Alternative approaches for analyses of production performance from automatic milking systems in South Africa

by

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Declaration

I, Anton Ulendo Gresse hereby declare that this dissertation, submitted for the MSc (Agric) Animal Science: Livestock Production and Ecology degree at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at any other University.

Gresse ________

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This study is dedicated to my grandfathers who set a great example for me,
men with wisdom I shall ever aspire to attain.

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Abstract

Globally, dairy producers are employing precision farming practices and incorporating computer software that enables producers to manage large herds at an individual animal level. South African dairy producers have been adopting similar strategies with a trend towards larger production units and the incorporation of automatic milking systems. The software employed in automatic systems record production, reproduction and health parameters on a daily basis. These systems record all variables and movements of individual animals, from the day of birth to the day the cow exits the herd. The majority of producers using automatic milking systems do not participate in national recording. The aim of this study was to perform a production analysis with the primary objective of constructing a template for extracting and analysing herd performance data from producers employing automatic management software in South Africa. Two large dairy herds, representing a TMR system, and a pasture-based production system participated in the study. Producers installed the AfiFarm herd management software from S.A.E Afikim, Kibbutz, Israel. By extracting animal records from multiple years, comprehensive data tables were constructed for different production analyses. Analyses included time-trend evaluation of herd numbers, mean production and reproduction performance at the heifer and cow level, distribution of exit reasons and assessing the relationship between the genetic merit of sires and the mean performance of their progeny. Findings from this study confirm that the AfiFarm herd management software permit extraction and analyses of multiple variables imperative to dairy management at the herd and cow level. The software has the potential to serve as a platform to add a vast number of dairy cow performance records for future analyses.

Contents

List of Abbreviations

AFC	Age at first calving
AFConc	Age at first conception
AFS	Age at first service
AI	Artificial insemination
AMS	Automatic milking system
AMY	Average milk yield
ARC	Agricultural research council
Ave	Average
BCS	Body condition score
BLUP	Best linear unbiased prediction
BW	Body weight
CO_2	Carbon dioxide
DD	Days dry
DFLI	Days between first and last insemination
DGAT1	Diacylglycerol O-acyltransferase 1 gene
DGP	Dairy genomic programme
DIMFS	Days in milk at first service
DIMMSA	Digital information and management systems South Africa
DNA	Deoxyribonucleic acid
DO	Days open
EBI	Economic breeding index
EBV	Estimated breeding value
FCM	Fat corrected milk
FMI	Fluid merit index
GEBV	Genomically enhanced estimated breeding value
GMACE	Genomic multiple across country evaluation
ha	Hectare
h^2	Heritability
HMI	Holstein merit index
ICAR	International committee for animal recording
ICP	Inter calving period
IFCN	International farm comparison network
IN	Insemination number
INTERBULL	International bull evaluation service
INTERGIS	Integrated registration and genetic information system
kg	Kilogram
Lact no	Lactation number
LMY	Lactation milk yield
Log	Logarithm
LPI	Lifetime profit index
MACE	Multiple-trait across country evaluation
mm	Millimeter
MPO	Milk producers’ organization
n	Number
NE	Effective population size
NMI	Net merit index
PDF	Precision dairy farming
PLI	Profitable lifetime index
rg	Genetic correlation
rBST	Recombinant bovine somatotropin
RPM	Rising plate meter

SA	South Africa
SCC	Somatic cell count
SCS	Somatic cell score
SD	Standard deviation
TMI	Total merit index
TMR	Total mixed ration
TPI	Total profitability index
USA	United States of America
VMS	Voluntary milking system
VWP	Voluntary waiting period
°C	Degrees celsius
σ_g	Genetic standard deviation

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Chapter 1: Introduction

Dairy production is a fundamental contributor to food security worldwide (Smith *et al*., 2013), with an estimated 120 million dairy production units across the globe (Milk SA, 2018). Production units vary between small subsistence units, keeping one to three cows to commercial farms managing large herds. In developed countries the number of dairy producers is decreasing while herd sizes are increasing. Together with herd size, the average daily milk yield of cows increased and can be attributed to advances in nutrition, technology applied for precise management and long-term genetic selection for high milk yield (Barkema *et al*., 2015). World milk production is around 826 million tonnes per year, with South Africa contributing 0.5% of total worldwide milk yield (Milk SA, 2018).

Global estimates suggest that demand for dairy products will increase by 20 million tonnes in 2018, with 6 million tonnes attributed to population growth and 14 million tonnes to an increase in per capita consumption (Milk SA, 2018). The estimated average global per capita consumption of dairy products is around 111.1 kg per year. The demand for milk in South Africa is on the rise with the national per capita consumption of dairy products estimated at 59 kg, 14 kg higher than the 45 kg estimated in 2005. The rise in domestic demand is expected to maintain pressure on the South African dairy industry.

In addition to providing essential nutrients, the South African dairy industry facilitates employment for people from different socio-economic backgrounds. Similar to global trends in dairy production, the number of South African dairy producers are decreasing while the size of herds is increasing. Fluctuating milk prices and high input costs in the form of feed, housing, labour, maintenance, veterinary costs and milking equipment are presenting a strain on profits. That has resulted in an increased size of farming operations to ensure a profitable enterprise (Scholtz & Grobler, 2009; Theron & Mostert, 2009). Producers rely on a large herd together with efficient milk yield to offset the pressure from market forces, balancing input-capital with optimum production levels determines the economic viability of a dairy enterprise. Feed management is a major component driving herd size and production levels. South African dairy cattle are managed either in pasture-based systems characterized by grazing protocols or total mixed ration (TMR) systems where cows are generally housed in intensive free stall housing units, receiving a specially formulated diet (Theron & Mostert, 2009; Scholtz *et al*., 2014; Williams *et al*., 2016).

To maintain profits, producers are reliant on healthy, fertile animals, producing at optimum levels regardless of the production systems employed. Comprehensive breeding objectives are cardinal in promoting genetic improvement of economically relevant traits. Desirable genotypes can be established by selecting genetically superior AI sires. South African producers have placed primary emphasis on yield and milk solids in past breeding objectives (Banga *et al*., 2014b). However, fertility and health traits have gained prominence in recent years. The declining reproductive performance of high yielding cows in South Africa have become a drawback by increasing breeding and feeding costs, while decreasing annual milk production in herds (Makgahlela *et al*., 2007; Mostert *et al*., 2010). The economic consequence of declining fertility has motivated producers to regard the latter among the primary goals in contemporary breeding objectives. Traits such as somatic cell count (SCC) and udder conformation were proven to increase longevity if incorporated in selection goals in South Africa (Du Toit *et al*., 2012c; Banga *et al*., 2014b). Producers are encouraged to consider multiple economically important traits when formulating breeding objectives and implementing selection criteria.

South African dairy producers have access to dairy animal recording organizations such as the national recording scheme and SA Stud Book. These organizations support producers in acquiring accurate phenotypic performance data and applying the data for genetic evaluation. Individual production, reproduction and health records permits informed breeding decisions as sub-optimal animals can be identified. Trends in herd numbers and age structure demonstrate the rate of internal growth and erosion of animals considered uneconomical (Muller & De Waal, 2016). Reasons for removing animals from the herd can be applied to monitor the proportion of voluntary and involuntary culling. The proportion of dairy herds participating in national recording is estimated at 13% (ICAR, 2016). Poor participation is a concern as performance of the national herd remains uncertain. Producers might be inclined to believe that the service received, does not merit the money spent, or that their automatic recording system employed provides sufficient data to track herd performance.

