merit, e.g. NTM values, from different complementary breeds. Secondly, the aim can be to produce an intermediate progeny that suit the production system better, e.g. beef breed crossed with a dairy breed for a high producing suckler cow. Thirdly, crossbreeding can be used to up-grade a specific herd from one to another breed. Fourth, crossbreeding is necessary when new composite or synthetic breeds are created. Crossed animals´ that are created as a step towards a composite breed are called intermediate crosses. In these first four described aims for crossbreeding as well as for within-breed selection the difference in additive genetic level between populations and individual animals are utilized. Fifthly, crossbreeding can be used to introduce new variation into another breed. E.g. if a numerically small breed has difficulties finding enough high merit unrelated animals, crossbreeding can aid this problem. The sixth, next possible aim is that crossbreeding is used to introduce a single gene giving a favorable characteristic that the current breed population doesn´t have. For e.g. introduction of polled genes into horned populations. The last described reason for crossbreeding is to utilize the bonus in the progeny from the heterosis effect (Simm *et al.*, 2000).

As a practical example crossbreeding is described as an option to handle problems like the decline in fertility. However, this will only work if other breeds exist with less problems. Crossbreeding as a method is by Rodrigues-Martinez *et al.* (2008) not considered as a long-term solution for problems like this as crossbreeding is not genetic improvement that is passed on to the progeny as e.g. within-breed selection does. If crossing is not continued in every generation the heterosis effect will disappear. Thus, crossbreeding is always dependent on within-breed selection and genetic improvement within-breeds (Rodriguez-Martinez *et al.* 2008). However, there are exceptions, if the problem is caused mainly by high inbreeding, crossbreeding can improve the progeny independently on the new breeds trait level.

2.7 Crossbreeding systems

Several crossbreeding systems exist that take advantage of the benefits with crossbreeding (Van Vleck *et al.*, 1987). The simplest crossbreeding that can be done is the two-breed cross. This cross is created by mating two animals of different breeds or lines. An illustration of the theoretic breed percentages in a two-breed cross are presented in Figure 2. The two breed cross results in 100 % heterosis effect (Lopez-Villalobos *et al.*, 2000; Sørensen *et al.*, 2008). When the crossed progeny never enters the breeding stock it is termed a terminal cross. For example, if a HF and a SRB is crossed and the progeny is only used for production and not for producing recruitment animals this is then called a two-breed terminal cross. The bull used for this crossing is referred to as the terminal cross sire (Van Vleck *et al.*, 1987).

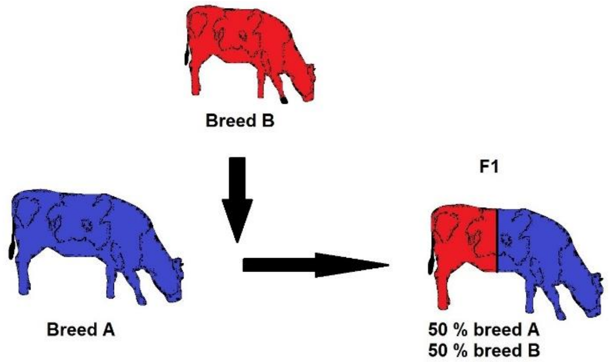

Figure 1. Illustration of two-breed cross.

Next crossbreeding system is the three-breed cross, which is illustrated in Figure 3. In this system, the progeny from the first and second generation are both F1 progeny as both have 100 % heterosis due to the inclusion of a third breed.

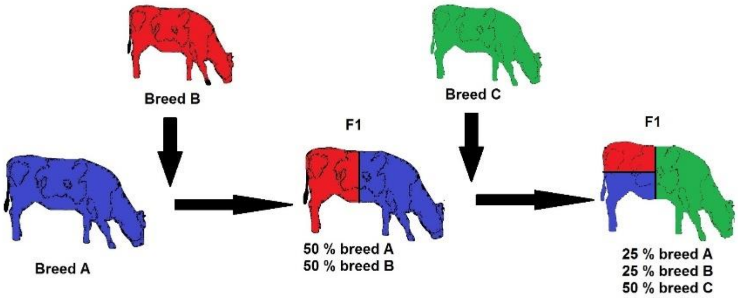

Figure 2. Illustration of three-breed cross.

Rotational crossbreeding is one way to utilize the heterosis effect and still produce animals for your own recruitment. The main idea of rotational crossing is that purebred bulls of two or more alternating breeds are used on the crossbreed cows. The bull usage should then alternate between the breeds used. Two-breed rotational crossing stabilizes on a heterosis effect of 67 %

and with three-breed rotational crossing the heterosis effect stabilizes on 86 % (Lopez-Villalobos *et al.*, 2000; Sørensen *et al.*, 2008;). In figure 4 and 5 illustrations of two- and three-breed rotational crossing is presented.

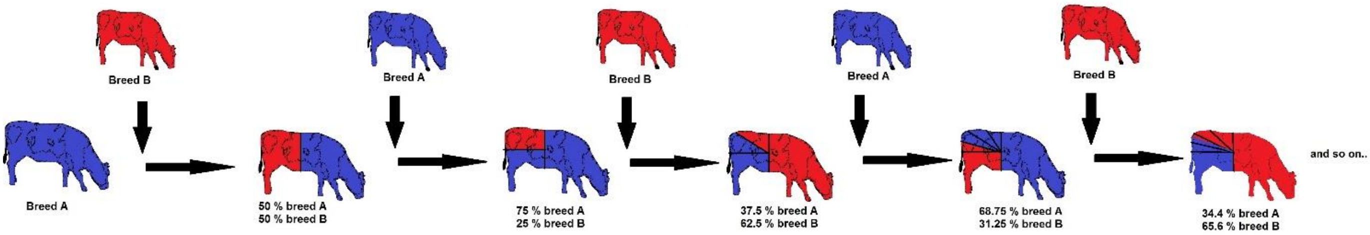

Figure 3. Illustration of two-breed rotational crossing.

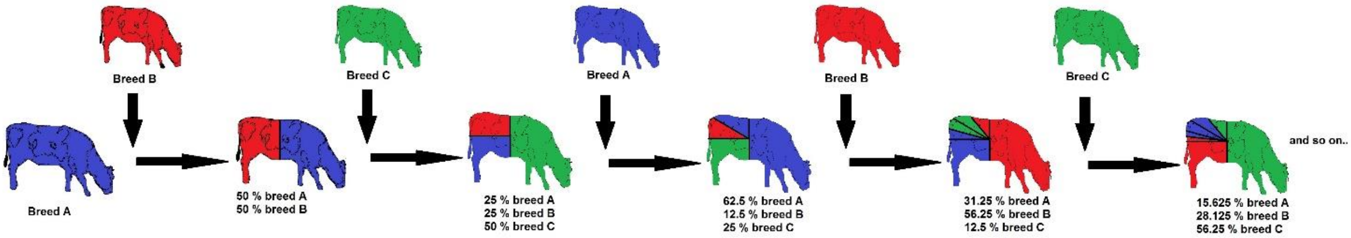

Figure 4. Illustration of three-breed rotational crossing.

Rotational crossing creates fluctuations in means of the populations genotype between generations, how big these fluctuations are, depend on how big the additive breed differences and heterosis effects are. To avoid these fluctuations a composite population could be created by crossing two-, three- and four-breed hybrids. In beef cattle, there are results indicating that optimum performance levels in major economical traits can be achieved with creating composite or synthetic populations. However, creating an new composite population requires massive resources (McAllister, 2002). Example of creation of composite populations or a new breed can be seen in paragraphs 2.10.1 and 2.10.2.

2.8 Breeds for dairy cattle crossbreeding

In general, for a profitable crossbreeding, it is important to consistently use systematic breeding strategies. Furthermore, the breeds used should preferably be similar with respect to their total merit, e.g. NTM value. How much the breeds total merit can deviate from each other depends on which crossbreeding system that are used. Where the three-breed rotational crossing have compared to two-breed rotational crossing a higher average heterosis effect and thus the third breed used in the system can deviate slightly in total merit (Sørensen *et al.*, 2008). Two other practical advices for deciding upon which breeds´ or animals that should be used for crossbreeding has for American HF been described by McAllister (2002). Firstly, using crossbreeding, begins with the choice of sires from the purebred population. It is then recommended to choose sires that are from the best 20 % of the population in the new breed. Secondly, it is important to have good availability of breeding animals and semen with high genetic quality (McAllister, 2002).

Usage of genomic selection in pure-bred animals to maximize the crossbred animal performance has by Esfandyari *et al.* (2015) been studied. They simulated the differences in F1 crossbred animal performance, when the breeding animals had been selected by genomic BV for pure-bred performance or for crossbred performance. These simulations suggest that the individuals selected for crossbred performance also gave progeny with better crossbred performance than when the parents were selected for purebred performance.

When planning the crossbreeding system, the different breed's requirement and the way they complement each other should be considered. If the breeds used at present have a low genetic level in important traits, another breed with high genetic level in these traits can be used to get a rapid improvement for these traits in the progeny (Sørensen *et al.*, 2008). As an example, some considerations have been described by McAllister (2002) that need to be made when choosing the breed or breeds for crossing with American HF. Firstly, the crossed-in breeds´ rate of genetic progress in yield traits need to be considered as it describes the strength of the current within-breed selection. Secondly, consider breeds with yield levels that are competitive with the breed, e.g. minimum 75 % of their level. Thirdly, the breed should have demonstrated heterosis with the starting breed in both yield traits and fitness traits. Finally, to counterbalance a possible disadvantage in breed additive genetic merit, the crossed in breed should have a demonstrated better maternal performance (McAllister, 2002).

To choose breeds for crossbreeding, production results and other traits must be considered. Production results and breed parameters of the two most common dairy cattle breeds in Sweden, HF and SRB, as well as two dairy cattle breeds that are commonly used in dairy cattle crossbreeding, Montbéliarde (Mb) and Jersey, are summarized in Table 1.

Table 1. Summary of average breed parameters for Swedish red and white cattle (SRB), Holstein Friesian (HF), Jersey and Montbéliarde (Mb).

Breed averages	SRB	HF	Jersey	Mb
Milk, kg ECM	9529	10239	9225[7]	8194[9]
Fat, kg	393	414	422[7]	274[9]
Fat, %	4.36	4.09	5.87[7]	4[9]
Protein, kg	322	345	297[7]	230[9]
Protein, %	3.57	3.4	4.13[7]	3.8[9]
Age at culling, months	61	60.1	60.6	59.6[6]
Nr. inseminations/cow	1.79	1.83	1.81	2.05[6]
SCC, thousand	254	254	254	235[5]
Lactation number	2.58	2.43	2.51	2.8[6] - 2.9[5]
Live Weight, kg	550-600[3]	680[8]	454[8]	600-750[4]
Height at withers, cm	140.4[2]	149.4[2]	129.4[2]	147.5[4]

[1]*Data are summarized Swedish animal statistics (Växa Sverige, 2016a) unless otherwise stated.* [2]*Breed averages from Nordic breeding evaluations (Pers. comm. Carlén, 2017),* [3] *Breed standard (Växa Sverige, 2016d),* [4]*Information from the breed organization* (Organisme de Sélection de la Race Montbéliarde, 2017a), [5]*Information from the breed organization* (Organisme de Sélection de la Race Montbéliarde, 2017b), [6] *Production results Irish study* (Walsh *et al.*, 2008), [7] *Breed statistics* (Viking Genetics, 2017), [8]*Figures from study (Capper and Cady, 2012),* [9] *Presented breed averages (ProCross, 2017).*

2.9 Crossbreeding studies

A Swedish study on SRB x HF crosses concluded that the heterosis effect between these two breeds in Sweden are small, however, still significant. Furthermore, these crosses were concluded to have the same or a higher production level than the best pure-bred animals (Ericson *et al.*, 1988). A more recent Swedish study estimated heterosis effects in SRB x HF and HF x SRB for several production and functional traits such as kg milk, number of inseminations, SCC and survival to 2nd and 3rd lactation. This study concluded that in most of the tested traits crossbreeding was most efficient and favorable in first lactation but heterosis existed in later lactations as well. Furthermore, crossbreeding was concluded as a favorable breeding strategy if the aim is to improve functional traits at herd level. SRB x HF crosses produced less milk than the purebred average cow, however, the solids amount is constant or even better (Jönsson, 2015). In Irish study on Norwegian Red cattle x HF crossbreds it was concluded that in several reproductive and survival traits this combination was a viable option to improve survival and reproduction efficiency compared to pure HF cattle. This positive effect is due to the additive genetic superiority in the Norwegian Red for these traits compared to the HF. Production of these crosses was also estimated to be competitive with purebred HF (Begley et al., 2008; Begley et al., 2009). In Table 2 a summary of estimated heterosis effects in literature between SRB/NRDC and HF can be seen.

Table 2. Summary of estimated heterosis effects for NRDC/SRB x HF crosses for traits of interest in phenotypic simulations.

Trait	Heterosis (%)	Reference
Kg milk*	1.6-3.7	Ericson *et al.*, 1988; Begley *et al.*, 2009; Jönsson, 2015
Kg protein*	1.3-3.5	Begley *et al.*, 2009; Jönsson, 2015
Kg fat*	1.8-4.5	Ericson *et al.*, 1988; Begley *et al.*, 2009; Jönsson, 2015
SCC	2.0	Jönsson, 2015
Survival to 3rd lactation	12.3-13.0	Jönsson, 2015
Number of services	2-3.4	Jönsson, 2015

**Calculated per 305 days lactation*
NRDC= Nordic red dairy cattle, SRB= Swedish red dairy cattle, HF=Holstein Friesian Dairy Cattle

Estimation for heterosis from a French population between HFxMb crosses are presented in Table 3. These estimates were done to investigate the effect of inbreeding in pure-bred Mb, HF and Normandie as well as the effect of crossbreeding in French dairy herds. Crossbred HF x Mb cow had higher fat and protein contents than HF cows as well as a lower SCC. These estimates are however done on a small number of crossbred animals (Dezetter *et al.*, 2015). Heins *et al.* (2012) investigated survival, lifetime production and profitability of HF x Mb and NRDC/SRB x HF crosses. Survival during first lactation was significantly higher in crossbred cows than in purebred HF. Also, the lifetime production where significantly larger for these crossbred cows, compared to the purebred HF cows. For life time profit both crosses had an estimated higher profit per day in comparison to HF (Heins *et al.*, 2012). In an ongoing study of crosses between HF, NRDC/SRB and Mb by Hazel *et al.*, (2016) several traits have been investigated. The crossbred cows where significantly smaller in stature than the HF, however, the body condition score was at the same time higher. Overall conception rate was higher for the crossbreds and for HF x Mb crosses the survival to 2nd lactation was significantly higher in comparison to HF (Hazel *et al.*, 2016).