Precision dairy farming procedures have become essential for upholding individual efficiency in large herds (Norton & Berckmans, 2017), advances in dairy management technology enable producers to record and monitor their herds. Automatic sensor-based systems permit daily measurements of animal variables imperative to management (Clark *et al*., 2016). Production levels, milk flow rate, milk composition, milk conductivity, milking time and body weight are variables routinely recorded in the parlour during milking sessions, while activity levels are monitored over 24 hours. A central management software combines these variables to identify and rank animals with sub-optimal production levels as well as animals with possible infectious or metabolic ailments. Birth dates, insemination dates and calving dates are recorded and saved, and applied for monitoring fertility traits. The technology allows breeders to scrutinize milk yield, fertility and health records of animals, increasing selection accuracy and intensity.

Modern dairy producers are challenged by the “big data” at their disposal and require expertise when analysing performance records (Crowe *et al*., 2018). Experts from multiple disciplines such as veterinarians and animal scientists could sanction specialized analyses and interpretation of on-farm data. These procedures may well transform the comprehensive data sets into valuable information. It is believed that up to 65% of cows in milk in South Africa are managed with automatic technology (Koos Coetzee, personal communication, e-mail:koos.coetzee@mpo.co.za). Data captured in these systems could facilitate methodical studies that can prove to be invaluable for evaluating herds not participating in national recording.

1.1 Justification

South African dairy producers are adopting automatic dairy management technology to facilitate management of large herds. Many of these producers don’t participate in national milk recording, thus performance records of herds managed in these systems remain unknown to the industry. The automatic software employed is characterized by routine comprehensive data capturing of multiple animal performance parameters. Information feedback by means of a central management software program facilitates precise herd management, permitting access to wide-ranging variables at the herd as well as individual heifer and cow level.

It is believed that the software implemented in these systems could be applied for scientific research, since data captured can potentially be extracted. Producers are conversant in functions imperative for short and medium-term management procedures, however, alternative analyses could contribute to economic efficiency by supporting informed management decisions. Evaluating historic herd performance together with trends and associations between production and reproduction traits can serve as standards for monitoring production outcomes.

1.2 Aim

The aim of this study was to perform a production analyses based on data from dairy herds using automatic herd management technology in South Africa in two different production systems. The objectives were;

1. to develop a template for historic data extraction from automatic management software in a TMR and pasture-based system, respectively;
2. to mine extracted data and analyse time-trend herd numbers and production output;
3. to establish mean phenotypic performance of multiple heifer and cow production and reproduction traits;
4. to determine the correlations between production and reproduction traits;
5. to scrutinize reasons for animals culled from these herds;
6. to examine the potential of progeny performance records documented in AMSs for evaluating AI sires.

Chapter 2: Literature review

2.1 Introduction

Proliferation in dairy cattle production is attributed to genetic progress and non-genetic, managerial inputs such as improved nutrition, health care, housing and milking facilities (Pryce *et al*., 2004). The South African dairy industry is diverse, and the production systems employed differ across the country. Therefore, a varied array of genetic and non-genetic factors needs to be considered when formulating breeding objectives for improving production.

Limitations regarding genetic improvement in South African dairy cattle include poor participation in national recording schemes resulting in challenges for genetic evaluations. Animal recording and genetic evaluations provides the foundation for making selection and management decisions. Production traits previously deemed important and receiving preference in selection programs have led to dwindled genetic integrity of fertility and health traits, resulting in unfavorable effects on economic sustainability (Makgahlela *et al*., 2007; Banga *et al*., 2009; Mostert *et al*., 2010; Oltenacu & Broom, 2010; Du Toit *et al*., 2012b; Banga *et al*., 2014b).

In this review, a broad overview of the dairy industry in South Africa is provided, considering both non- and genetic factors. Research performed on South African dairy cattle is discussed with relevance to the different production systems applied, and the traits included in selection programs. Reference is made to the role of automatic milking systems (AMSs) and the challenges faced by the dairy industry.

2.2 Characteristics of South African dairy

Livestock serves to address malnourishment and unemployment in developing countries (Randolph *et al*., 2007). Global estimates suggest that more than 600 million people live and work on dairy farms (Milk SA, 2018). It is estimated that the South African dairy industry employs around 60 000 workers, administrators and managers in the primary dairy sector (DAFF, 2017). The dairy industry thus aids in facilitating a secure source of income to an increasing population. Producers create employment for rural communities that are otherwise limited to livelihoods in urban areas.

Dairy production differs from other agricultural products as it is produced daily, thus ensuring regular revenue. It delivers a liquid product that spoils, so producers have limited time to negotiate prices (Douphrate *et al*., 2013). Unfortunately, the South African dairy industry periodically suffers market fluctuations. Milk prices fall, and farmers are forced to exit the industry, followed by a rise in demand and an increase in milk price received by producers, until there is a surplus. Reduced milk prices, high production costs, weak exchange rates and consumer demands are commercial challenges facing modern dairy producers in South Africa. Political instability and land claims in South Africa are additional factors contributing to dairy farmers exiting the industry.

South Africa has an estimated 1.37 million dairy cattle (Meissner *et al*., 2013), primary dairy breeds are SA Holstein, Jersey, Ayrshire and Guernsey (Maiwashe *et al*., 2006), with the Holsteins being the largest in number. In South Africa, the number of dairy producers has decreased from 3 551 in 2009 to 1 364 in 2018 (Milk SA, 2018), a reduction in the number of milk producers is expected to continue. The most dairy cows are concentrated at the coastal regions of South Africa. The Western Cape, Eastern Cape and Kwazulu-Natal delivers most of the South African dairy production, with the largest herds and highest increase in cow numbers and milk yield (Table 2.1).

Table 2.1 Dairy production statistics determined per province in 2017 (source, Milk SA, 2018)

Province	Number of milk producers	Ave. number of cows in milk/herd	Percentage distribution of milk production	Percentage change in production since 1997
Western Cape	481	268	26.8	+75
Eastern Cape	244	606	29.7	+221
KwaZulu-Natal	247	594	28.2	+168
Northern Cape	7	398	0.7	-13
Free State	249	117	5.6	-54
North West	165	87	2.4	-72
Gauteng	98	188	3.7	+25
Mpumalanga	87	139	2.5	-66
Limpopo	15	191	0.4	+49

The inclination towards less producers was complimented by larger herd sizes and higher production output per unit. South African herds estimated in 2017 vary, with a mean herd size of 354 milk and dry cows. Large herds exceeding 1000 cows were estimated to be 14.4% of local herds (Milk SA, 2018), thus roughly 196 South African producers were included in this category. With the trend towards less producers and larger production units it is expected that the mean herd size will continue to increase. According to projections, there will be less than 1000 producers with a mean herd size of 720 cows in 2026 (Coetzee, 2018).

There are two main dairy production systems used in South Africa, which are similar to other countries in the world, namely TMR systems and pasture-based systems (Theron & Mostert, 2009; Scholtz *et al*., 2014; Williams *et al*., 2016). In South Africa approximately 30% of producers make use of TMR systems while pasture-based systems are on the rise with 65-70% of producers employing the system (Heinz Meissner, personal communication, e-mail: heinzmeissner@vodamail.co.za). The international farm comparison network (IFCN) determined that a typical South African herd size managed in TMR based systems, is composed of 630 cows producing 11 400 kg milk/cow/annum. The typical herd size on pasture-based systems is lower at 520 cows producing 5 950 kg milk/cow/annum. Total mixed ration systems in South Africa exhibit similarities to the same systems in the USA, while pasture-based systems are comparable to the large grazing systems in New Zealand (Coetzee, 2018).

Dairy cows on pasture-based systems may receive supplementary feed, depending on the region, seasonal changes in climate and production level. Pasture-based production tend to be limited to areas with a temperate climate and sufficient water supply. Dairy producers in the Eastern Cape and Kwazulu-Natal predominantly employ pasture-based dairy production systems (Lassen, 2012). Pasture species must be cultivated and managed while cattle must often be fetched by hand over long distances, requiring high labour and management input (Dodzi & Muchenje, 2011). Grassland allocation and stocking rates are important management factors to consider in a pasture-based system. Stocking rate (cows/ha) and pasture dry matter available/ha determines milk production per hectare and thus profitability. Macdonald *et al*. (2008) suggests the use of a comparative stocking rate where the body weight of animals is compared to the level of dry matter available. This gives a reasonable estimation of the number of animals to be allowed per hectare, based on their requirements, and the feed (grazing and supplementary feed) available.

Zero grazing or TMR systems are characterized by cows housed or confined to a pen, in regions where grazing is not a cost effective option (Haskell *et al*., 2006). Total mixed ration systems require infrastructure to facilitate housing and feeding of animals, feed must either be produced and mixed on the farm or purchased from a feed company. Cows in TMR systems have a higher milk yield compared to cows on pasture-based systems (Roche *et al*., 2006, Neser *et al*., 2014), which is explained by feeding specialised diets high in energy and protein. The use of TMR systems in central and northern provinces (Gauteng, Mpumalanga, Limpopo, Free State and the North West) in South Africa are prevalent, with several producers in the Western Cape also employing TMR systems (Theron & Mostert, 2009; Lassen, 2012; Coetzee, 2018).

2.3 Genetic improvement of South African dairy herds

Genetic progress of South African dairy cattle can be monitored and preserved by applying animal recording and genetic selection principles (Mostert *et al*., 2008; Banga *et al*., 2014a). The establishment of balanced breeding objectives and the solicitation of accurate dam and sire selection promotes a genetically competent herd.

2.3.1 Breeding objectives and selection criteria

Breeding objectives are defined by the traits related to increasing profit (Sölkner *et al*., 2008). The focus is therefore on selection and genetic improvement of profitable traits in the next generation, to facilitate a viable operation. Traits of economic importance to producers and buyers have always included yield traits, such as milk volume, milk fat, and milk protein yield. Only more recently traits like SCC (indicating mastitis), calving interval, live weight and longevity have been receiving preference (Mostert *et al*., 2008; Banga *et al*., 2010; 2014a; Byrne *et al*., 2016).

There is controversy regarding the scientific development and enforcement of balanced breeding objectives for South African dairy cattle (Banga *et al*., 2014a; b). Previous breeding objectives emphasized production traits, resulting in fertility and health traits losing genetic integrity (Mostert *et al*., 2010; Du Toit *et al*., 2012b; Banga *et al*., 2014b). Unfortunately pressure from market forces and low milk prices continue to force producers to focus on high production levels.

The emphasis on milk volume and composition is evident in both TMR and pasture-based systems (Banga *et al*., 2014a). Differences in the payment system can alter the weight placed on production traits, as some milk buyers pay a premium for milk solids, while others will promote volume. In addition to milk volume and composition, lactation persistency contributes to production income. A persistent cow is able to maintain a constant level of milk production throughout her lactation (Mostert *et al*., 2008). Persistency can also be defined as the ability of a cow to maintain high milk yield after reaching the peak of her production, thus it signifies the flatness of her production curve (Jensen, 2001; Mostert *et al*., 2008).

Production traits in dairy cows have low to moderate heritability values, ranging between 0.17 and 0.32 (Maiwashe *et al*., 2008; De Ponte Bouwer *et al*., 2013; Neser *et al*., 2014). Neser *et al*. (2014) reported heritability for milk production (305-day equivalent) in primiparous South African Holstein cows at 0.23 in a TMR system and 0.32 in a pasture-based system. The stronger response to selection for production traits compared to fertility traits serves as incentive for breeders to focus on yield traits in pursuing economic gain.

It is challenging to genetically predict future performance of fertility traits as they are difficult to measure and have low heritability values, ranging between 0.01 and 0.09 (Pryce *et al*., 1997; 1998; Makgahlela *et al*., 2009; Mostert *et al*., 2010; Ben Zaabza *et al*., 2016). Even though reproduction traits have low heritability values, literature suggest adequate additive genetic variation to allow genetic improvement (Berry *et al*., 2003). Reproductive vigor in high yielding cows in TMR systems (Cabrera, 2014), as well as cows in pasture-based systems (Shalloo *et al*., 2014), shows economic return. Seasonal breeding practices in pasture-based systems, supports the emphasis on fertility in breeding goals (Berry, 2015).

By monitoring herd health, economic viability and efficiency will be promoted, while lowering veterinary costs. Cow health and fitness compliments all economically important traits, selecting against difficulties such as mastitis and lameness, directly and indirectly promote optimum production levels, while supporting reproductive performance in both TMR and pasture-based systems (Dube *et al*., 2008; Olechnowicz & Jaskowski, 2011; Banga *et al*., 2014a).

Inclusion of non-production traits in future breeding objectives, will promote a genetically balanced cow. Norwegian countries have been achieving genetic progress in production, reproduction and health traits by implementing comprehensive breeding objectives (Heringstad *et al*., 2003b; Kargo *et al*., 2014). By consulting fertility and health records, breeders can track herd performance and adjust their breeding goals to address possible constraints.

A fertile dairy heifer or cow will conceive and maintain pregnancy if inseminated at the time of ovulation (Pryce *et al*., 2004). Variation in heifer and cow fertility traits, has shown that traits must be considered within the heifer period or respective parity (Mostert *et al*., 2010; Muuttoranta, 2015). The physiological condition of an animal changes over time and lactations, metabolic and physiological strain of milk production is not yet evident in heifers, giving a better indication of the animal's reproductive ability (Tiezzi *et al*, 2012). Cows tend to exhibit deterioration in fertility traits in later lactations. The capacity of a cow to maintain reproductive efficiency during her productive lifetime should form an integral part of management and breeding goals, to facilitate genetic progress.

Age at first calving and inter calving period are fertility traits used to measure heifer and cow fertility in South Africa (Makgahlela *et al*., 2009; Neser *et al*., 2014). Age at first calving indicates successful onset and detection of ovulation during the first breeding event (Bach & Ahedo, 2008; Hammoud *et al*., 2010). The trait has economic importance as it influences the number of calves produced per cow, determines rearing costs and affects subsequent reproductive and production performance. The trait serves as an indication of management during the rearing period to allow heifers to reach the appropriate body weight and condition for successful onset of ovulatory activity, conception and maintenance of pregnancy. Age at first calving can be subdivided to explain its components; the age heifers are first inseminated (successful onset of ovulation), the number of inseminations to conception (ability to conceive), days between first and last insemination and age at first conception (Heise *et al*., 2018).

Inter calving period (time between subsequent calving events), is similar to age at first calving, determined by multiple count and interval traits. The most important count trait is number of inseminations to conception, complimented by the interval trait, days between first and last insemination (indicates conception rate). Other interval traits include days in milk first inseminated (which is an indication of successful recycling and detection of heat) and days from calving to conception (days open) (Ghiasi *et al*., 2011; Potgieter *et al*., 2011).