A study by Heins and Hansen (2012) investigated the effect of crossing HF with NRDC, Mb and Normande to improve fertility, SCC and production. The traits investigated were fertility, SCC, 305 days’ milk production (including fat and protein). From this study, the Normande cow was excluded as a potential dairy breed to use for improvement of the HF declining fertility and udder health while still maintaining a high production. The Normande was excluded due to HF x Normande crosses having lower average production than the other studied crosses in comparison to the purebred HF. However, both NRDC and Mb was considered as potential breeds for crossing with HF (Heins & Hansen, 2012).

Table 3. Summary of found literature estimated heterosis effects for HF x Mb crosses for traits of interest in phenotypic simulations

Trait	Heterosis (%)	Reference
Kg milk*	6.0	Dezetter *et al.*, 2015
Kg protein*	5.7	Dezetter *et al.*, 2015
Kg fat*	6.4	Dezetter *et al.*, 2015
SCC	1.4	Dezetter *et al.*, 2015
Conception rate (CR), %	6.5	Dezetter *et al.*, 2015

**Calculated per 305 days lactation*
HF= Holstein Friesian dairy cattle, Mb= Montbéliarde dairy cattle

A New Zealand study by Lopez-Villalobos *et al.* (2000b) investigated profitability's of different mating systems for the breeds HF, Jersey and Ayrshire breeds (NRDC included). The mating systems investigated were within-breed selection, two-breed and three-breed rotational crossbreeding. Some heterosis estimates from this study are presented in Table 4. The profitability was estimated with current market values for milk and beef. In this study, it was concluded that changes in payment for fat in proportion to protein content affected the profitability more in herds where Jersey crosses where used. Changes in beef payment had on the other hand a bigger effect on crosses where HF and Ayrshire breeds were included. The heterosis estimates between Jersey x HF and Jersey x Ayrshire showed high estimates for F1 crosses in milk, fat, protein, live weight (LW) and survival. HF x Ayrshire breeds had lower heterosis estimates for these traits. The crossbred herds in this study had generally lower replacement rates compared to the purebred herds. The dry matter (DM) requirements were investigate in this study and it was concluded that Jersey herds had the lowest total DM need per herd. In comparison, the HF had the highest DM intake. Ayrshire herds were in between and crossbred Jersey x Ayrshire herds had the second lowest DM requirement. The production differed between these breed combinations with 9347 kg ECM/year for Jersey cows, 9413 kg ECM/year for Jersey x Ayrshire crosses, 8815 kg ECM/year for HF herds, 8948 kg ECM/year for Ayrshire herds and 9349 kg ECM/year in HF x Jersey crossed herds. Giving a calculated feed efficiency (kg ECM/kg DM intake) of 2.23 for Jersey herds, 2.13 for Jersey x Ayrshire, 1.95 for Ayrshire, 2.03 for HF x Jersey and finally 1.77 for HF herds (Lopez-Villalobos *et al.*, 2000b).

The feed used for maintenance for a cow is directly affected by a cows' LW as well as the level of activity, e.g. milk production. To reduce the environmental impact of dairy production the possibility prevails to reduce the LW of a cow while still maintaining the production. For the Jersey and the HF, a study has compared the environmental effect of these two breeds for cheese production. This study show that the Jersey cows´ improved milk solids and reduced live weight in comparison to the HF cows gives more produced cheese per consumed natural resource. Thus, the greenhouse gas emissions (in this case per unit produced cheese) is reduced when milk from Jersey cows are used for cheese production (Capper & Cady, 2012).

Table 2. Summary of found literature estimated heterosis effects for NRDC/SRB and Jersey crosses for traits of interest in phenotypic simulations.

Trait	Heterosis (%)	Reference
Kg protein*	4.6	Lopez-Villalobos *et al.*, 2000b
Kg fat*	4.5	Lopez-Villalobos *et al.*, 2000b
Survival	4.7	Lopez-Villalobos *et al.*, 2000b
Kg live weight	2.3	Lopez-Villalobos *et al.*, 2000b

**Calculated per 225 days lactation*
NRDC= Nordic red dairy cattle, SRB= Swedish red dairy cattle

In a study by VanRaden and Sanders (2003) estimates of a general heterosis effects across breeds in the U.S. was done. The breeds included in the study were; Ayrshire, Brown Swiss, Guernsey, Jersey, Milking Shorthorn and HF. For kg milk/day the heterosis was 3.4%, heterosis for kg fat/day was 4.4%, kg Protein/day was 4.1%, SCC was 0.7%, heterosis for productive life was 1.2% and heterosis for mature size was estimated to 3.0% (VanRaden & Sanders, 2003). A Danish study also estimated general heterosis effects for six types of traits for F1 crosses, two-breed rotational and three-breed rotational crossing at equilibrium. These estimates were done using scientific literature available in 2004. For three-breed rotational crosses production traits has a general heterosis of 2.5%, Fertility traits 9%, maternal calving ease 13%, maternal stillbirth 2-3%, longevity 9-13 % and income per cow is generally estimated to a minimum of 9%. For F1 crosses production traits had a heterosis of 3%, fertility 10%, maternal calving ease 15%, maternal stillbirth 2-3%, longevity 10-15% and the general income heterosis is estimated to a minimum of 10 % (Sørensen, 2007).

2.10 Crossbreeding: cases from practical agriculture

2.10.1 Santa Gertrudis

Crossbreeding has in the USA. been used to create a new breed that is more environmentally suitable for production in harsh, hot and humid areas, the Santa Gertrudis. The Santa Gertrudis breed was created at the Kings Ranch in Kingsville, Texas (USA) and recognized by the U.S. Department of Agriculture as a new breed in 1940. The breed is today used in ranching systems all over the world for both crossbreeding and as a purebred (King Ranch, 2016).

The Santa Gertrudis was originally created using systematic crossing of the two breeds Brahman cattle and British Shorthorn. Years of selective experimental crossing then resulted in the founder sire, called Monkey. The founder sire was then used on a group of F_1 Brahman x Shorthorn heifers and with linebreeding the characteristics of the founder sire were maintained. The

Santa Gertrudis animals are today recognized as being 5/8 British Shorthorn and 3/8 Brahman (King Ranch, 2016; Santa Gertrudis Breeders International, 2016).

2.10.2 Brangus

The Brangus breed was created in the USA by crossbreeding of Brahman and Angus cattle. The first experimental crosses where made in 1912 at the USDA Experiment Station at Jeanerette, Louisiana. The aim with the crossing was to create a beef-breed that would utilize the Brahman´s ability to produce well in harsh conditions and the Angus breeds excellent beef producing qualities. The appearance of the animals should be solid black or red as well as polled (International Brangus Breed Association, 2008).

The American Brangus Breeders Association was founded in 1949 (renamed to International Brangus Breeders Association (IBBA)). Todays registered Brangus cattle descend from founder cattle registered that year or enrolled Brahman and Angus related cattle since then. These latter enrolled cattle are what the association’s claims make the herd book of the Brangus breed unique. Herds with registered Angus or Brahman cattle can be up-graded to Brangus herds by crossing in Angus or Brahman cattle. Animals that then have the proportions of 5/8 Angus and 3/8 Brahman can be registered and certified as pure Brangus. The intermediate crosses until the desired breed proportions are also certified by the IBBA. This enables new bloodlines to be created within the Brangus breed still (International Brangus Breed Association, 2008). An example of crossing to create a Brangus animal is shown in Figure 6, the process can be sped up by purchasing crossed bulls or crossed bull semen.

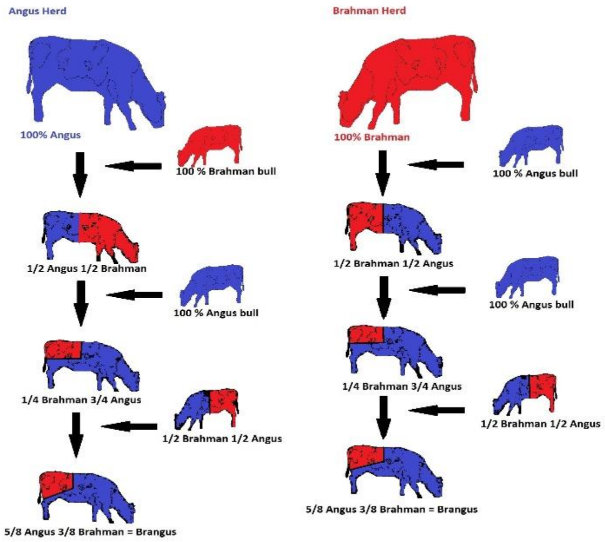

Figure 5. Example of crossbreeding to create an animal of the Brangus breed.

2.10.3 ProCross

A three-breed rotational crossing system (see figure 5) of the breeds HF, SRB/NRDC and the Mb is marketed and founded by the breeding cooperation's Coopex Montbéliarde and Viking Genetics. This system is known as the ProCross crossbreeding program and used in systems focusing on dairy production (ProCross, 2016).

In paragraph 4.1.2. information from a commercial Swedish dairy farm, Nilsson's in Skråmered, that are using ProCross in their livestock production is presented.

3 Material and Method

3.1 Data and literature compilation

Literature on crossbreeding and within-breed selection were collected as a continuous process throughout the whole project. The literature used in this study represent both published scientific articles and information published by the cattle industry. Information at herd levels were gathered during interviews as described in paragraphs 3.1.1. Some additional information on herd data and breeding work were gathered though personal communication. Herd data used in simulations were gathered from the official milk recording database.

The two herds included in the study where selected to meet certain requirements. One herd should currently be using systematic crossbreeding as the main breeding method and the other herd pure-breeding with SRB. Both herds should have loose housed systems and conventional intensive dairy production. The herd selected as the crossbred herd for interviews is one of the predecessors in Sweden using the ProCross system and the herd is located in south of Sweden in Skråmered, Halland county. For simulations and interviews in a purebred SRB herd, the research herd SLU Röbäcksdalen was chosen as it already has major data recordings available and a high genetic merit SRB population. The SLU Röbäcksdalen herd is located in the North of Sweden in Umeå, Västerbotten County.

3.1.1 Interviews

Two qualitative interviews were completed. The qualitative alignment was chosen as it is useful to gather information from persons with local knowledge, about actual working conditions, opinions and perceptions. When interviewing, the approach is different if it is an informant or respondent that is interviewed. The informant contributes information on actual relationships and perceptions on other´s opinions. The respondent contributes with more direct opinions on own perceptions and emotions. However, in practice both can be the same person (Olsson & Sörensen, 2011). In this project, the interviewed persons were both respondents and informants.

Preparations for the interviews differed some between the two. Both included going through literature on within-breed selection and crossbreeding before questions were created. The overall aim with the interviews was to gather information and viewpoints on different breeding work at the SLU Röbäcksdalen herd and the Nilsson's in Skråmered herd. The first interview was with Karimollah Rahimi who is the herd manager at SLU Röbäcksdalen. The SLU Röbäcksdalen herd is currently not using crossbreeding. The aim was to investigate today´s working conditions, pros and cons with the herd, opinions and viewpoints on how changing to crossbreeding would work in practice. Furthermore, to increase the connection between the herd and the crossbreeding schemes that will be created, it was also of interest which crossbreeding methods they are more prone to use and which phenotypes they are inclined to improve. Questions asked can be seen in Appendix 1. The second interview was conducted with Anders Nilsson, herd owner at Nilsson's in Skråmered. In contrast to Röbäcksdalen, they are currently using the crossbreeding program ProCross. The aim with this interview was to increase the knowledge on how crossbreeding can be used in Swedish dairy production and investigate opinions on pros and cons with it in comparison to pure breeding. Information gathered will be used as a practical example for crossbreeding in Sweden. Questions asked can be seen in Appendix 2.

3.2 Test population

At present the SLU Röbäcksdalen herd consists of purebred SRB and is used for research on animal nutrition, animal health, dairy cattle management and sustainable food production (SLU, 2016). The herd is kept in two different stables, one insulated and one uninsulated. All cows are loose-housed and in total there are three different groups of milking cows today. Animals are during the summer kept outside on pastures and during winter housed inside. Due to the location of the farm the pasture season is at least 60 pasture days (6h/day) long and should occur during the period 1 May to 15 October (SJVFS 2010:15). The cows are milked two times a day in parlor and are fed roughage ad libitum. A short summary of the present production result and herd data is shown in Table 5.

Table 3. Short summary of one year production results and herd data collected 11-11-2016 in the SLU Röbäcksdalen herd.

	All cows	1st lactation cows
Mean cow number	127.3	-
ECM kg/year	8469	-
Fat kg/year	364	-
Protein kg/year	368	-
SCC in bulk	183	-
Total calving	137	47
Total difficult calving	5	4
Calving interval, months	12.7	-
Age at first calving	-	24.9
Replacement rate	37 %	-
Total number of disease treatments	52	11
Total number of mastitis treatments	33	11
Mean cow age in herd	4.5 years	-
Mean cow height at withers	136.9 cm	-
Mean NTM value	3.59	-
Highest NTM value	20	-
Lowest NTM value	-10	-

ECM = Energy corrected milk. NTM = Nordic Total Merit index

3.3 Current breeding program

The SLU Röbäcksdalen breeding goals is connected to the breeding aim of the SRB breed. The breeding bulls used are selected through NTM values. Furthermore, in the herd health-related traits like mastitis resistance and survival are in focus when choosing AI bulls (Pers. comm. Hultdin, 2016). The SRB breeding goal, aims to have a high producing cow with high fat and protein content as well as good meat production and good longevity. The cows should be functional with easy calving, good fertility and health as well as good claws. A good milkability and temperament is also aimed for. Health properties of the breed are considered unique and to enable a good production economy (Växa Sverige, 2016d).

The reproduction method used is only AI and the insemination doses are bought from the breeding company Viking Genetics which is partly owned by Växa Sverige, the advisory organization used at SLU Röbäcksdalen. The breeding plan is updated every 8th week before ordering new AI doses. Cows and heifers that are next up for insemination are then discussed as well as run in the breeding tool Genvägen before AI bulls are chosen. The strategy is to use the top bulls available to increase the genetic progress. Animals with high NTM index (+16) are put under special attention so that the newest top AI bulls can be used for them. All bulls used as well as all cows on the farm are genomic tested. The herd is also connected to IndividAvel (linear conformation classification) (Pers. comm. Hultdin, 2016) meaning that all first lactation cows are scored for conformation and workability traits, such as milkability and temperament. Breeding values are then estimated for these traits (Växa Sverige, 2016e). Beef breed bulls through AI are also used on low index cows or cows that no recruitment is planned from. This progeny is not recruited from and the bull calves are sold to a beef producer. Sexed semen is used on cows that has been proven to be good producers and with good working abilities (Pers. comm. Hultdin, 2016). The usage of bulls was during 2016 approximately 5.8 % beef breeds, 91.4 % were progeny tested and 8.6 % of the used AI bulls were young bulls.

3.4 Creation of breeding schemes

For this study literature on scientific crossbreeding studies were compiled to investigate common crossbreeding schemes and breeds used in dairy cattle crossbreeding. Some practical examples were studied to increase the knowledge on crossbreeding. Information from the herd manager at SLU Röbäcksdalen on practical applications with crossbreeding were also considered. From this, two crossbreeding schemes were created to fit the SRB cows at SLU Röbäcksdalen These are presented in paragraphs 2.4.1 and 2.4.2.

For the new crossbred cows the general "breeding goal" is stated as: They should be robust animals, with high disease resistance and lifetime production. The cow should get pregnant when inseminated at the right time (at peak of oestrus) and the calving should be easy. They should also have a conformation that fits well in size to the surroundings and enables them to move well and easy as well as produce during many lactations. The milk produced should be high in quality and the cow should be efficient in converting feed into milk.

For the crossbred animals, the milk recording will be used to register information on the herd. In this project the phenotypes kg milk, kg fat, kg protein, survival (increased culling age in months), SCC, number of inseminations per pregnancy, height at withers and LW are of extra interest. Data for these, except for LW, are already collected and summarized in the milk recording and it is important that this continues to be done for the crossbreds as well.

3.4.1 Crossbreeding Scheme 1

Crossbreeding scheme 1 is based on a three-breed rotational crossing system and the breeds used are SRB, HF and Mb (named ProCross). In Figure 7 the breeding flow from a pure SRB herd to a ProCross herd is illustrated. The ProCross system will theoretically stabilize at a heterosis level of 86 %.

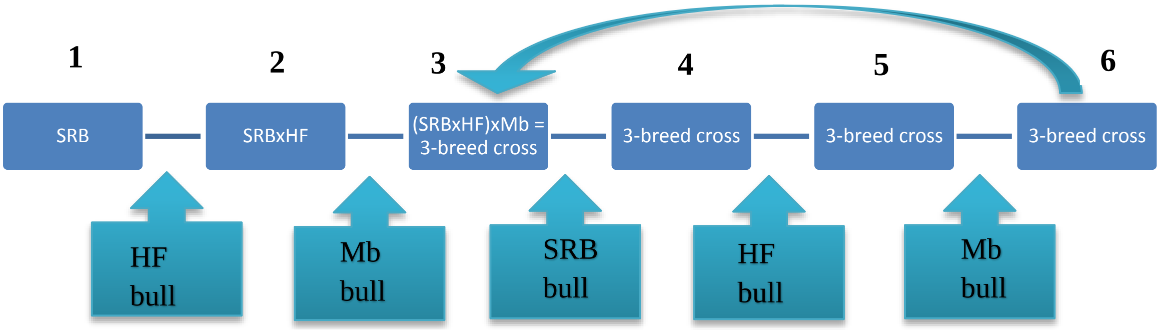

Figure 7. Illustration of breeding flow in crossbreeding scheme 1. From a pure SRB herd to a herd with only three-breed crosses. Numbers in figure represents group numbers used in Table 6. SRB = Swedish red and white cattle, HF= Holstein Friesian cattle, Mb = Montbéliarde cattle.

The breed distribution of the herd will change when using ProCross, this is illustrated in figure 8. This change in breed distribution will not happen instantly but the figure illustrates how the distribution will be when the herd has stabilized and all animals are three-breed crosses. To enable selection between the crossed animals it is important to continue the recording of traits as today. Top AI bulls should be used from all three breeds at all time. When using Mb bull on heifers it is advised that x-vik semen is used to ensure heifer calves, which are smaller than bull calves and are expected to give fewer calving problems.

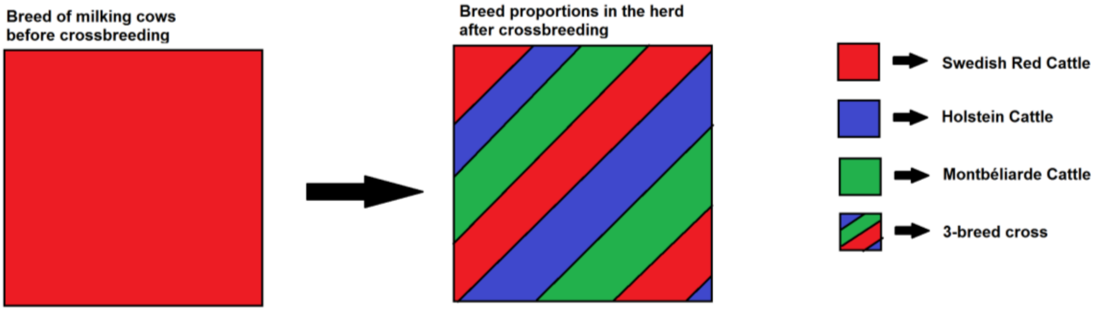

Figure 8. Illustration of breed proportions in the herd with crossbreeding scheme 1.

3.4.2 Crossbreeding Scheme 2

The three-breed rotational crossing scheme used in option 2 is similar to the ProCross scheme, figure 7 also applies to this scheme if Jersey is substituted with HF. This breeding scheme with, SRB, Jersey and Mb is named SJM cross. The principle for the breeding flow from a pure-bred SRB herd to a herd with only three-breed crosses is illustrated in figure 7. The breed proportions in the herd will change in the same way as for the ProCross option and thus Figure 8 applies on the SJM cross, except that Jersey is used instead of HF. The SJM will stabilize on a theoretical heterosis level of 86 %. It is advised that top AI bulls for all three breeds are used for all breeding animals. As in ProCross, when using Mb bull on heifers, it is advised that x-vik semen is used to ensure heifer calves.

3.5 Simulations

Literature of phenotypes investigated for heterosis between the chosen breeds in ProCross and the SJM cross were compiled, interviews was also conducted and the combined information was then used to decide for eight traits to investigate further. Traits chosen should preferably have a previously shown heterosis effect with the SRB/NRDC breeds and the other breeds used in the simulations in combination with being of specific interest for this herd. When the heterosis was not known, they were estimated with the help of scientific literature on production differences between crossbreds and purebreds. The calculations done when estimating these are shown in Appendix 3. General heterosis estimates were used for the two growth traits, as well as for the heterosis estimates used for the, Jersey x Montbéliarde crosses, where no crossbreeding studies was available with both breeds present.

The traits chosen were kg milk, kg fat, kg protein, survival as age at culling, SCC, CR, height at withers and LW. Simulations were done using three different models created in Excel 2016. Model 1 and 2 are similar and represents the ProCross and SJM cross, these two models only differ between the breeds used. Model one and two includes the heterosis effect as well as an effect of annual genetic improvement coming from the purebred sires. Model three simulates the genetic improvement in purebred SRB and thus only the effect of genetic improvement within the breed is included. All three models simulate 30 years of breeding and cows are assumed to have 1 calf/year with a sex distribution of 50/50. Only cows in lactation 1-5 are included in the simulations and after lactation five all cows are assumed to be slaughtered.

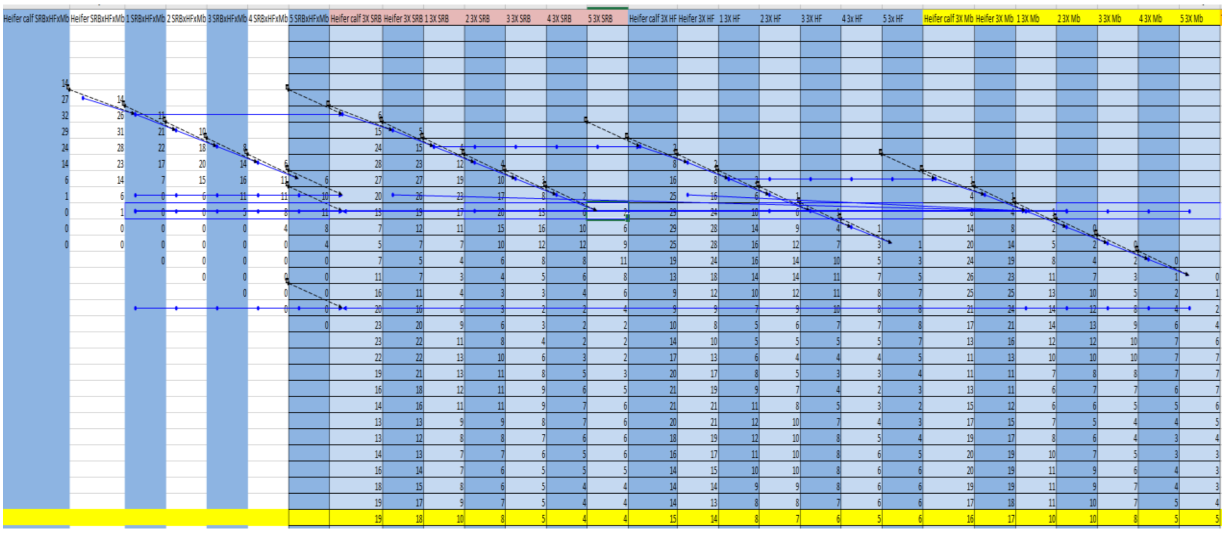

Figure 9. Illustration of parts of the animal flow from a purebred herd to a crossbred herd. This animal flow is used in the simulation models for the ProCross scheme and the SJM scheme. The arrows show from which group every animal comes from and the numbers show how big proportion of the total herd every group is. Every row in the figure represents 1 year.

For the models 1 and 2 the herd was divided into different groups depending on age and breed. For the model 3 only seven age groups were used, calf, heifer and lactation 1-5. The groups used in ProCross are presented in Table 6. In Figure 9 parts of the animal flow between these groups in model 1 and 2 for the SJM and ProCross scheme is shown. For the SJM cross the same groups were used except that in all groups HF is substituted for Jersey. In the groups termed 3X (e.g. 1-5 3X SRB) the breed proportions are assumed to be at equilibrium with an steady state of 86% heterosis in the simulations. For all the models' mortality (involuntary deaths generating costs) and culling (exclusion from herd by slaughter or sold, generating income) is assumed to be the same if the groups are in similar age categories, e.g. SRB heifer and 3X Mb heifer has the same mortality and culling rate. Mortality figures used are numbers available from the RBD herd. Culling figures used are estimated to maintain a stable herd size and assumed to be the same within age categories independent on group.

Table 4. Groups used for simulations of crossbreeding scheme 1.

Group nr.	Group	
1	SRB heifer calf	Age 0-12 months, purebred
1	SRB heifer	Age 13-24 months, purebred
1	1-5 SRB	Five different groups one for each lactation, purebred
2	SRBxHF heifer calf	Age 0-12 months, two-breed cross
2	SRBxHF heifer	Age 13-24 months, two breed cross
2	1-5 SRBxHF	Five different groups one for each lactation, two-breed cross
3	(SRBxHF)xMb heifer calf	Age 0-12 months, three-breed cross with Mb bull
3	(SRBxHF)xMb heifer	Age 13-24 months, three-breed cross with Mb bull
3	1-5 (SRBxHF)xMb	Five different groups one for each lactation, three-breed cross with Mb bull
4	3X SRB heifer calf	Age 0-12 months, three-breed cross with SRB bull as sire
4	3X SRB heifer	Age 13-24 months, three-breed cross with SRB bull as sire
4	1-5 3X SRB	Five different groups one for each lactation, three-breed cross with SRB bull as sire
5	3X HF heifer calf	Age 0-12 months, three-breed cross with HF bull as sire
5	3X HF heifer	Age 13-24 months, three-breed cross with HF bull as sire
5	1-5 3X HF	Five different groups one for each lactation, three-breed cross with HF bull as sire
6	3X Mb heifer calf	Age 0-12 months, three-breed cross with Mb bull as sire
6	3X Mb heifer	Age 13-24 months, three-breed cross with Mb bull as sire
6	1-5 3X Mb	Five different groups one for each lactation, three-breed cross with Mb bull as sire

SRB=Swedish red dairy cattle, HF=Holstein Friesian cattle, Mb=Montbéliarde dairy cattle

Input data used for the three models can be seen in Appendix 4. For all three models two different scenarios for the start population were used. Firstly, with mean values from the Röbäcksdalen herd and secondly with mean values for the whole SRB population. Starting mean values used for the rest of the breeds are the same in all simulations. The genetic trend used for the simulations are also shown in Appendix 4, all genetic trends used for the Nordic breeds are estimated from genetic trends in population means between approximately year 1991-2014. In the simulations, these calculated trends are assumed to remain the same for all 30 simulated years. For the trait height, the genetic trend is set to 0 as these traits have an optimum value and were assumed to remain similar over time. Changes in height in simulations are thus only seen in the crossbreeding schemes where breeds with different mean heights are used.

3.6 Economic assessment

The economic effect of the two crossbreeding schemes and the within-breed selection was calculated in calculation sheets available using Agriwise. Agriwise is an economical tool created for advising and financial planning in agricultural businesses (more information at www.agriwise.org). In Appendix 5 an example of the calculation sheet used can be seen. Simulated production values from the three scenarios for the SLU Röbäcksdalen herd were used in the analysis (the ProCross system, SJM system and within-breed selection). The difference in phenotypic traits was the basis for the different changes made in the economic calculations.

Payments and costs used in the scenarios represent current market prices, however, a sensitivity analysis of cost and payment changes were included. To get different price estimations at different fat, protein and SCC levels the tool "Räknesnurran" available from the dairy Arla Foods amba was used. Arla Foods amba are currently the largest dairy processing company in Sweden. Feed amount, feed production cost and other individual herd costs in the production were obtained from an earlier economic farm analysis from 2015. In all scenarios, these remained the same. To account for different maintenance requirements of feed the simulated average LW were used for these changes. Feed consumption from the 2015 economic farm analysis were used as a basis for the purebred simulations and the other scenarios were against this adjusted based on their feed intake. The average increase in feed intake were assumed to be 0.12 % per kg extra LW. This increase is estimated from calculations that can be seen in Appendix 5.

The basic payment for meat and from sold animals was set the same in all analysis and income was only varied with the different LW and replacement rates in scenarios. For the sensitivity analysis of payment three different levels were used, current prices, +10 % and -10 %. The economic results presented in the report is contribution margin 1 and thus costs for buildings, machinery, work etc. is not accounted for, only the direct production related costs. In the final analysis, the results from the different scenarios are compared where the calculations of within-breed selection are considered to give control values.

4 Results

4.1 Interviews

Information gathered in the two interviews are summarized and presented in this section.

4.1.1 SLU Röbäcksdalen

Today SLU Röbäcksdalen consists of pure-bred SRB. The biggest strength with the herd is the milk, they produce a good amount of milk with a good quality in solids, furthermore, the cows have a good milkability. The biggest weakness of the herd is the productive life of the cows. The mean productive life today is three years which he believes is too low (Pers. comm. Rahimi, 2016)

He would like to improve the todays breeding work by increasing the focus on cows that are more robust and that live longer. Improving the disease resistance is for him a way to achieve that, with the focus on mastitis resistance. He believes that the practical difficulties with breeding depends on which breed you have. At SLU Röbäcksdalen where they have SRB the biggest difficulty is to find bulls suitable for their cows. Too many of the cows are closely related to the available bulls and avoiding inbreeding is then much harder. However, this problem has been reduced slightly by the incorporation of AI bulls from Finland and Denmark. Another difficulty with breeding is the time aspect. Achieving your goals takes a lot of time and you cannot be sure that the good cow that you recruit from will get an as good or better heifer. However, according to him genomic selection is a good tool as it makes the breeding go faster. He also highlights that genomic selection is useful in optimizing the usage of the stable building. Many buildings today are built for just enough cows and if selection then can be done earlier in life the worst calves can be sold at a younger age (Pers. comm. Rahimi, 2016).