A lower calving interval is perceived to increase fertility and subsequently reproductive performance in dairy cows, since it comprises multiple fertility traits. Even though estimated breeding values (EBVs) are calculated for inter calving period, it is expected that genetic progress will be slow, due to low heritability values (0.03 to 0.09) (Makgahlela *et al*., 2007; Mostert *et al*., 2010). If breeders record only calving interval, cows that did not have a subsequent calving event will be neglected (Muller *et al*., 2014). By recording component traits that can be measured earlier in lactation, data on the reproductive performance of all cows in the herd will be available, presenting impediments in reproductive performance and management.

Both age at first calving and inter calving period are measured by calving dates, where its component traits requires insemination records (Mostert *et al*., 2010; Heise *et al*., 2018). Impaired fertility will escalate the values for the mentioned traits, augmenting costs for multiple inseminations and maintaining animals with long lactation or dry periods (Makgahlela *et al*., 2007; Yusuf *et al*., 2010). The perceived genetic and phenotypic decline in South African dairy cattle fertility can be attributed to the unfavorable genetic correlation with milk production traits (Muller *et al*., 2014). Table 2.2 illustrate this antagonistic relationship from a study on South African Holstein cattle.

Table 2.2 Mean performance values together with heritability and genetic correlations observed in South African Holstein cattle (source, Makgahlela *et al*., 2009)

Trait	Mean	h^2	$r_g{}^a$ Lactation 1	Lactation 2	Lactation 3
Inter calving period (days)	396	0.03	0.69	0.37	0.52
Age at first calving (months)	28	0.24	-0.43	-0.35	-0.29

(a)Genetic correlations with lactation milk yield

The suggested age at first calving for Holstein heifers is between 23 and 24 months (Ettema & Santos, 2004; Wathes *et al.,* 2014; Elahi Torshizi, 2016). Genetic correlations between age at first calving and milk yield seen in Table 2.2, suggest that heifers that were genetically inclined to produce at high levels, especially in their first lactation were likely to calve down earlier (presumably within 23 to 24 months). Having heifers calve down too young or too late, increases the probability for health and reproductive problems, resulting in early culling and additional rearing and veterinary costs (Zavadilová & Štípková, 2013). Hossein-zadeh (2011) found the heritability of age at first calving in Iranian Holsteins to be 0.34, which is higher than the value determined by Makgahlela *et al*. (2007)

for South African Holsteins (Table 2.2). These moderate heritability values indicate that the trait is more heritable than fertility traits measured later in life and can be improved through selection. Breeders should be able to detect possible limitations in fertility management of heifers, if age at first calving and its accompanied component traits are routinely recorded.

A moderate to high positive genetic correlation between calving interval and milk yield (Table 2.2), suggests that cows with a high genetic merit for milk yield tend to exhibit post calving fertility problems. Studies found, that calving interval for all dairy breeds in South Africa is increasing (Makgahlela *et al*., 2007; Mostert *et al*., 2010). Mostert *et al*. (2010) determined that Holsteins had the highest increase at 1.25 days/year, followed by the Ayrshire at 0.71 days/year, Guernsey 0.57 days/year and the Jersey breed at 0.50 days/year since 1980. Appropriate fertility traits in selection indexes is the most promising opportunity to ensure long term reproductive efficiency (Berry *et al*., 2016).

It is emperative when evaluating mentioned reproduction traits, to consider management protocols unique to a given producer (Muller *et al*., 2000). The rational decision made by managers on the timing of insemination, inseminator proficiency and semen quality are managerial components influencing fertility traits. The genetic association between fertility and yield traits together with the mentioned managerial factors contribute to a strong correlation between interval fertility traits and lactation length (Němečková *et al*., 2015). Interval fertility traits will be increased if breeders extend the lactation period, by prolonging breeding in high producing cows. As a result, lactation length and subsequent lactation milk yield is so strongly correlated with reproduction traits, that lactation length can be analysed as an indication of fertility (Tiezzi *et al*, 2012). The principle is observed in a recent study by Abin *et al*. (2018), who found that interval fertility traits are increasing in high-input, production systems in South Africa, with the days in milk (mean 346 days) upwards of the conventional 305 days.

Differences in production system, infrastructure, calving year, calving season, and lactation number are fixed effects contributing to variation in measured fertility traits (Muller *et al*., 2014). Cows in TMR based systems, may receive a nutrient dense ration, but the physiological pressure of continuous high yield, contributes to reproductive limitations. Cows tend to have lower post-partum ovarian activity, resulting in poor signs of oestrus and conception rates. In pasture-based systems, the maintenance of body condition and energy stores are vital for optimal season-based reproductive functioning (Mee, 2012). Fertility promotes longevity as heifers and primiparous cows are readily involuntarily culled due to reproductive reasons.

The longevity or functional herd life of a dairy cow is a fitness trait that is defined as follows; Longevity is the ability of a cow or heifer to avoid voluntary or involuntary culling, due to poor production, infertility, changing markets, change in management or health problems (Du Toit *et al*., 2009). South African dairy producers are encouraged to implement longevity in their breeding goals (Imbayarwo-Chikosi *et al*., 2015). By considering longevity in breeding objectives and selection programs, breeders improve the return on investment, as the lifetime profit per animal will increase (Pérez-Cabal & Alenda 2003). Selecting to improve functional herd life, promotes genetic integrity of fertility and health traits (i.e. improved conception rates, less calving difficulties, lower calving intervals, resistance to mastitis, lameness and metabolic problems) (Sewalem *et al*., 2008; Du Toit *et al*., 2009; 2012b).

By improving the functional herd life in the herd, there will be a higher proportion of older cows producing at optimum levels, increasing their lifetime milk yield (Banga *et al*., 2009; Du Toit *et al*., 2012b). The need for replacement animals will decrease, saving expenses for rearing and/or purchase of heifers (Kahi & Nitter, 2004; Sewalem *et al*., 2006b; Banga *et al*., 2014b). Breeders will thus be able to select replacement animals more intensely, accelerating genetic progress in the herd (Du Toit *et al*., 2012b). Pritchard *et al*. (2013b) concluded that UK Holsteins with a longer productive life had shorter calving intervals, less days to first insemination, required less inseminations and had a lower SCC. Productive life had a negative genetic correlation with yield traits, articulating the antagonistic relationship between high yield and fertility traits.

Longevity will impact economic and socio-economic conditions, as it contributes to animal welfare and sustainable production (Pritchard *et al*., 2013a). In South Africa, there is concern that longevity is decreasing since the national average lactation number for dairy cattle is estimated at

2.3 (Scholtz & Grobler, 2009), an estimate supported by findings in the Logix Milk Annual Report 2015/2016 for registered and commercial dairy breeds. The average lactation number varies between breeds and is higher for Jerseys than Holsteins (Logix Milk Annual Report 2015/2016).

Longevity can be improved by selection, but genetic progress will be slow due to low heritability estimates (0.02 to 0.03) (Du Toit *et al*., 2009). It has become necessary to develop a means to evaluate longevity early in life, as this trait can only be accurately measured at the end of an animal's productive life (Du Toit *et al*., 2012b). Udder conformation traits, such as fore udder attachment, rear udder height and udder depth can be applied in selecting for prolonged functional herd life (Du Toit *et al*., 2012c).

Poor udder health in high producing cows, regularly result in involuntary culling (Chiumia *et al*., 2013). Mastitis is a prevalent disease in dairy cattle and is characterized by inflammation of the mammary gland (Mostert *et al*., 2004a; Dube *et al*., 2008). By adversely affecting udder health, mastitis also threatens milk quality, production levels and longevity, which has a direct effect on profit (Neerhof *et al*., 2000; Dube *et al.,* 2008). Clinical mastitis escalates veterinary costs, discarded milk contaminated with antibiotic substances, labour input and disease risk for other animals in the herd (Sewalem *et al*., 2006b).

Mastitis is primarily caused by environmental bacteria, thus its prevention depends on effective vaccination, together with environmental and parlour bio-security management. The documented frequency of mastitis in dairy cows across the first three lactations tend to exceed 20% of health incidents (Miciński *et al*., 2009; Pritchard *et al*., 2013a). Studies found the percentage of cows involuntarily culled due to mastitis or related udder complications to fluctuate between 6% and 26.9% (Mohammadi & Sedighi, 2009; Pinedo *et al*., 2010; Ansari-Lari *et al*., 2012; Chiumia *et al*., 2013). The percentage of cases vary between production systems, breeds used and the level of daily milk production. The incidence of mastitis cases generally increases with lactation number (Miciński *et al*., 2009; Mohammadi & Sedighi, 2009; Pritchard *et al*., 2013a), which can be explained by the compound effect of multiple lactations on mammary tissue integrity, facilitating a higher exposure to infection later in life.

It is difficult to select for resistance, as mastitis has low heritability values, is often difficult to detect and is not regularly recorded in recording schemes (Mostert *et al*., 2004a). To overcome the challenges of selecting directly for mastitis resistance, SCC is alternatively employed as a selection criterion (Zwald *et al*., 2004). It is relatively inexpensive to measure and accurately done by recording schemes in South Africa. Its use as an indirect selection tool for mastitis resistance is possible due to a strong, unfavorable positive genetic correlation between SCC and mastitis (Zwald *et al*., 2004; Dube *et al*., 2008), this correlation ranges between 0.30 and 0.97 (Klungland *et al*., 2001).

For more efficient analysis, the logarithm of SCC (Log_{10} SCC) is used in evaluations, which is depicted as somatic cell score (SCS) (Dube *et al*., 2008). Somatic cell score has a higher heritability value compared to mastitis, enabling a stronger selection response. Udder conformation traits have comparatively higher heritability values than mastitis and SCS (Table 2.3), serving as indicator traits against mastitis. Conformation traits are easily measured and regularly recorded, making selection for a sound udder easier (Dube *et al*., 2008).

Table 2.3 Heritability values for mastitis and udder conformation traits

Trait	Heritability (h^2)	Reference
Mastitis	0.02	Koeck *et al*., 2012
SCS	0.11	Walsh *et al*., 2007
Fore udder height	0.19	Ptak *et al*., 2011
Rear udder height	0.27	Ptak *et al*., 2011
Udder width	0.20	Ptak *et al*., 2011
Udder depth	0.27	Ptak *et al*., 2011
Fore teat placement	0.28	Ptak *et al*., 2011
Rear teat placement	0.26	Ptak *et al*., 2011
Teat length	0.29	Ptak *et al*., 2011
Central ligament	0.18	Ptak *et al*., 2011
Udder cleft	0.13	Dube *et al*., 2008
Fore udder attachment	0.16	Dube *et al*., 2008

A balanced and well-rounded udder is associated with lower infections and SCC levels. Some milk buyers pay a premium for milk with a SCC below a certain threshold, and a penalty if it exceeds the threshold (Banga *et al*., 2009; 2014a). Mastitis remains a welfare and economic concern in high-input and smallholder dairy systems in South Africa (Abin *et al*., 2018). Continued inclusion in breeding objectives and adopting strategies to combat the ailment is imperative. In addition to udder health, body weight (BW) and body condition score (BCS) can be measured and applied to monitor the general condition and energy status of animals.

Together, BW and BCS have the potential to serve as indicator traits when selecting for increased herd health and reproductive performance. The genetic correlation between BCS and BW is moderate to strong (Toshniwal *et al*., 2008). Both traits have moderate heritability values (0.58 for mean BCS and 0.6 for mean BW) (Berry *et al*., 2003). Body condition is scored by visual appraisal and specific body measurements (palpation) and serves to indicate the level of energy reserves (mainly body fat) (Roche *et al*., 2004).

Studies have found that energy stores may vary with 40% between cattle of similar body weights (Roche *et al*., 2004), making BCS a more reliable measure of energy reserves. South Africa, USA, and Ireland use a 5 point system, where countries like Australia and New Zealand make use of an 8 and 10 point system. By recording BW with BCS, information on possible nutritional and health constraints will be available.

A unit increase in live weight might have a negative effect on profit, giving it a negative economic value (Banga *et al*., 2009; 2010; 2014b). This is mostly due to the fact that larger animals have higher maintenance requirements, and thus elevated nutritional requirements, resulting in less efficient cows as cost per unit output is higher. This is a controversial concept, as the optimum body weight deemed most efficient will differ across breeds, production systems and countries.

It is common practice to breed cows at a BCS of at least 3 in South Africa. Cows must preferably not lose more than 0.5 body condition between calving and breeding (Buckley *et al*., 2003). Body reserves mobilized during early lactation results in a decrease in BCS, which may impair reconception and expose cows to health constraints like mastitis (Buckley *et al*., 2003; Toshniwal *et al*., 2008). The notion is augmented by the negative genetic correlation between BCS at different stages of lactation and milk yield (-0.14 to -0.51) (Berry *et al*., 2003). Cows with higher milk yields tend to be genetically predispositioned to lower BCS, due to mobilization of more body tissue, having prevalent negative effects on fertility (Berry *et al*., 2004; Roche *et al*., 2006).

By focusing selection on high yield, dairy cows might show a continued genetic decline for a healthy BCS throughout the lactation period. Nutrition can be applied to support a positive energy balance, especially during the breeding and gestation period (Roche *et al*., 2006). This can be done to a large extent by feeding high energy concentrates. However, the genetic makeup of animals will govern the efficiency of mobilizing feedstuffs to meet energy requirements for production.

It was found that North American Holstein cows had higher milk production levels but strains from New Zealand, producing at lower levels, lost less body condition throughout their lactation. The differences in breeding objectives by which a strain was developed tend to have an effect on milk yield and BCS (Roche *et al*., 2006). The effect of the production system on changes in BCS and BW throughout the lactation, will be a valuable tool in determining if a cow is adapted to the feeding and reproduction management implemented. Breeders will benefit from selecting fertile cows that maintain BCS together with desired production levels (Berry *et al*., 2003; 2004).

2.3.2 Genetic evaluation and selection tools

Dairy cattle recording organizations aid South African dairy breeders by tracking herd performance and guiding genetic selection decisions. Estimated breeding values and selection indexes are genetic tools, which are applied in selecting cattle based on their estimated genetic merit, determined from progeny performance and pedigree information. Genetic evaluation services, estimate breeding values and construct selection indexes which enable breeders to accurately rank potential breeding stock based on genetic merit.

The South African milk recording scheme dates back to 1917 and is run by the Agricultural Research Council (ARC), on behalf of the South African government (Ramatsoma *et al*., 2014). The performance of dairy cattle participating in the national recording scheme is stored on the integrated registration and genetic information system (INTERGIS) and used for estimating EBVs (Mostert *et al*., 2010). The national milk recording scheme has continued to evolve and now record numerous performance and health traits (http://www.arc.agric.za). The Scheme aims to support the South African dairy industry to produce milk efficiently and economically.