For improvement by breeding in the herd he believes that these five following traits are most important. Firstly, improvement of the longevity by increased number of lactations per cow and secondly, disease and mastitis resistance. Thirdly, the shape of the udder and fourth, improvements for easy calvings. Finally, the milk should be improved and not just the amount but also the solids need to be considered. The traits that are of most importance to improve for an increased profitability is mastitis resistance as well as the cows' ability to produce milk. For improved animal welfare by breeding he believes that functional traits like a good exterior that allows an easy calving and good movement as well as good legs and claws are important to improve (Pers. comm. Rahimi, 2016).

If crossbreeding were to be used at Röbäcksdalen in the future, he expresses two concerns. Firstly, he is not sure whether this would be suitable for the research that are done at the farm, as he believes crossbreeding would give different groups of animals. Secondly, he is unsure how the control of cows achieving the goals set up would be done when they are crossed. Also, he expresses the concern on how to value the crossbred animals breeding value, in pure-bred cows he gets calculated index values to use for selection of bulls to inseminate. To him it is important that if using crossbreeding, there are clear goals and strategies for breeding set up before using it. If that is not the case, he thinks it wouldn´t work in a good way. One big advantage with crossbreeding is that inbreeding wouldn't be a problem anymore. However, he has difficulties seeing how it would work in the long run and thinks that crossbreeding might increase the need for breeding advisors at the farm. To him the biggest fear for usage of crossbreeding is that it wouldn´t get the desired effect and that the progeny would even get worse than the parental generations (Pers. comm. Rahimi, 2016).

When considering potential breeds that could be used in the herd he expresses that it is hard to know which would be best. Today some beef breeds are used on animals that are not recruited from and for them the most important is that they give easy calving. Otherwise the beef breed used doesn't matter to him. He is very positive to the usage of Mb and Brown Swiss, however, the HF he is less positive to. He expresses that their only advantage compared to the SRB is that the give a little bit more milk. Furthermore, he thinks the HF is everywhere and that is not the case with the SRB. In general, he believes that this is a Swedish research station and the research done here should then be done with Swedish cattle (Pers. comm. Rahimi, 2016).

A few crossbreeding systems that could be used at the farm were presented to him. The first one that he considered were two-breed rotational crossbreeding. This system he had no doubts would work practically at the farm. Secondly, he considered three-breed rotational crossing, at the beginning he was hesitant to this system and thought it would be hard to keep track of what bull should be used at what cow. However, when presented to solutions like different colored ear tags as a tool help the logistics he became more positive for the system. In conclusion, he thought that if more than two breeds should be used there would have to be good tools available to ease the logistics. He was also presented to systems having a purebred nucleus with either a two-breed cross group or a purebred nucleus with two- and three-breed crosses. After this he concluded that he thought all these systems would work practically with good planning and clear routines (Pers. comm. Rahimi, 2016).

In general, he believes that crossbreeding would give increased work at the farm with following up the result of the breeding as index values from breeding organizations wouldn't be available for the crossed animals any more. He is also concerned what animals the crossbreeding would give and thinks that with pure-breeding it is more certain what type of animals you will get (Pers. comm. Rahimi, 2016).

4.1.2 Nilsson's in Skråmered

Five years ago, the Nilsson's in Skråmered herd consisted of 90 % HF and 10 % SRB cows. The herd was (and still is) a dairy production herd with approximately 200 cows plus recruitment animals. The herds average milk production was 11 000 kg with fat content of 4.1% and protein of 3.6 %. The milking was, and is still, done three times a day in parlor. The cows are feed with Mullerup mixfeeder with a mixture of grass silage, corn silage, straw, grains, protein meal and minerals combined with 3 kg pelleted feed/day at milking. In trait terms the herd´s strength was the amount of milk and the weaknesses was the fertility and high somatic cell count (SCC). Due to this, the most common causes of culling were fertility problems, high SCC and mastitis with an average life length of 2.5 lactations per cow. Furthermore, they experienced that the HF breeding focused too much on milk production and to a lesser extent on other traits. This combination of reasons led to that they started to look for other breeding possibilities to increase the sustainability of the herd as well as the sustainability of their production (Pers. Comm. Nilsson, 2016).

To be more prepared for the future, different crossbreeding systems were considered to increase the herd's sustainability. A lot of the information studied came from both France and the USA. Different breeds were considered but in the end, they decided to go for the ProCross system. In autumn 2011, they started crossing their cows with the ProCross system. The biggest difficulty before starting with ProCross was the resistance they experienced from different dedicated breeding persons in Sweden. Many tried to persuade them that this was not a good alternative and even claimed that crossbreeding would lead to bankruptcy and a big loss in production. They also received the advice to keep 25 % of the best animals as pure-bred so that bull calves could be sold in the future. Despite this they chose to go with 100 % ProCross in the herd as they felt that, why couldn't these 25 % become even better? (Pers. Comm. Nilsson, 2016).

Today the production has increased to an average of 13 000 kg with solids of 3.6 % in protein and 4.3 % in fat. At the same time the herd size has increased to 280 milking cows, however, no changes have been done in the feed ration. The whole herd does not yet consist of only ProCross animals and today there is approximately 100 HF cows left in production, but all recruitment calves are now three-breed crosses. The biggest difference with the animals today is that they feel more robust and are more alert and viable already from birth. The cows are also smaller and fit the stables and equipment better than before. Thus, they seem to have much easier to move around as well as getting up and down in the cubicles. As an example, before ProCross, they had to constantly alter equipment and cubicles to fit their big HF, but now they can change this back again. Regarding legs and udders, they seem to last longer for their ProCross animals than their previous HF. This far, the legs and udders have greater standards in the same lactation number compared to their previous HF cows. However, it is not yet possible to show this in numbers as they haven't had the ProCross animals long enough. One disadvantage with the crossbred animals is that teat-suckling are more common than before. Their overall experience is that the ProCross animals makes the farm more prepared for the future as the production feels more sustainable (Pers. Comm. Nilsson, 2016).

In cattle breeding it is according to Nilsson (2016) not only one trait that is important; instead the focus should be on many different traits. Prolonged life is a trait he thinks is of great importance to improve for a better economy. He also believes that this is connected to an increased animal welfare, as a good animal welfare is necessary for the cows to be able to produce well and for a long time. In summation, healthier animals produce better, which is good both for the farmer as well as the animal welfare (Pers. Comm. Nilsson, 2016).

The breeding today at the Nilsson in Skråmered farm is done following breeding schemes that is updated once every month, however, at these updates there are mostly small changes made. The use of AI is mostly done by the foreman of the farm and at present no sexed semen is used at the farm, there are however plans for implementing this in the future. To know which breed to mate a heifer or cow with they look at the cow identity card and inseminate with a sire of the breed that is furthest back (HF, SRB or Mb) in the pedigree. This cow is then inseminated with the same breed during her lifetime. When choosing a bull, they prioritize bulls with easy calving's as well as good results in other traits such as high milk production with good inclusion of solids. They consider easy calving´s and calves not being too big at birth as traits of extra importance when choosing Mb bulls as well as when heifers are being inseminated. All breeding work is done without help from advisory organizations and they feel that the breeding work today is much easier with the ProCross system than before. For example, choosing bulls is much easier now than before. However, in the beginning they had a setback where they got problems with calving difficulties due to usage of the wrong bull. Today they have solved this problem and are after to this much more careful and puts higher demands that the bull used should fit their cows and heifers. At present when choosing animals for recruitment all crossbreed heifers are saved as they are still in the process of changing the herd into being only ProCross. Regarding the bull calves, some has been sold to other milk producers that want to speed up the process of changing into ProCross. The rest are sold for beef production where the buyer claims to be very pleased with these crossbred calves (Pers. Comm. Nilsson, 2016).

In retrospect, something they want to have done differently is to already at the start put high demands on the companies selling AI doses (semen) to them. Another wish is that the breeding companies should have been a little bit more prepared and available to them at the startup with ProCross, but maybe they were too early with wanting to change into crossbred animals. He also points out the importance of keeping purebred herds as they are dependent on these to be able to get breeding material in the future. However, with all facts on hand, he claims to be very satisfied with changing into ProCross. Furthermore, with the recent economic depression in the milking industry this has really been the best option for them (Pers. Comm. Nilsson, 2016).

4.2 Simulation results

4.2.1 Purebred SRB

Summarized results for simulated phenotypes are presented in Table 7. A large increase in milk/kg cow can be seen for both starting scenarios, the SLU Röbäcksdalen mean and the SRB population averages. All traits have improved except for number of inseminations which has increased slightly in both scenarios. Fat percentage in milk increases in the SLU Röbäcksdalen population from 4.8 % to 4.9 % and in the average SRB population it increases from 4.36 % to

4.41 %. Protein in milk increases from 3.66 % to 4.1 % in the SLU Röbäcksdalen herd and in the average SRB population from 3.6 % to 4.0 %. When studying a shorter time of 15 years the simulations of the SLU Röbäcksdalen herd shows a kg ECM production of 10 780 per cow/year and the age at culling has increased to 65.34 months in average.

Table 7. Results from simulations of phenotypic changes with 30 years of within-breed selection in Swedish red dairy cattle (SRB). Calculated from both SLU Röbäcksdalen (RBD) herd means and SRB breed means.

Mean values	RBD 2017	RBD 2047	SRB 2016	SRB 2047
Milk kg/cow	7568	10635	9014	12667
ECM kg/cow	8477	13273	9529	14920
Fat kg/cow	364	518	393	559
Protein kg/cow	277	439	322	511
SCC in tank	183	183	254	254
Culling age (months)	54.1*	76.9*	61	86.8
Nr. Inseminations	2.1	2.13	1.79	1.81
Live weight, kg	-	-	575	608
Height at withers, cm	136.9	136.9	140.4	140.4

*ECM = Energy corrected milk, SCC =somatic cell count, *average age in RBD herd,*

Table 8 shows the phenotypic difference from the starting population. Both starting populations has an equal percentage increase but the increase in units differs. Culling age increases with 22.8-25.8 months which would mean that every cow can be keep in production for 1.8-2 lactations more if the calving interval 12.7 remains. This would then with the simulated production results give approximately 23891 kg ECM/cow during her whole productive life in the Röbäcksdalen herd and in the average crossbreed SRB 29840 kg ECM/cow. Increased productive life of 1.8 lactations (1.9 years/cow) means that the Röbäcksdalen herd can lower the replacement rate from 37% to 23%/year. For the average SRB herd this means a lowered replacement rate from 37% to 22% (2.1 years extra).

Table 8. Results from simulations of phenotypic changes with 30 years of within-breed selection in Swedish red dairy cattle (SRB). Calculated from both Röbäcksdalen (RBD) herd means and SRB breed means.

	RBD 2047	SRB 2047	% change
Milk kg/cow	+3067	+3653	+40.5 %
ECM kg/cow	+4796	+5391	+56.6 %
Fat kg/cow	+154	+166	+42 %
Protein kg/cow	+162	+189	+58.7 %
SCC in tank	+0	+0	+0 %
Culling age (months)	+22.8*	+25.8	+42.3 %
Nr. Inseminations	+0.03	+0.02	+1.1 %
Live weight, kg	-	+33	+5.7 %

*ECM = Energy corrected milk, SCC =somatic cell count, *average age in RBD herd,*

4.2.2 Crossbreeding scheme 1 - SRB, Holstein and Montbéliarde

The change of purebred SRB into ProCross animals is shown in Figure 10. Breed groups varies most in the beginning and after approximately 14 years of crossbreeding only three breed groups remain. All groups are three-breed crosses; however, the breed proportions vary between categories with 57 %, 29 % and 14 %. For instance, the 3X SRB cow is 57 % SRB, 29 % Mb and 14 % HF.

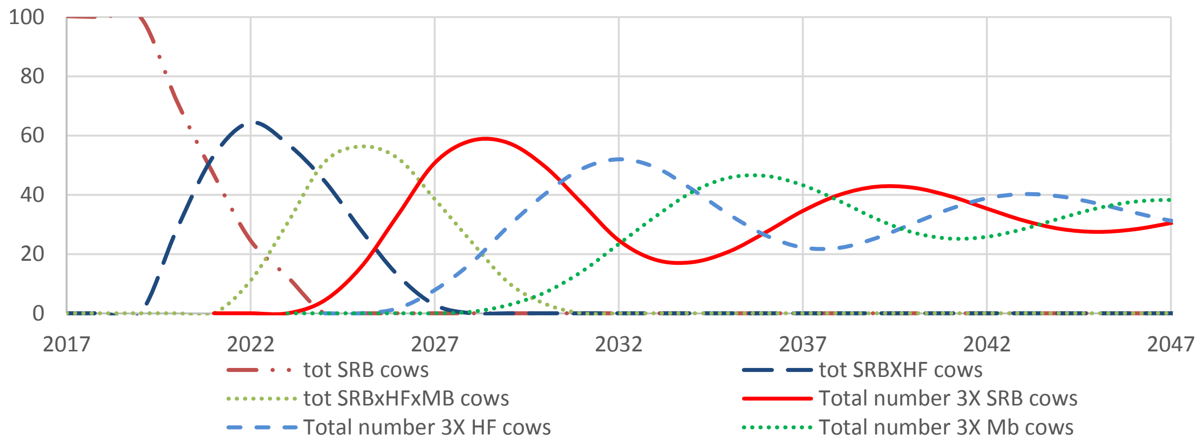

Figure 10. Illustration of breed group distribution in percent over time in the ProCross scheme.

The breed proportions affect the change in traits. Figure 11 shows an example of how kg ECM is affected by the different breed groups in cows from the ProCross system. Year 2047 the ECM/cow varies between 13284-14729 kg with 3X SRB group having the lowest production and the 3X HF having the highest.