Organizations such as SA Stud Book also provide genetic evaluation services. Programs such as Logix Milk record phenotypic animal performance, analyse data and apply the results for genetic evaluation and monitoring herd performance (http://www.saStud Book.co.za/p112/services/logix-animal-recording-services.html). Results allow breeders to make informed decisions about which animals should be selected for breeding, which is a major step in achieving economic efficiency. To ensure genetic progress of the herd, producers should select animals with superior performance to produce more proficient progeny. By recording performance of dairy herds in the country, valuable information regarding national production can be established (Fouché, 2010; De Ponte Bouwer *et al*., 2013).

There are multiple South African herd-based computer programs developed to aid producers in recording and managing dairy cattle. AgriMilk is a dairy herd managing software, developed in South Africa and approved by the ARC for documenting recorded animal parameters. AgriMilk saves herd distribution numbers, individual birth dates, calving dates, insemination dates and dry up dates. The software can connect with milk meters to document daily milk production (http://www.softwarefarm.co.za/Agrimilk.php).

Digital information and management systems South Africa (DIMMSA) is a software employed to evaluate herd performance data. Used in day-to-day management, the program specializes in running analyses to track herd performance. Records are entered into the program and preset analyses are executed (http://www.dimssa.co.za/feat.html). These systems are valuable for storing and analysing recorded animal and herd performance.

The international committee for animal recording (ICAR) is an international non-government organization formed in 1951. The organization is responsible for establishing standards and methods for identifying animals and recording animal parameters, ICAR certifies the use of equipment and processes for recording and genetic evaluation of multiple traits (https://www.icar.org/). Both the ARC and SA Stud Book adhere to ICAR standards for recording, analysing and evaluating dairy cattle records, to be implemented in genetic evaluations.

Recording organizations, estimate EBVs by using best linear unbiased prediction (BLUP) models (Mostert *et al*., 2004b; Brotherstone & Goddard, 2005), which incorporates the pedigree and performance of parents, siblings and progeny. The information made available by the recording organizations will benefit breeders by enabling them to make informed breeding decisions.

In order to rank and select AI sires, EBVs are calculated for each sire by using performance data of his progeny (Zwald *et al*., 2003; Mostert *et al*., 2004b). These EBVs are incorporated in international genetic evaluations, done by INTERBULL, to enable comparisons across countries. Estimated breeding values from countries participating in international genetic evaluations are treated as a different trait, in a multiple-trait analysis. This analysis is then employed in a multiple-trait across country evaluation (MACE). INTERBULL uses MACE for international sire evaluation, South Africa is a member of INTERBULL, thus the EBVs of international sires are available for use by local breeders and recording organizations (Mostert *et al*., 2006).

Differences in management and environment must be identified and considered when selecting sires (Weigel *et al*., 2001). Since South Africa is home to different management and payment systems, breeders are encouraged to select sires whose progeny will perform proficiently in a given environment. With the majority of popular AI sires bred and tested in other countries (Weigel, 2001), the estimated genetic contribution of AI sires in South African herds comes into question.

In Norwegian countries, extreme differences between environments has led to a change in sire ranking based on the predicted performance of a given sire's progeny, in a specific environment (Kolmodin *et al*. 2002). Mulder *et al.* (2006) concluded that when the genetic correlation between two traits in different herds were lower than 0.61, it was desirable to employ breeding objectives specific to the given environment. They found that milk production traits, tend to have a higher correlation between environments, than health and fertility traits. The influence of different climatic, feed and economic environments on the measurement and selection of sires is expected.

SA Stud Book determines EBVs and selection indexes for AI sires to be used for selection in South African herds on the SADairyBulls platform (www.sadairybulls.com). Estimated breeding values presented on SADairyBulls are expressed on the South African scale which are directly comparable to that of the national population. These EBVs published on SADairyBulls, originates from different sources, depending on the sire's specifics. Values for local bulls are determined from the measurements of relatives included in the Logix Milk genetic evaluation.

For international bulls, multiple platforms are combined. If a bull is included in MACE from INTERBULL, the MACE breeding values are integrated with EBVs predicted from progeny participating in Logix Milk, to establish EBVs on the South African scale, with increased reliability. For young genomically tested Holstein bulls with a genomic multiple across country evaluation (GMACE) breeding value, the same principle as MACE breeding values is enforced, therefore blending with Logix EBVs, based on reliability.

If bulls don't participate in MACE then EBVs based on the Danish (Denemark, Finland and Sweden) or Canadian (all other countries) scales are converted to the South African scale (by use of the INTERBULL conversion equations). When international bulls have sufficient locally measured daughters (reliablility of EBVs reach 80 %) then only the breeding values estimated from these daughters are used (Bernice Mostert, personal communication, e-mail: bernice@Stud Book.co.za).

By genetically evaluating bulls based on the performance of their progeny in a specific environment, selection for preferred genotypes can be made (Zwald *et al*. 2003). It is thus possible for South African breeders to accurately select sires whose daughters will perform best in their management system, by consulting EBVs and selection indexes, which are based on national standards and markets.

Genetic selection indexes are a linear combination of economically desirable traits, which allow breeders to achieve breeding objectives (Banga *et al*., 2014a). The prerequisites for a selection index, include defining which traits the breeder wants to improve. Secondly, the importance of a trait must be determined, and a weighing factor assigned to each trait. The weight of a trait will be determined by its contribution to economic gain. It is important that traits included in the index are measurable, and EBVs should be available. Traits included must have sufficient additive genetic variance to ensure a selection response (Pryce *et al*., 2004).

Most selection indexes for dairy cattle place primary emphasis on production traits, followed by fertility, health and durability traits, such as longevity, udder and body conformation traits (Miglior *et al*., 2005). To aid breeders, the EBVs determined by recording organizations for specific traits are included in indexes (Ramatsoma *et al*., 2014). The total genetic value of an animal is thus reflected in a selection index, by combining multiple traits deemed important in achieving a breeding objective

(Byrne *et al*., 2016). Popular selection indexes for Holsteins in South Africa and countries abroad are listed in Table 2.4.

Table 2.4 Selection indexes employed for Holstein selection

Selection Index	Country	Reference
Fluid Merit Index (FMI)	South Africa	www.sadairybulls.com
Holstein Merit Index (HMI)	South Africa	www.sadairybulls.com
Lifetime Profit Index (LPI)	Canada	Nayeri *et al*., 2017
Profitable lifetime Index (PLI)	United Kingdom	Oltenacu & Algers, 2005
Total Merit Index (TMI)	Norway	Kargo *et al*., 2014
Net Merit Index (NMI)	United States	Gay *et al*., 2014
Total Profitability Index (TPI)	United States	Miglior *et al*., 2005
Economic Breeding Index (EBI)	Ireland	Cummins *et al*., 2012

The FMI and the HMI are calculated by utilizing EBVs estimated in the Logix Milk Genetic Evaluations, allowing selection of sires based on the predicted performance of their daughters under South African conditions. The composition of both indexes is presented in Table 2.5.