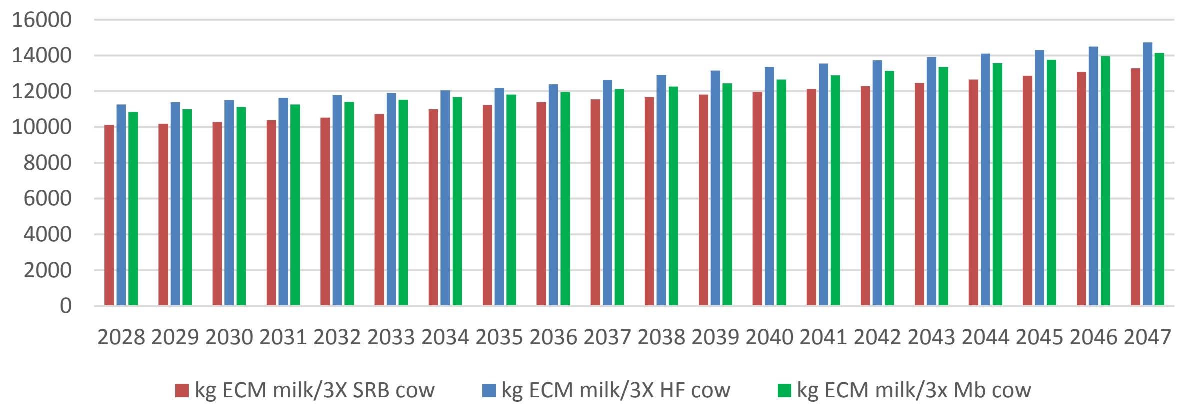

Figure 11. Kg ECM milk from three-breed crosses with different breed proportions in ProCross

Table 9 shows the phenotypic changes in the ProCross population. Most traits have with this crossbreeding system been improved, however, one exception is the height trait where the genetic trend is excluded in the simulations and only the expected height range is shown. Fat content in milk has for the SLU Röbäcksdalen population decreased from 4.8 % to 4.3 % and in the average SRB population it has changed from 4.36 % to 3.76 %. The protein content has for the SLU Röbäcksdalen population increased from 3.66 % to 3.78 % and in the crossbreed SRB population from 3.57 % to 3.84 %.

Table 9. Results from simulations of phenotypic changes with 30 years' usage of the ProCross scheme on Swedish red and white dairy cattle (SRB). Calculated from both SLU Röbäcksdalen (RBD) herd means and SRB breed means.

	RBD 2017	RBD 2047 ProCross	SRB 2016	SRB 2047 ProCross
Milk kg/cow	7568	12330	9014	12976
ECM kg/cow	8477	14064	9529	14581
Fat kg/cow	364	532	393	545
Protein kg/cow	277	466	322	488
SCC in tank	183	148	254	164
Culling age, months	54.1*	81.6*	61	84.7
Nr. inseminations	2.1	1,93	1.79	1,83
Live weight, kg	-	-	575	670
Height at withers, cm	136.9	145-150	140.4	147-151

*ECM = Energy corrected milk, SCC =somatic cell count, *average age in RBD herd,*

The phenotypic difference in the simulated traits is shown in table 10. The traits in the SLU Röbäcksdalen crossbreds is improved between 26.2-68.2 %. The SRB population is improved between 35.4-51.5 % and only impaired in one trait with 5 %. Culling age is improved between 23.7-27.5 months and with a calving interval of 12.7 months this would mean that cows could on average bee kept in production for 1.87-2.17 lactations more. This would then increase the average cow productive life and give 30519 kg ECM more milk/cow in the SLU Röbäcksdalen herd and 27266 kg ECM more milk/cow in the average SRB herd. Increased longevity means that a lower replacement rate is needed. The present replacement rate of 37 % can with an increased productive life of 2.17 lactations (2.5 year/cow) in the crossbred SLU Röbäcksdalen herd lower the replacement rate to 20 %. For the average crossbred SRB herd the replacement rate will change from 37 % to 22.4 % (1.98 years extra).

Table 10. Phenotypic improvement in units and percentage with 30 years' usage of the ProCross scheme on Swedish red and white dairy cattle (SRB). Calculated from both SLU Röbäcksdalen (RBD) herd means and SRB breed means.

	RBD mean 2047		SRB mean 2047	% change
Milk kg/cow	+4762	+62.9 %	+3962	+43.9 %
ECM kg/cow	+5587	+39.7 %	+5052	+53 %
Fat kg/cow	+168	+46.2 %	+152	+38.7 %
Protein kg/cow	+189	+68.2 %	+166	+51.5 %
SCC in tank	-135	-26.2 %	-90	-35.4 %
Culling age (months)	+27.5*	+50.8 %	+23.7	+38.8 %
Nr. Inseminations	-0.17	-8 %	+0.04	+5 %
Live weight, kg	-	-	+95	+16.5 %

*ECM = Energy corrected milk, SCC =somatic cell count, *average age in RBD herd,* When the whole herd is a ProCross population the average live weight will vary between breed proportions. The live weight varies between 652-683 kg/cow, giving the highest live weights when the cows have the biggest proportion of Mb. The heights at withers vary most in the beginning of the simulated period, but the variation decreases when the whole population is crossbreed. With ProCross the average height will in year 2047 vary between 145-150 cm.

4.2.3 Crossbreeding scheme 2 – SRB, Jersey and Montbéliarde

Figure 10 also illustrates the change of purebred SRB into SJM animals if HF is substituted to Jersey. It shows that breed groups vary most in the beginning and after approximately 14 years of crossbreeding only three breed groups remain. All groups in the end are three-breed crosses, however, the breed proportions vary in between categories with 57 %, 29 % and 14 %. E.g. the 3X SRB cow is 57 % SRB, 29 % Mb and 14 % J. Also in SJM the breed proportions affect the change in traits. Figure 12 shows an example of how kg ECM is affected by the different breed groups. Year 2047 the ECM/cow varies between 13117-13900 kg with 3X SRB group having the lowest production and the 3X J having the highest.

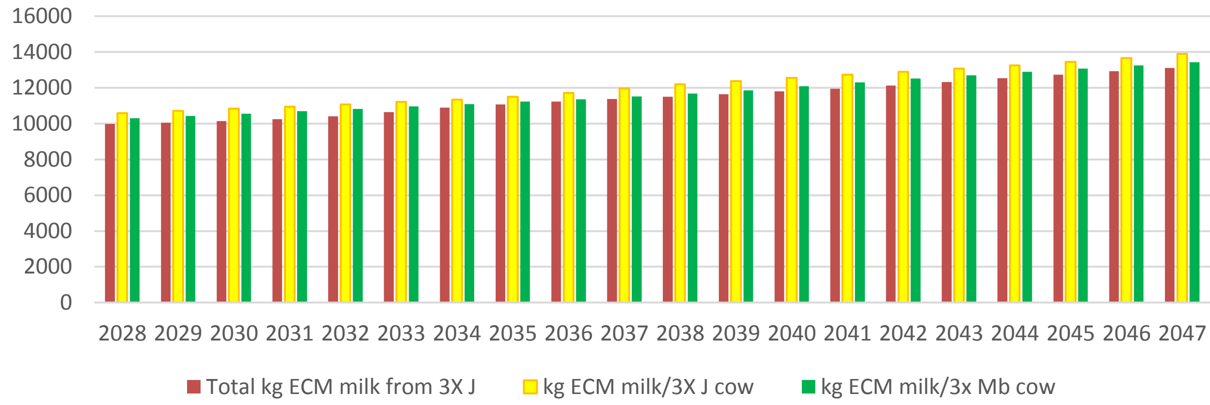

Figure 12. Variation of kg ECM in different breed groups with crossbreeding scheme 2.

A summary of all phenotypic changes when using SJM is shown in Table 11. Most traits have been improved over time. Except in the height trait, where the genetic trend is excluded and only the expected height range is show and in the average SRB simulations for number of in-seminations where a slight impair can be seen. Fat content has in the SLU Röbäcksdalen herd changed from 4.8 % to 5.3 % and in the average SRB it changes from 4.4 % to 5.1 %. The protein content has changed from 3.66 % to 4.2 % in the SLU Röbäcksdalen herd in in the average crossbreed SRB from 3.6 % to 4.1 %.

Table 11. Results from simulations of phenotypic changes with 30 years' usage of crossbreeding scheme 2 in Swedish red dairy cattle (SRB). Calculated from both Röbäcksdalen (RBD) herd means and SRB breed means.

	RBD 2017	RBD SJM 2047	SRB 2016	SRB SJM 2047
Milk kg/cow	7568	10329	9014	10947
ECM kg/cow	8477	13441	9529	13958
Fat kg/cow	364	543	393	556
Protein kg/year	277	429	322	451
SCC in tank	183	144	254	159
Culling age, months	54.1*	81.7*	61	84.7
Nr. inseminations	2.1	1,9	1.79	1.8
Live weight, kg	-	-	575	590
Height at withers, cm	136.9	138-144	140.4	139-145

*ECM = Energy corrected milk, SCC =somatic cell count, *average age in RBD herd,*

Table 12 show that the Röbäcksdalen herd would with SJM be improved in the investigated traits with between 9.5-54.9 % and a crossbred average SRB population would be improved with between 17-46.7 %. With SJM the culling age is improved between 23.7-27.6 months and with a calving interval of 12.7 months this would mean that cows could on average bee kept in production for 1.87-1.99 lactations more. This would then give between 26 748 kg ECM more milk/cow in the Röbäcksdalen herd and 26101 kg ECM more milk/cow in the crossbreed average SRB herd. The increase in 1.99 lactations (2.1 year/cow) more per cow means that the Röbäcksdalen herd can lower the replacement rate from 37 % to 22 %/year. In the crossbred average SRB herd the replacement will change from 37 % to 22.4 % (1.98 years extra).

Table 12. Phenotypic improvement in units and percentage with 30 years' usage of crossbreeding scheme 2 on Swedish red and white dairy cattle (SRB). Calculated from both Röbäcksdalen (RBD) herd means and SRB breed means.

	RBD 2047	% change	SRB 2047	% change
Milk kg/cow	+ 2761	36.5 %	+1933	+21.4 %
ECM kg/cow	+ 4964	58.6 %	+4429	+46.5 %
Fat kg/cow	+179	49.2 %	+163	+41.5 %
Protein kg/cow	+152	54.9 %	+129	+40 %
SCC in tank	-39	-21.2 %	-95	-37.4 %
Culling age, months	+27.6*	51 %	+23.7	+38.9 %
Nr. Inseminations	-0.2	-9.5 %	+0.01	+0.6 %
Live weight, kg	-	-	+15	+2.6 %

*ECM = Energy corrected milk, SCC =somatic cell count, *average age in RBD herd,*

In the final SJM population the average live weight will vary between breed proportions. The variation will be smallest when they have Jersey in big proportion. The live weight varies between 533-618 kg/cow in year 2047. The height variation is largest in the beginning but will decrease when the whole population is crossbreed. With SJM the average height will in year 2047 vary between 138-144 cm.

4.3 Comparison Phenotypic effect

The kg ECM production is in Figure 13 compared between all tested scenarios. The figure show that all scenarios where the SRB mean population is used as starting population have a higher ECM production/cow and year than the RBD starting population. All crossbred scenarios show a faster production increase in the beginning. However, the pure-bred scenarios are after a few years able to catch up this increase. They seem to catch up after year 2024 when the rotational crossbreeding starts. Of the crossbred scenarios, the ProCross scheme seem to give the highest kg ECM production.

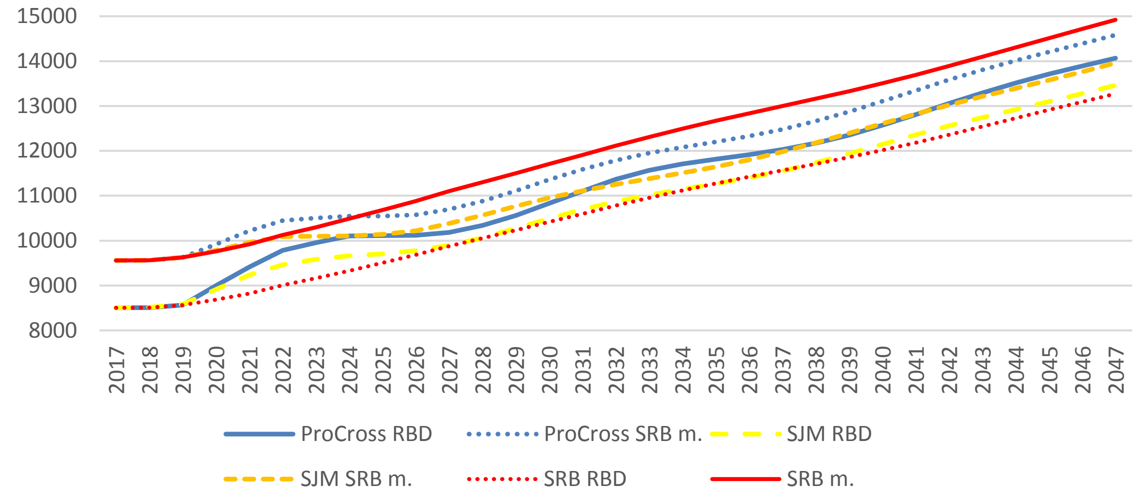

Figure 13. Comparison of kg ECM production/cow and year between all simulated scenarios.

Fat and protein production is compared between the scenarios in Figure 14. The purebred SRB mean population has the highest simulated production for both fat and protein. However, the pure-bred RBD population has at the same time the lowest production. For fat production, the SJM cross gives larger production or similar compared to the two ProCross schemes. Produced protein per cow/year is between the crossbred populations largest for the ProCross system.

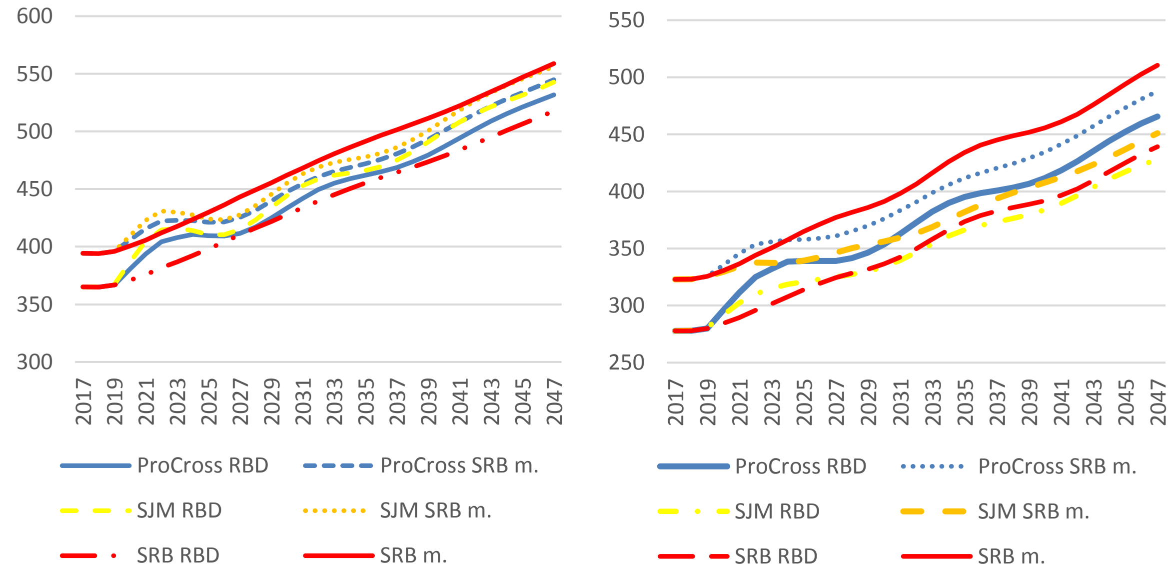

Figure 14. To the left, a comparison of the simulated average kg fat production per cow and year. To the right, average kg protein production per cow and year is compared between simulated scenarios.