Table 2.5 Composition of the FMI and the HMI (source, www.sadairybulls.com)

	Selection Index	
Traits	HMI	FMI
Milk volume	0.02	0.28
Butterfat	0.12	0.13
Protein	0.31	0.04
SCS	-0.06	-0.06
Fertility	0.12	0.12
Herd Life	0.20	0.20
Udder	0.08	0.08
Size/Frame	-0.05	-0.05
Feet and Legs	0.04	0.04

The HMI focuses on protein yield, whereas the FMI focuses more on milk volume. South African breeders are thus able to determine the value of a potential AI sire based on the production trait most profitable in their unique management system and payment scheme. Inclusion of non-production traits illustrate that selection for economic efficiency in South African Holstein cattle requires fertile and healthy cows. The economic and consumer perception benefit in improving non-production traits can serve as incentive to potentially increase the weight of these traits in future indexes (Egger-Danner *et al*., 2015).

Genomically enhanced estimated breeding values (GEBVs) serve as additional genetic selection tools, increasing the accuracy of selection. These breeding values can be determined earlier in life when progeny testing is not available (Schaeffer, 2006; Veerkamp & Beerda, 2007). Thus, considering GEBVs available for AI sires, enables selection of bulls earlier and with more accuracy. Genomic selection will accelerate genetic progress, as more traits can be included in selection, and phenotypic recording limited to a few thousand animals to serve as a reference population (Boichard & Brochard, 2012). To address the possible genotype by environmental interaction, the reference population must include adequate numbers from different management systems.

With new technology, the price of genotyping animals has decreased and by increasing the number of gene markers, the accuracy of genomic prediction has improved. International genetic evaluations done by INTERBULL, facilitates the collection of genotypes and performance values of dairy cattle from across the globe. Genetic linkage facilitated by the AI industry reduces the pressure on domestic genotyping (Van Marle-Köster *et al.*, 2013).

Globally, genomic selection is successfully incorporated in the AI industry. Several major genes have been identified and linked to milk production and fertility traits. Genes like DGAT1 is used for assisted selection for milk composition traits (Nayeri *et al.*, 2016). New genes linked to lactation persistency, longevity and lifetime profit have been identified (Nayeri *et al.*, 2017). The reliability of genomic breeding values for selecting against health constraints in female Holsteins were estimated to be above 50% (Vukasinovic *et al.,* 2017). Traits like mastitis, metritis, lameness, retained placenta, ketosis and displaced abomasum can potentially be selected for directly, without using indicator traits. Breeders can select the best heifers to breed, by identifying animals that are genetically inclined to be fertile and healthy.

The dairy genomic programme (DGP) which is currently running in South Africa, encourages producers to record animal performance and make DNA samples available for sequencing (Joubert, 2018). Breeders will potentially be able to cost effectively genotype all heifers and cows in their herd. In addition to improving production, reproduction and health traits, parentage can be established, inbreeding levels controlled and genetic defects identified early in life.

2.4 Precision dairy farming and automatic milking systems

Precision dairy farming (PDF) is characterised by management tools and strategies, which increase the accuracy of measuring and managing animal performance. Dairy cows are on average, in a producing state longer than any other livestock species. Technology applied to monitor cow parameters on an individual level is imperative to ensure optimum production levels and avert fertility and health constraints, through early detection (Norton & Berckmans, 2017).

Sensor-based systems are used to identify animals, detect oestrus, determine individual animal requirements or shortcomings, automatically administer feed and alert managers for physical inspection (Banhazi *et al*., 2012; Boichard & Brochard, 2012). Dairy cattle are dynamic beings, measuring multiple real time variables at regular intervals is necessary to recognise individuals to examine. Parameters indicating health constraints allow for early intervention, reducing veterinary costs (Singh *et al*., 2014). Herd and individual animal performance data enables specialists from different disciplines (veterinarians, nutritionists, management consultants, AI consultants etc.) to support dairy producers in achieving management objectives.

The use of automatic milking systems (AMSs) and its accompanied features allow dairy producers to implement PDF principles. Automatic milking systems are characterised by sensor-based technology, capturing individual animal performance and applying the recorded data for management (Keeper *et al*., 2017). With the increase in herd size in South Africa, the need to implement precision technology is inevitable. In South Africa, 65-70% of all cows in milk are estimated to be in a system applying automatic technology. The number of South African dairy cows projected by the MPO in January 2018 is estimated at 615 000 cows and the number in milk, 554 000 cows. It is thus estimated that between 360 100 and 387 800 lactating cows are managed in AMSs in South Africa (Koos Coetzee, personal communication, e-mail:koos.coetzee@mpo.co.za).

AfiMilk and DeLaval-ALPRO are popular systems used by South African AMS producers and provide dairy farmers with comprehensive automatic management technology. These systems make use of a management software, which serves as a central database for receiving and processing sensor-collected data (Gray, 2014; Van den Berg & Howarth, 2014). Reports containing herd and individual cow performance can be extracted from the software to be analysed and applied in subsequent management decisions. DeLaval is a company of the Tetra Laval group from Sweden and has been working with South African dairy farmers for over 100 years (http://www.delaval.co.za/About-DeLaval/). AfiMilk from S.A.E Afikim, Kibbutz, Israel is proficient in managing large dairy herds, the system was developed and first tested in 1977 (www.afimilk.com).

Voluntary milking systems (VMSs) are a category of AMSs, where animals visit the milking parlour by choice, motivated by supplementary feed and water delivery (Tse *et al*., 2016). Cows are milked by a robot and not exposed to fixed time milking sessions. Robotic milking systems can be applied in pasture as well as TMR production systems (Lyons *et al*., 2013). The use of VMSs in South Africa are rare, with only a single producer employing the system. Voluntary milking systems are often referred to as automatic milking systems. Automatic milking systems in this study, refer to production systems that incorporate automatic sensor based technology, with a central management software program, such as AfiMilk and DeLaval-ALPRO. Europe has the highest proportion of VMSs with the technology becoming popular in countries like Canada and the USA (Tse *et al*., 2016). The DeLaval VMS (DeLaval, Tumba, Sweden) and the Lely Astronaut VMS (Lely Industries N.V., Maasluis, the Netherlands) are prevalent systems available (Tse *et al*., 2016; Rodenburg, 2017). Table 2.6 exhibit features and measurements performed by AfiMilk, ALPRO and DeLaval VMSs.

Table 2.6 Features of AMSs

Feature	AfiMilk	ALPRO	DeLaval VMS
Animal Identification	x	x	x
Measure milk flow rate	x	x	x
Measure milk volume	x	x	x
Measure milk composition	x	x	x
Measure milk conductivity	x	x	x
Measure activity	x	x	x
Automatic feeding	x	x	x
Automatic weighing	x	x	x
Automatic sorting	x	x	x
Automatic cluster removal	x	x	x
Robotic cluster attachment			x
Robotic teat cleaning			x

The systems discussed have sensors that work in unison to monitor parameters imperative to cow management. During each milking session, a cow's production rate (milk volume and flow rate), milk composition, activity level, milk conductivity and weight are automatically documented. Milk conductivity is measured during each milking event as an indication of udder infection and mastitis (conductivity increases with SCC). Activity levels can be measured by pedometers (AfiMilk), attached to the leg of animals or activity meters (ALPRO) could be placed around the neck. Both measure daily activity (steps taken), lying bouts and lying time. The activity levels measured determine the daily routine of animals at the cow, group and herd level, deviations indicate possible health, stress or fertility events. Animals on heat can show an increase in physical activity of 67%, a drop in daily milk yield together with a rise in the mean number of steps taken per hour signal the system to sort animals and alert managers for inspection (Miciński *et al*., 2010). The success of pedometers and activity meters in identifying cows expressing oestrus, is in excess of 80% (Saint-Dizier & Chastant-Maillard, 2012).