Survival in the different scenarios is compared in Figure 15. Different types of starting numbers have been used and comparing scenarios from the SRB mean with the RBD mean is thus hard. However, for RBD both ProCross and SJM cross gives better survival than the purebred scenario. To the right in Figure 15 the average cow weight is compared between ProCross, SJM cross and pure breeding. The SJM and the SRB cows are both smaller than the ProCross cows. The SJM is smallest of all and both crossbred populations vary a lot in live weight at the beginning, however, the variation is reduced during time.

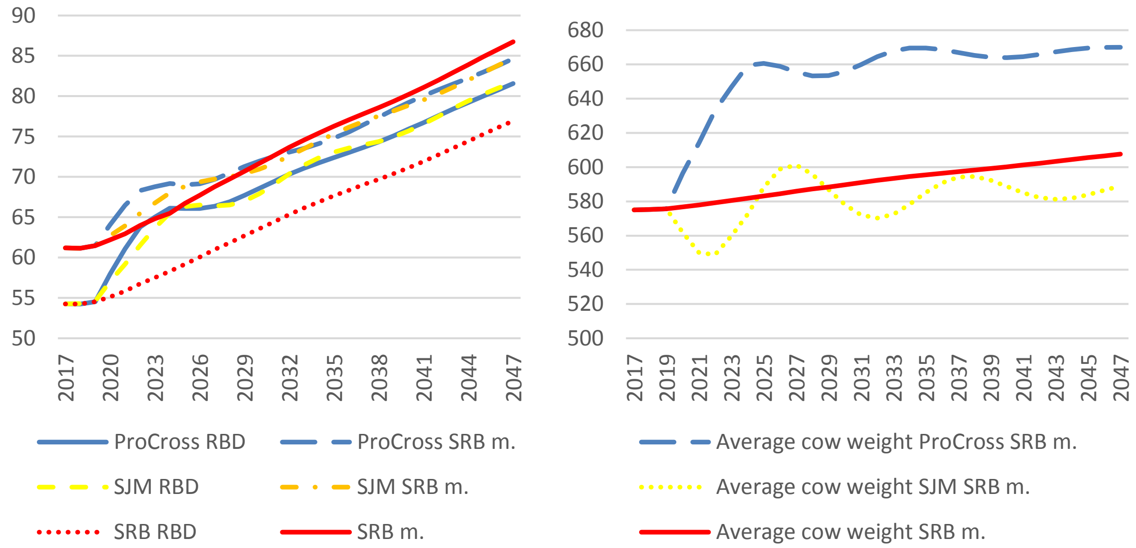

Figure 15. To the left, comparison of survival trait measured in average culling age. All scenarios for Röbäcksdalen (RBD) represents the average age in the herd and not average culling age. To the right, comparison between simulated scenarios of the average cow live weight in kg during the 30 simulated years.

4.4 Economic effect

The estimated economic results for 30 years of within-breed selection on the SLU Röbäcksdalen herd are shown in Table 13. With the estimated average payment, every cow would after the costs for feed, rearing, inseminations, veterinarian etc. has been removed give an income of 49 580 SEK. This is an increased income of 35 392 SEK/cow or 149 % in comparison to when 2016 years' production result is estimated similarly. However, a 10 % change in milk price affects the economic result by ±5670 SEK/cow. In Table 13 one also shows the estimated economic result for within-breed selection in an average SRB herd. Variation of 10 % in milk price gives a change in income of ±5041 SEK/cow. This shows that with the estimated current milk price the SLU Röbäcksdalen herd would be slightly more profitable than the average SRB herd after 30 years of within-breed selection. However, the SRB mean herd would be less sensitive for changes in milk price.

Table 13. Yearly contribution margin 1 for all simulated scenarios. Results are presented in SEK/cow for average prices and ± 10 %.

Simulated scenario	Average prices	+ 10 %	-10 %
RBD 2016	14 188	14 861	13 515
RBD 2047	49 580	55 245	43 915
SRB 2047	44 772	49 813	39 730
RBD ProCross 2047	39 116	43 776	34 456
SRB ProCross 2047	38 453	39 367	37 552
RBD SJM 2047	45 482	50 678	40 286
SRB SJM 2047	45 486	47 158	43 813

Economic effects of crossbreeding in the Röbäcksdalen herd with HF, SRB and Mb in ProCross is shown in Table 13. These suggest that ProCross would improve 2016 years' result by 24 978 SEK/cow or by 76 %. Milk price variation by 10 % will affect the herd by ±4660 SEK/cow. Using ProCross on an average SRB herd is estimated to give an economic result of 38 453 SEK/cow which is shown in Table 13. Sensitivity analysis for milk price shows that this result is affected with ±1815 SEK/cow. Comparing the economic results of ProCross for the two starting populations shows that the Röbäcksdalen herd would gain slightly more from using ProCross than an average SRB herd. However, a ProCross crossbred average SRB herd would be less milk price sensitive than the SLU Röbäcksdalen herd.

Crossbreeding with SJM at SLU Röbäcksdalen where the SRB, Jersey and Mb breeds are used, is estimated to give an increased income of 31 294 SEK/cow or 121 % in comparison to 2016 years´ estimated result. Table 13 shows all estimated economic results for this scenario. Variations of 10 % in milk price show that this result is affected by ± 5196 SEK/cow. The Economic effect of SJM in an average SRB herd is also presented in Table 13. With average prices this gives an estimated economic result of 45 486 SEK/cow and with a 10 % milk price change the result would be affected by ± 3345SEK/cow. Given the estimated current milk prices the two starting populations would give a similar average economic result. However, the SLU Röbäcksdalen herd seems to be more sensitive to changes in milk prices.

5 Discussion

5.1 Interviews

Differences exist between the two herds and the two informants' perspectives. Nilsson's in Skråmered started out with mostly HF cattle and with a bigger herd (200 cows) than SLU Röbäcksdalen which have SRB and around 120 milking cows. Another difference is the two herds NTM where the SLU Röbäcksdalen herd is perceived as a higher genetic merit herd than the Nilsson in Skråmered herd was when they had purebred HF. Furthermore, the two breeds different levels in e.g. fertility and other traits affects the informants as well. The herds are also affected differently by market changes due to one being a commercial herd and one being a research herd. For the SLU Röbäcksdalen herd this means that there might be more factors to adjust the choice of breeding method to than in the Nilsson in Skråmered herd. Such as, how different breed groups in the herd would affect research results and how the overall SRB population would be affected by changing to crossbreds. Still similarities seem to exist, when both herds were purebred both informants described the herds strength and weaknesses similarly. Strengths being good milk production and weaknesses being high SCC, mastitis problems, longevity and low robustness of the cows. Furthermore, both informants seem to aim at breeding for improvement in several traits instead of having a narrow focus on milk production only. Both wants to improve longevity, mastitis resistance, robustness as well an improved milk production with good solids quality (Pers comm. Nilsson, 2016; Pers comm. Rahimi, 2016).

For Nilsson's in Skråmered the change into ProCross animals felt like the best option to increase the herds sustainability and to be more prepared for future market changes. It has led to increased total production and seem to improve the herds health, suitability to stable and cubicle size, robustness and longevity (Pers. comm. Nilsson, 2016). However, the total effect of the change is not yet fully known as the herd still has some purebred animals left and their ProCross animals has not been in production long enough. Concerns regarding crossbreeding was from Rahimi (2016) expressed. These were regarding that more advising from organizations would be needed and that the selection of breeding animals would become hard. The practical breeding work with three-breed rotational crossbreeding is from the Nilsson's in Skråmered´s experience easy to handle. They use no additional tools or advising organizations for it and they also experience that choosing bulls and planning the breeding is easier now when inbreeding is not a problem anymore. However, this far they have no tool, only their own monitoring, available for selection within their ProCross animals until the cow has started to produce milk and these results can be used (Pers. comm. Nilsson, 2016). This lack of early breeding evaluation might in the future slow down the herds genetic progress.

In summation, the herd manager at SLU Röbäcksdalen attitude to crossbreeding is good and he is open to all suggested crossbreeding systems if planning is done carefully and easy to follow. He has no breed that he would prefer to use however, he is less keen to using HF and personally prefers using a domestic breed (Pers. comm. Rahimi, 2016). There are however not many large populations of Swedish breeds available and thus when crossbreeding, using foreign breeds seem unavoidable. The biggest problem raised by the herd manager if changing to crossbreeding today is however how future crossbred animals breeding values should be estimated at an early age.

5.2 Phenotypic effect

The seven traits simulated in the study are kg ECM, kg fat, kg protein, SCC, age at culling, live weight and height. Heterosis is thought to be biggest for longevity and functional traits compared to production traits (Simm *et al.*, 2000; Sørensen et al., 2008). This inclines that there might be other traits not tested that might be affected more than the ones included in this study.

Improvement can in these simulations be seen in both ProCross and SJM. From the SLU Röbäcksdalen perspective crossbreeding improved kg protein/cow the most in ProCross and kg ECM/cow in SJM. These differences might be due to the crossed breeds different strengths were for example the Jersey and SRB both has high solids production which increases the ECM in the SJM cross a lot. With within-breed selection the most improved trait was kg protein/cow. In all simulations ProCross, SJM for the SRB mean population gave a slight deterioration in number of inseminations. This shows that the used breeds starting mean needs to be at a better level than the starting population to be improved by crossbreeding, or the heterosis effect needs to be larger. For the within-breed selection no change is seen in SCC and the fertility trait, but number of inseminations is impaired for both starting scenarios. This impair is due to the estimated negative genetic trend used.

Phenotypic changes for live weight are interesting from a feed efficiency perspective as well as from an economic perspective. Profitability effects of this has by (Lopez-Villalobos *et al.* (2000b) been studied. Where the smallest Jersey cow´s hade lowest DM intake and production costs in comparison with the bigger HF that had the highest. Crossbreeds had intermediate costs and the Ayrshire x Jersey cross was the second lowest. Furthermore, the larger breeds where affected more by meat payment changes than the smaller ones (Lopez-Villalobos *et al.*, 2000b). This might be due to a lower maintenance need for feed when the cows are small whereas larger cows usually give a higher carcass income when the cow is culled. Changes in height are of interest due to size suitability of cubicles and other stable interiors which might increase the cow welfare and possibility to rest and produce well. The phenotypic results suggest that the SJM would give cows with lower live weight as well as less height in comparison to the other scenarios. The weight is however bigger in comparison to 2016 years' results. Cows from ProCross would have both the highest live weight and the highest mean range for height at withers of all three scenarios simulated.

Comparing SCC between the scenarios show that SJM seem to give the lowest SCC and within-breed selection the highest. For an increased longevity both ProCross and SJM seem to improve the average age at culling in the Röbäcksdalen perspective similarly by approximately 50 % in comparison to within-breed selection that improves the longevity by 42 %. The improved longevity in an average crossbred SRB herd would with ProCross and SJM be improved by approximately 39 %. Highlighting that the difference in effect for crossbreeding is depending on the starting populations values.

The simulated results are dependent on heterosis estimates used. Many estimates for heterosis effects between breeds exists (e.g. Ericson *et al.*, 1988; Lopez-Villalobos *et al.*, 2000b; VanRaden & Sanders, 2003; Dezetter *et al.*, 2015; Jönsson, 2015). Between some of the breeds simulated in this study no estimates seem to exist. Estimates between Mb and Jersey crosses as well as estimates between Mb and SRB/NRDC crosses have not been found. This might then affect the accuracy of these phenotypic simulations as some values used are general heterosis estimates and calculated estimates.

The genetic trend within the breeds will also affect how crossbred animals' phenotypes changes over time (Hansen *et al.*, 2005). In this study, no genetic trends were available for the Mb breed and the combined average genetic trend for all breeds in this study were used instead. This might lower the accuracy of these estimates. The genetic increase in traits from these trends are added in using multiplication. This might give and larger increase than if the traits were increased by addition of trait units only. Furthermore, the genetic trends are in this case assumed to remain the same for 30 years more and this might in reality not be true. Meaning that the phenotypic values (e.g. production) might not reach as high levels as in these simulations. Also mean values used as starting values for the populations has a big effect on the simulated results. In this study mean values available from the Swedish milk recording and from breeding companies have been used. These are assumed to reflect the average breeding animals used in the populations. This might however not be the case for all herds and thus the real phenotypic change might differ. All scenarios in this study are however based on the same assumptions which make it possible to still compare results between the scenarios even if the phenotypic changes might be over or under estimated.

5.3 Profitability

The profit of a crossbreeding system depends on each used breed´s total merit (Sorensen *et al.*, 2008). When using systematic crossbreeding like ProCross and SJM the total profit then depends on the used breeds combined merit. In this study, the combined merit is only evaluated based on the seven traits simulated. Thus, there might be other traits affecting the profit of these simulated crossbreeding systems. Furthermore, the economic value of having a smaller cow (e.g. lower height at withers) that can move in stables and cubicles easier is hard to estimate, as it might have an indirect impact on production through behaviors such as resting, ruminating and eating time. Therefore, no adjustment in the economic calculations has been done for the trait height at withers.

A comparison of contribution margin 1 per cow/year for all scenarios can be seen in figure 10. This indicates that herds with lower starting production (SLU Röbäcksdalen in comparison to the SRB mean) would gain more profit on changing to crossbreeding. However, the contribution margin from the purebred SRB is higher or similar to the SJM option. For an optimum profit this then creates a possibility to divide the herd in two groups. One where the best purebred animals is keep and used for within-breed selection and another where the lower producing animals are improved more rapidly by crossbreeding. In theory, this option would in total increase the herd´s contribution margin 1 faster than choosing just one breeding method. How the proportions of these two groups should be, will probably change depending on how big the variation in the traits are within the herd.

Studies have concluded that for herds having HF and crossing with the breeds used in ProCross (SRB/NRDC and Mb) it gives a higher or similar production in the progeny (Begley *et al.*, 2009; Heins *et al.*, 2012; Hazel *et al.*, 2016) However, no studies have been found comparing this from an SRB or NRDC perspective. Figure 16 illustrates that from an SRB perspective contribution margin 1 after 30 years of ProCross is lower in a crossbred herd than in the purebred SRB herd. Looking at SJM in comparison to within-breed selection for SRB indicates that SJM would be a more equally profitable breeding system for a SRB herd than the ProCross. However, with 10 % milk payment changes, the ProCross system is less sensitive and seem to maintain a more stable profit regardless of payment. Thus, ProCross higher average milk production seems to lower the economic sensitivity for changes in milk price.

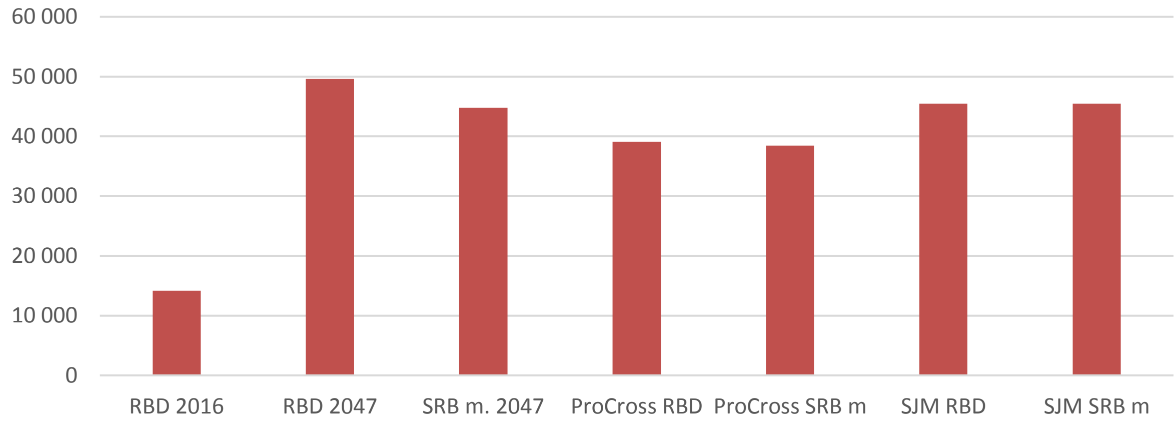

Figure 16. Comparison of changes in contribution margin 1 per cow and year with two different starting populations, the SLU Röbäcksdalen herd (RBD) and an average Swedish red dairy cattle (SRB m.) herd, for within-breed selection, crossbreeding with crossbreeding scheme 1 (ProCross) and crossbreeding scheme 2 (SJM).

In this study SJM seem to be the crossbreeding option of the tested schemes that give the highest contribution margin 1. The within-breed selection does however give a higher profit in comparison two these two crossbreeding schemes. Notable is, that the scenario having the highest ECM production (SRB mean 2047) does not have the best profit. Indicating that other traits than milk production as well as milk composition (affecting the milk price) are important when looking at total profitability in a dairy herd. However, other combinations of breeds might still exist that increase the profit more than these two tested breeding schemes. As a suggestion, the combination of SRB, Jersey and HF might be even more profitable. However, that combination would probably be affected more by aspects like larger height and size variation within the herd. Furthermore, as F1 animals utilizes a higher heterosis than three-breed crosses and that tools as sexed semen are available today (Lopez-Villalobos *et al.*, 2000; Sørensen *et al.*, 2008) the possibility of having a purebred nucleus combined with F1 production animals might still give an higher profit than within-breed selection. This must however be studied further. Another possible way to increase the profit is to increase the usage of beef bulls or gender sorted AI for bull calves on cows that no recruitment is done from (Hohenboken, 1999; Sørensen *et al.*, 2008). These calves can then be sold at a higher price. For the smaller SJM Cross this might especially be a good option to increase the beef revenues. Which beef breed to use has not been studied here, but traits like good calving ability and growth should be considered when choosing the beef breed.

5.4 Future aspects for sustainable crossbreeding

Preferably before changing to crossbred dairy cattle other aspects than economy should be considered as well. Some of these was raised in the interview with Rahimi (2016): How should breeding animals be evaluated when crossbred? How does crossbred animals affect the validation of future research in the SLU Röbäcksdalen herd? It should also be considered whether there is other traits or aspects that can be impaired by changing into a crossbred herd. Or if there are other welfare of economically valuable traits that is improved by the crossbreeding scheme used. Furthermore, as Nilsson (2016) mentions as well as Rodriguez-Martinez *et al.* (2008) crossbred herds will always be dependent on continued high leveled within-breed selection. The effect that changing a purebred herd into a crossbreed will have on the total breed population should always be considered. Saving a purebred nucleus in the herd might thus increase the future sustainability of the pure-bred population. As described by McAllister (2002) another important aspect is to continue using high merit bulls and that there is a good availability of breeding animals and AI. Otherwise the risk might be that the crossbred cows' genetic merit is continually at a lower level than the pure-bred.

5.5 Conclusion

From a herd perspective, the starting populations affects how big the economic and phenotypic effect will be with crossbreeding. The best breeds to use for profitable crossbreeding seem to depend on which breed you are starting with and how the payment for products is set. These results suggest that from an SRB and an SLU Röbäcksdalen perspective, the best option for crossbreeding is SJM, rotational crossbreeding with SRB, Jersey and Mb. Other crossbreeding options not investigated in this study might also exist that increases profit even more. Generally using crossbreeding on low producing animals seem to improve the production profit faster than pure-breeding. However, within-breed selection has in the long run a slightly better profit so for a fast increased overall profit the possibility of combining both within-breed selection and crossbreeding might be the best. To verify the results it is important to test this in further studies using real phenotypic data from systematically crossbred animals.

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Appendix 1

Questionnaire to herd manager at Röbäcksdalen.

Current state

- What do you think is the greatest strength with the herd today?
- What do you think is the greatest weakness with the herd today?
- What would you want to change with todays planning of the breeding?
- Which practical issues do you have with the breeding work today?
- Which traits do you think is the most important to improve in the herd today? Of the below listed traits, which are the five most important?

Total milk amount
Fat in milk
Protein in milk
Udder shape
Size (height)
Feeding efficiency
Easy calving's
Fertility (calving interval, service per lactation)
Robustness/productive life (increased number of lactations per cow)
Another trait:

- Which trait/traits do you think is most important to improve by breeding for a good economy?
- Which trait/traits do you think is most important to improve by breeding for an enhanced animal welfare?

Crossbreeding in the future?

- If crossbreeding were used at the farm which practical issues do you expect?
- Do you expect any practical advantages with crossbreeding?
- Can you see any overall benefits with usage of crossbreeding instead of pure breeding?
- Which overall disadvantages can you see with crossbreeding instead of pure breeding?
- Which is your biggest concern if you would change into crossbreeding?
- When choosing breeds to cross into the herd, which would you like to use? Why, why not?

- Different crossbreeding strategies are suggested below. Do you think they would work practically?

- *Alternating two-breed crossing. The entire herd is crossbreed.*
- *Alternating three-breed crossing. The entire herd is crossbreed.*
- *Pure breed SRB 50-60 % of the herd. The rest are two breed crosses that you do not recruit from.*
- *Pure breed SRB 50-60 % of the herd. Three- and two-breed crosses on the rest of the herd. No recruitment from the three-breed cross.*

Appendix 2

Questionnaire for the Nilsson's in Skråmered herd.

Before crossbreeding

1. Before starting with crossbreeding, how was the state of the herd then? Which pros and cons did the animals have then?
2. What breed did you have and how many animals?
3. What was the most common reason for culling a cow then?
4. For how many lactations on average could you keep a cow?
5. What practical issues did you have with the breeding work?
6. What made you change to crossbreeding?
7. What practical difficulties did you expect when changing to crossbred animals? Did you experience other difficulties when changing to crossbred animals?

Current state

1. For how long have you worked with ProCross? Is the whole herd crossbred today?
2. Why did you choose ProCross? Did you consider other breeds?
3. Which pros and cons do you see with using crossbreeding?
4. What is the biggest difference at the herd since you started with ProCross animals?
5. Which is the biggest advantage and disadvantage with the ProCross animals?
6. How much milk does the herd produce today? Protein and fat content?
7. Which is the main reason for culling a cow today?
8. How many lactations do you keep a cow today?
9. Has the variation between the animals in size, production etc. changed since starting with ProCross?
10. Which traits do you think is the most important to improve in the herd today? Of the below listed traits, which are the five most important?

Total milk amount
Fat in milk
Protein in milk
Udder shape
Size (height)
Feeding efficiency
Easy calving's
Fertility (calving interval, service per lactation)
Robustness/productive life (increased number of lactations per cow)
Another trait:

11. Which trait/traits do you think is most important to improve by breeding for a good economy?
12. Which trait/traits do you think is most important to improve by breeding for an enhanced animal welfare?

13. How is the planning of the breeding done today?
14. How do you choose recruitment animals for the herd today?
15. How do you do follow-up of the breeding goals at the farm?
16. Is there anything you would like to change with today's breeding planning?
17. What was the biggest difficulty when starting up with ProCross? Is there anything you would have wanted to do differently?

Appendix 3

Heterosis estimation

Description of calculations for estimation of missing heterosis effects in literature.

SRB/Mb estimated from Hazel et al., 2016.

			Difference from HF		
	HF	HFxMb	HFxSRB	Dif. HFxMb	Dif. HFxSRB
milk kg ECM	10249	10465	10257	216	8
kg fat	408	417	413	9	5
% fat	3.72	3.81	3.92	0.09	0.2
Kg protein	332	343	336	11	4
% protein	3.03	3.13	3.19	0.10	0.16
				Dif.=HF-(HFxMb) Dif.=HF-(HFxSRB)	

	Calculated crossing result		Est. heterosis		
	SRBxMb (difference)	SRBxMb production (P)	SRBxMb %	SRB average	Mb average
milk kg ECM	112	8973.5	1.012639	9529	8 194
kg fat	7	367	1.019444	393	327
% fat	0.145	4.275	1.035109	4.36	3.9
Kg pro-tein	7.5	306	1.025126	322	275
% pro-tein	0.13	3.555	1.037956	3.57	3.28
	=dif. HFxMb/2 +dif.HFxSRB/2	P=(Mb average+ SRB aver-age)/2+calculated crossing result			

Based on assumption that 50 % of the crossed animals' production difference comes from breed A and 50 % from breed B.

Appendix 4

Input data

Model 1 – ProCross input data

	SRB RBD calf	SRB RBD heifer	SRB RBD 1	SRB RBD 2+	SRB calf	SRB heifer	SRB 1	SRB 2+
Kg milk	0	0	7568	7568	0	0	9014	9014
Milk, kg ECM	0	0	8477	8477	0	0	9529	9529
Fat, kg	0	0	364	364	0	0	393	393
Fat, %	0	0	4.8	4.8	0	0	4.36	4.36
Protein, kg	0	0	277	277	0	0	322	322
Protein, %	0	0	3.7	3.7	0	0	3.57	3.57
Age at culling, months	0	0	54.1	54.1	0	0	61	61
Conception rate/inseminations per cow	0	0	2.1	2.1	0	0	1.79	1.79
SCC, thousand	0	0	183	183	0	0	254	254
live weight	85	400	575	575	85	400	575	575
Height, cm	70	135	136.9	136.9	70	135	140.4	140.4

	HF calf	HF heifer	HF 1	HF 2+	Mb calf	Mb heifer	Mb 1	Mb 2+
Kg milk	0	0	10133	10133	0	0	8379	8379
Milk, kg ECM	0	0	10239	10239	0	0	8 194	8 194
Fat, kg	0	0	414	414	0	0	327	274
Fat, %	0	0	4.09	4.09	0	0	3.9	4
Protein, kg	0	0	345	345	0	0	275	230
Protein, %	0	0	3.4	3.4	0	0	3.28	3.8
Age at culling, months	0	0	60.11	60.11	0	0	59.6	59.6
inseminations per cow	0	0	1.83	1.83	0	0	2.05	2.05
SCC, thousand	0	0	254	254	0	0	235	235
live weight	85	415	680	680	85	415	675	675
Height	80	140	149.4	149.4	75	140	147.5	147.5

	Heterosis %		
	SRBxHF	SRBxMb	HFxMb
Kg milk	1.024777778	1.013	1.06
Milk, kg ECM	1.027125	1.013	1.06
Fat, kg	1.027125	1.019	1.064
Fat, %	1.02557143	1.035	1.064
Protein, kg	1.02557143	1.025	1.057
Protein, %	1.02557143	1.038	1.057
Age at culling, months	1.1265	1.05	1.05
inseminations per cow	0.97333333	0.97	0.935
SCC, thousand	0.98	0.993	0.986
live weight	1.03	1.03	1.03
Height	1.03	1.03	1.03

Model 2 – SJM input data

	SRB RBD calf	SRB RBD heifer	SRB RBD 1	SRB RBD 2+	SRB calf	SRB heifer	SRB 1	SRB 2+
Kg milk	0	0	7568	7568	0	0	9014	9014
Milk, kg ECM	0	0	8477	8477	0	0	9529	9529
Fat, kg	0	0	364	364	0	0	393	393
Fat, %	0	0	4.8	4.8	0	0	4.36	4.36
Protein, kg	0	0	277	277	0	0	322	322
Protein, %	0	0	3.7	3.7	0	0	3.57	3.57
Age at culling, months	0	0	54.1	54.1	0	0	611	611
inseminations per cow	0	0	2.1	2.1	0	0	1.79	1.79
SCC, thousand	0	0	183	183	0	0	254	254
live weight	85	400	575	575	85	400	575	575
Height	70	135	136.9	136.9	70	135	140	140.4

	J calf	J hei-fer	J 1	J 2+	Mb calf	Mb heifer	Mb 1	Mb 2+
Kg milk	0	0	7199	7199	0	0	8379	8379
Milk, kg ECM	0	0	9241	9241	0	0	8 194	8 194
Fat, kg	0	0	422	422	0	0	327	274
Fat, %	0	0	5.87	5.87	0	0	3.9	4
Protein, kg	0	0	297	297	0	0	275	230
Protein, %	0	0	4.13	4.13	0	0	3.28	3.8
Age at culling, months	0	0	60.6	60.6	0	0	59.6	59.6
inseminations per cow	0	0	1.81	1.81	0	0	2.05	2.05
SCC, thousand	0	0	254	254	0	0	235	235
live weight	85	350	454	454	85	400	675	675
Height	65	125	129.4	129.4	75	140	147.5	147.5

	Heterosis %		
	SRBxJ	SRBxMb	JxMb
Kg milk	1.034	1.013	1.03
Milk, kg ECM	1.034	1.013	1.03
Fat, kg	1.045	1.019	1.03
Fat, %	1.045	1.035	1.03
Protein, kg	1.046	1.025	1.03
Protein, %	1.046	1.038	1.03
Age at culling, months	1.047	1.05	1.125
inseminations per cow	0.9	0.97	0.9
SCC, thousand	0.993	0.993	0.993
live weight	1.023	1.03	1.03
Height	1.03	1.03	1.03

Model 3 – SRB

	SRB RBD calf	SRB RBD heifer	SRB RBD 1	SRB RBD 2+	SRB calf	SRB heifer	SRB 1	SRB 2+
Kg milk	0	0	7568	7568	0	0	9014	9014
Milk, kg ECM	0	0	8477	8477	0	0	9529	9529
Fat, kg	0	0	364	364	0	0	393	393
Fat, %	0	0	4.8	4.8	0	0	4.36	4.36
Protein, kg	0	0	277	277	0	0	322	322
Protein, %	0	0	3.7	3.7	0	0	3.57	3.57
Age at culling, months	0	0	54.1	54.1	0	0	611	611
inseminations per cow	0	0	2.1	2.1	0	0	1.79	1.79
SCC, thousand	0	0	183	183	0	0	254	254
live weight	85	400	575	575	85	400	575	575
Height	70	135	136.9	136.9	70	135	140	140.4

Genetic trends

The genetic trends are in the simulation models used as percentile changes increasing every year. The increase is however only incorporated in first lactation cows and every cow will have the same trait value her whole productive life. The genetic change per trait and year is calculated below.

Index units = IU

SRB

Kg milk, 100 IU (year 2014) – 75 IU (year 1991) =25 IU
25/23years=1,09 IU/year → 1.09/100= 0.0109 → 1.09 %/year
+1 IU = 70.3 kg

Kg Milk ECM (yield), 100 IU (year 2014) – 68 IU (year 1991) =32 IU
32/23years=1,39 IU/year → 1,39/100= 0,0139 → 1,39 %/year

Kg protein, 100 IU (year 2014) – 65 IU (year 1991) =35 IU
35/23years=1,52 IU/year → 1,52/100= 0,0152 → 1,52 %
+1 IU = 2,1kg

Kg fat, 100 IU (year 2014) – 75 IU (year 1991) = 25 IU
25/23years=1,09 IU/year → 1,09/100= 0,0109 → 1,09 %/year
+1 IU = 2,5 kg

Conception rate (Fertility), 101 IU (year 2014) – 102 IU =-1 IU
-1 IU/23=-0,043 IU/year → -0,043/102= -0,00041 → 0,041 %/year
+1 IU = -0,08 (early fertility treatments) or -0,19 (late fertility treatments)

SCC (Udder health), 101 IU (year 2014) – 101 IU (year 1991) = 0
- → 0 %/year +1 IU = -0.33 udder health

Survival (Longevity), 100 IU (year 2014) – 75 IU (year 1991) = 25 IU
25/23 years =1,09 → 1,09/100 =0,0109 → 1,09 %/year

Live Weight (Growth), 102 IU (year 2014) - 98 IU (year 1991) = 4 IU
4/23years= 0,17 IU/year → 0,17/102= 0,0017 → 0,17 %/year
+ 1 IU = 2,2 grams/day

Height (Stature), 101 IU (year 2014) – 92 IU (year 1991) = 9 IU
9/23years= 0,39 → 0,39/101= 0,0039 → 0,39 %/year
+1 IU=0,25cm
Optimum value: 142 cm, Swedish mean value: 140.4 cm

Holstein

Milk kg, 100 IU (year 2014) – 68 IU (year 1991) =32 IU
32/23years=1,39 → 1,39/100= 0,0139 → 1,39%/year
+1 IU= 65,3kg

Milk ECM (yield index), 100 IU (year 2014) – 63 IU (year 1991) =37 IU
37/23=1,61 IU/year → 1,61/100= 0,0161 → 1,61 %/year

Kg protein, 100 IU (year 2014) – 60 IU (year 1991) = 40 IU
40/23years=1,74 IU/year → 1,74/100= 0,017 → 1,7%/year
+1 IU= 2,0kg

Kg fat, 100 IU (year 2014) – 71 IU (year 1991) =29 IU
29/23years=1,26 IU/year → 1,26/100=0,0126 → 1,26 %/year
+1 IU = 2,5kg

Conception rate (Fertility), 100 IU (year 2014) - 110 IU (year 1991) = -10 IU
-10IU/23years= -0.43IU/year→ -0,43/110 = -0,004 → -0,04%/year
+1 IU = -0,11 (early fertility treatments) or -0,17 (late fertility treatments).

SCC (Udder health), 100 IU (year 2014) – 98 IU (year 1991) = 2 IU
2 IU/23years=0,087 IU/year → 0,087/100=0,00087 → +0,087 %/year
+1 IU = -0,44 % in udder health

Survival (Longevity), 100 IU (year 2014) – 78IU (year 1991) = 22 IU
22IU/23years=0,96IU/year → 0,96/100=0,0096 → +0,96 %/year

***Live Weight (Growth*),** 100 IU (year 2014) - 110 IU (year 1991) = -10 IU
-10 IU/23years= -0.43 IU/year→ -0,43/110 = -0,004 → -0,04 %/year
+1 IU = 2,0 g/day

Height (Stature), 112 IU (year 2014) - 74 IU (year 1991) = 38 IU
38/23years=1,65 IU/year → 1,65/112=0,015 → 1,5 %/year
+1 IU= 0,23 cm
Optimum value: 148 cm, Swedish mean value: 149.4 cm.

Values used are from a document used at a NAV workshop 2017-19-1 and from NAVET; nordic.mloy.fi/NAV (2017-02-09). Document received from Emma Carlén through personal communication.

Jersey

Milk kg, 100 IU (year 2014) – 82 IU (year 1992) =18 IU
18/22years=0,81 → 0,81/100 = 0,0081 → 0,81 %/year
+1 IU = 57,3 kg milk
Milk ECM (Yield index), 100 IU (year 2014) – 65 IU (year 1992) = 35 IU
35/22years =1,59 IU/year → 1,59/100=0,0159 → 1,59 %/year

Kg protein, 100 IU (year 2014) – 70 IU (year 1992) = 30 IU
30/22years= 1,36 IU/year → 1,36/100=0,014 → 1,4 %
+1 IU = 1,7kg

Kg fat, 100 IU (year 2014) – 68 IU (year 1992) =32 IU
32/22years=1,45 IU/year → 1,45/100= 0,0145 → 1,45 %
+1 IU= 2,1 kg

Conception rate (Fertility), 101 IU (year 2014) – 102 IU =-1 IU
-1 IU/22=-0,045 IU/year → -0,045/102= -0,00044 → 0,044 %/year

SCC (Udder health), 100 IU (year 2014) – 105 IU (year 1992) = -5 IU
-5/22years= -0,23 → -0,23/105=-0,0022 → -0,22 %/year
+1 IU= -0,51 % in udder health

Survival (Longevity), 100 IU (year 2014) – 80 IU (year 1992) = 20 IU
20/22years= 0,91 → 0,91/100=0,0091 → 0,91 %/year

Live Weight (Growth), 100 IU (year 2014) – 102 IU (year 1992) = -2 IU
-2/22= -0,09 → -0,09/102=-0,00088 →-0,088 %/year
+1 IU = 2,2 grams/day

Height (Stature), 105 IU (year 2014) – 90 IU (year 1990) = 15 IU
15/24years=0,625 IU/year → 0,625/105= 0,006 → 0,6 %
+1 IU = 0,14cm
Optimum value: 129 cm, mean value: 129.4 cm

Values used are from a document used at a NAV workshop 2017-19-1 and from NAVET; nordic.mloy.fi/NAV (2017-02-09). Document received from Emma Carlén through personal communication.

Montbéliarde

Montbéliarde is a French breed so no values are available from the Nordic breeding evaluation, NAV. No values for the genetic trends for the Montbéliarde breed is available online through their breed organization. Therefore, all values for genetic trends used in the simulations are set to the joint average genetic trends from the SRB, Holstein and Jersey trends calculated above.

Milk kg, (1,09 %/year + 1,39 %/year + 0.81 %/year)/3=1,097 %/year

Milk ECM, (1,39 %/year +1,61 %/year + 1,59 %/year)/3=1,53 %/year

Kg protein, (1,52%+1,7%/year+1,4%)/3=1,54 %/year

Kg fat, (1,09 %/year + 1,26%/year + 1,45 %)/3=1,27 %

Conception rate, (0,041 %/year+ -0,04%/year + 0,044 %/year)/3=0,015%
SCC, (0 %/year + 0,087 %/year + -0,22 %/year)/3= -0,044

Survival, (1,09 %/year + 0,96 %/year + 0,91 %/year)/3=0,99 %/year

Live weight, (0,17 %/year + -0,04 %/year + -0,088 %/year)/3= 0,014 %/year

Height(stature), (0,39 %/year 1,5 %/year 0,6 %)/3=0,83 %/year

Appendix 5

Feed intake estimation

Estimations for maintenance increase per kg live weight change. Maintenance calculations based on this formula: MJ/day=live weight^0.75 × 0.515

live weight	MJ maintenance needs	increase/100kg	% increase/ 100kg	% increase/1kg
400	46.06300034			
500	54.45462007	8.391619731	0.182177011	0.00182177
600	62.43392909	7.979309027	0.146531351	0.001465314
700	70.08591685	7.651987753	0.122561368	0.001225614
800	77.46842372	7.38250687	0.105335097	0.001053351
900	84.62313513	7.154711417	0.092356486	0.000923565
1000	91.58138962	6.958254482	0.082226385	0.000822264

factor	0.515	% average increase/ 1 kg:	0.001218646

Current market prices

Prices and costs used for analysis of economy in within bred selection (SRB), crossbreeding scheme 1(ProCross) and crossbreeding scheme 2(SJM) in the Röbäcksdalen herd (RBD).

Scenario		SEK
SRB RBD 2047		
Total milk price	4.9 % fat, 4.10 % protein, 10635 kg milk/cow/year	3.803/kg
Quality addition SCC	183 000	0.0761/kg
SRB mean 2047		
Total milk price	4.41 % fat, 4.0 % protein, 12 667 kg milk/cow/year	3.58
Quality addition SCC	254 000	0.0329
ProCross RBD 2047		
Total milk price	4.3 % fat, 3.87 % protein, 12 330 kg milk/cow/year	3.471
Quality addition SCC	143 000	0.0694
ProCross SRB mean 2047		
Total milk price	3.76 % fat, 3.84 % protein 12 976 kg milk/cow/year	3.27
Quality addition SCC	164 000	0.0654

SJM 2047		
Total milk price	5.3 % fat, 4.3 % protein 10 329 kg milk/cow/year	4.05
Quality addition SCC	144 000	0.081
SJM SRB mean 2047		
Total milk price	5.1 % fat, 4.1 % protein 10 947 kg milk/cow/year	3.872
Quality addition SCC	159 000	0.0774
Meat prices		
Cow Sweden	Average 2017-01-16	38.83/kg[1]
Calf sold alive	Average 2017-02-06, 85 kg calf SRB/SLB breed	2720/calf[1]
Calf sold alive, addition heifer	Montbeliarde breed	200/calf[2]
Calf sold alive, addition bull	Montbeliarde breed	600/calf[2]
Insemination prices		
SRB, Jersey, HF bull	Top bulls	212/insemination[3]
SRB. Jersey, HF bull	X-vik/y-vik samen	314/insemination[3]
Meat breed bull	Top bulls	97/insemination[3]
Meat breed bull	X-vik/Y-vik semen	314/insemination[3]
Mb bull	Average price	191/insemination[4]
Mb bull	Average for X-vik/Y-vik semen	383/insemination[4]
Extra costs/cow	Approximate cost for cow-control, pregnancy analysis, milk testing etc.	497/cow

Milk prices calculated assuming 127.3 cows/year in the herd, SRB=Swedish red and white dairy cattle, HF=Holstein Friesian dairy cattle, Mb= Montbéliarde cattle [1]average market prices (ATL, 2017), [2] slaughter house averages (HKscanagri, 2017), [3] bull catalogue November-February 2016-2017 (Växa Sverige, 2016f), [4]online semen sales prices 2017-02-16 (Växa Sverige, 2017a).

Agriwise calculation sheet

In this part, an example of the Agriwise calculation sheet used is shown. Only contribution margin 1(TB 1) is used in the results part.

	bas- 608kg ko, mindre/mer +- 0,12 % i foder						
		Avkastning, kg ECM			13 273	43,5 kg ecm/dag	
		Andel mejerimjölk			93,6%		
	Intäkter och särkostnader	Överutfodring/spill grovf.			5,0%		Produktionskostnad,
	per ko och år	Överutfodring/spill kraftf.			4,0%		öre/kg
			Kvant	Pris	kr		
	INTÄKTER						
3110	Levererad mjölk	kg	12 424	4,108	51 038		
93121	Livkalv, kviga, egen uppfödning	st	0,23	1 125	259		
3121	Livkalv, kviga, försäljning	st	0,27	2 920	788		
3121	Livkalv, tjur	st	0,5	3 320	1 660		
3133	Kött, utslagsko	kg	67	38,83	2 602		
3180	Nationellt stöd, mjölk	kg	12 424	0,80	9 939		
3180	Nötkreatursstöd	st	1,0	824	824		
3180	Stöd för utökad klövvård	st	0,0	220	0		
93192	Flytgödsel, nöt, 9% ts, intern	ton	24,8	0,00	0		
	SUMMA INTÄKTER				67 110		
	SÄRKOSTNADER						
94113	Kalvfärdig kviga	st	0,23	11 000	2 530		20,36
4134	Mjölknäring (kalvnäring)	kg	21	15,37	323		2,60
4151	Hö, inköpt	kg ts	0	1,50	0		0,00
94151	Hö, egenproducerat	kg ts	336	0,61	205		1,65
4155	Ensilage, inköpt	kg ts	0	0,00	0		0,00
94155	Ensilage, egenproducerat	kg ts	4 883	1,24	6 055		48,74
94154	Bete	kg ts	640	0,29	186		1,50
4153	HP-massa	kg	0	0,00	0		0,00
4135	Betfor	kg	0	1,57	0		0,00
4133	Fodersäd, inköpt	kg	1 465	2,82	4 131		33,25
94133	Fodersäd, egenproducerat	kg	1 607	1,75	2 812		22,63
4132	Högmjölkarkoncentrat	kg	534	3,34	1 784		14,36
94152	Foderhalm	kg ts	0	0,19	0		0,00
4138	Mineralfoder	kg	40	7,87	315		2,54
4157	Strömedel	kg	285	0,19	54		0,43
4170	Semin- och kontrollavgift	kr	2,13	749	1 595		12,84
4173	Veterinär, medicin	kr	1	775	775		6,24
4174	Rådgivning	kr	1	70	70		0,56
5310	El	kWh	881	0,68	599		4,82
6312	Djurförsäkring	kr	1	131	131		1,05
4180	Diverse kostnader	kr	1	1 630	1 630		13,12
	SUMMA SÄRKOSTNADER 1				23 195		186,70
0000	Byggnader, underhåll	kr	59 000	1,8%	1 062		8,55
0000	Utfodringssystem, underhåll	kr	3 300	2,0%	66		0,53
0000	Foderberedningsanl. underhåll	ton	3,07	25,00	77		0,62
0000	Ränta djurkapital	kr	11 156	7%	781		6,29
10000	Ränta rörelsekapital	kr	6 544	7%	458		3,69
	SUMMA SÄRKOSTNADER 2				25 639		206,37
0000	Byggnader, avskr + ränta	kr	59 000	8,0%	4 720		37,99
0000	Utfodringssystem., avskr + ränta	kr	3 100	13,5%	419		3,37
0000	Foderberedningsanl., avskr + ränta	ton	3,07	73,00	224		1,80
20000	Arbete	tim	23	223,00	5 129		41,28
	SUMMA SÄRKOSTNADER 3				36 131		290,82
	TÄCKNINGSBIDRAG						
30000	TB 1 = INTÄKTER - SÄRKOSTNADER 1				43 915	Mjölk minus foder, öre/kg	284
	TB 2 = INTÄKTER - SÄRKOSTNADER 2				41 471	Rörlig produktionskostnad	248
	TB 3 = INTÄKTER - SÄRKOSTNADER 3				30 979	Fast produktionskostnad	43

Example of Agriwise calculation sheet. This figure represents the Röbäcksdalen scenario for within breed selection in year 2047.

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