A deviation in body weight, milk yield or milk fat percentage serves as indicators of metabolic disturbances such as ketosis and acidosis. Deviations are calculated by comparing measurements from a recent milking session with the mean performance of an animal over a reference period (generally 10 days) and/or the mean of the group. These deviations are combined with parameters like days in milk, days from last insemination, days pregnant and lactation number, in order to identify cows to be sorted and inspected (Diepersloot, 2011; Van den Berg & Howarth, 2014). Automatic milking systems thus support producers by identifying cows to be inseminated, dried up, close to calving or that must be checked for physical, metabolic and udder difficulties.

The international committee for animal recording is determining protocols for recording parameters in AMSs. Components of both AfiMilk and DeLaval have received ICAR approval, although many of the milk composition sensors are not recognised. Sensors don't necessarily record milk composition accurately, as these sensors must be calibrated on a regular basis. However, the milk composition data from these sensors has the potential to rank animals in a herd, or to identify animals with metabolic ailments. The data captured by the technology applied in AMSs facilitates short and medium term management. Records documented in AMSs presents herd and individual animal data for potential genetic evaluation of production, fertility and health traits.

2.5 Future management challenges

Producers are faced with breeding, welfare and consumer perception challenges to incorporate in their management protocols. Future challenges include increasing environmental temperatures and heat stress (Williams *et al*., 2016), monitoring inbreeding levels (Maiwashe *et al*., 2006; Du Toit *et al*., 2012a) and awareness of social acceptance of cattle production (Boichard & Brochard, 2012). Inbreeding levels are a concern, which can be alleviated through appropriate mate allocation programs (Maiwashe *et al*., 2006; Du Toit *et al*., 2012a). Animal welfare and the effect dairy production has on the environment, are consumer related concerns to consider (FAO, 2006; Boichard & Brochard, 2012; Scholtz *et al*., 2013). Performance records documented in AMSs could potentially aid producers by monitoring the effect of management decisions.

The period between calving and first insemination, termed the voluntary waiting period (VWP) is a managerial decision that influences interval fertility traits. After calving, it is imperative that cows be allowed time for uterine involution and recovery of the reproductive tract. It has been shown that a period of 60 days is adequate for recovery but fluctuates between herds and production systems. Producers with high producing cows may delay insemination in order to extend days in milk (Miller *et al*., 2007). DeJarnette *et al*. (2007) found that the mean VWP between different herds and breeds was 56 days. Producers decided to alter the time to first insemination, due to differences in the health status of cows, breeding season, parity and production levels. The days in milk at breeding may be prolonged for older cows or cows with a high production level, poor body condition (which indicates a negative energy balance) or health status (Chang *et al*., 2007). A fixed VWP is desired when calculating and interpreting interval fertility traits, to assess reproductive performance of the herd. Management software employed in AMSs, monitor calving dates, expression of oestrus and insemination dates (Keeper *et al*., 2017), allowing producers to enforce a fixed VWP and identify cows not conceiving in a suitable timeframe.

The length of the non-lactation period or dry period at the end of lactation, prior to calving, is a management decision and imperative for pregnant cows. This time allows recovery of energy reserves and involution of mammary epithelium cells, which permits optimum milk production in the following lactation. Papillae of the rumen and small intestine recuperate and the microbial population changes, which aids in nutrient supply for lactogeneses (Annen *et al*., 2004). The diet received during the far-off dry period and the subsequent change in the rumen microbial population prepares the cow for the high energy ration received during the transition period of the following lactation.

It is common practice to administer intra-mammary antibiotics during the dry period which combats existing infections and prevents the occurrence of possible future infections. Cows are dried up with a fixed time before calving or when daily milk production decreases, thus the dry period is influenced by timing of conception (days open) and lactation persistency. Dry periods that are too long or too short could increase the metabolic stress during the transition period, adversely affecting reproduction (Steeneveld *et al*., 2013; Useni *et al*., 2014).

Studies show that Holstein cows have optimal reproductive functioning with a dry period between 45 and 60 days (El-Tarabany, 2015). Kuhn *et al*. (2006a) suggested that a dry period between 55 and 70 days was desired to prime cows for the subsequent lactation. A short dry period (≤10 days) can increase clinical udder difficulties and decrease lactation milk production by 17% in primiparous and 13% in multiparous cows (Sawa *et al*., 2015). In large herds managed with AMSs, the implementation of efficient recording and recognition programs are vital to ensure cows are admitted to dry-off programs with sufficient time before calving.

Management software in AMSs has the capability of documenting pedigree information, which if implemented correctly could alert breeders of a possible inbreeding risk. Inbreeding reduces additive genetic variation within a breed or population because a gene pair at a given locus comes from common ancestors (Sewalem *et al.,* 2006a). This mechanism is accompanied by a rise in recessive genes and a reduction in the expression of dominant genes, having detrimental effects on production, growth, health and fertility traits (Weigel, 2001). Inbreeding reduces the future selection response, due to lowered genetic variation and depresses performance values for economically important traits (Maiwashe *et al.*, 2008; Du Toit *et al.*, 2012a). The severity of the effect on animal performance is termed inbreeding depression and varies between populations and breeds (González-Recio *et al.*, 2007).

The deleterious effects of inbreeding are more prevalent in younger animals and early in lactation (Thompson *et al.,* 2000a;b). Due to international trade of semen (for AI) the genetic variation of dairy herds is declining (Maiwashe *et al.*, 2006). The global selection of a handful of popular dairy bulls for all breeds has led to inbreeding. Dairy cattle that appear to be unrelated based on pedigree information are often related to some degree due to common ancestry (Weigel & Lin, 2000).

Effective population size (Ne) is a measure of genetic variability within a breed or population; larger Ne values indicate less inbreeding and more genetic variation. It is speculated that a Ne of 50-100 will ensure adequate variation and prevent future problems with inbreeding (Sørensen *et al.*, 2005). There is limited literature available on the rate and level of inbreeding or the Ne of South African dairy breeds. Maiwashe *et al.* (2006) determined the approximate Ne for Holstein, Jersey, Ayrshire and Guernsey cattle to be 137, 108, 148 and 165 animals respectively.

Although inbreeding has not reached critical levels in South African breeds, it might be necessary to manage future mate allocation to prevent related animals from breeding (Du Toit *et al.*, 2012a). Weigel & Lin (2000) found a 1.6% and 1.9% reduction in inbreeding in Holsteins and Jerseys respectively when using a computerised mate allocation program. Numerous management systems, including those implemented in AMSs, employ software which integrate pedigree and EBV information to allocate an ideal AI sire for breeding.

Most of the international dairy sires are evaluated under temperate conditions, while South Africa is characterized by tropical and sub-tropical climates. Since dairy cattle perform optimally in temperate environments, the effect that the environment might have on the genetic potential of dairy animals is cause for concern (Muller *et al.*, 1994; Zwald *et al*., 2003; Van Niekerk *et al.*, 2006). It has been shown that dairy cattle production decreases in tropical areas compared to temperate areas, due to heat and physiological stress caused by high temperatures and parasites (Usman *et al*., 2013). De Rensis & Scaramuzzi (2003) found that the conception rate of heat stressed cows was 20-30% lower compared to winter times.

Dairy cows are homeotherms and normally experience heat stress at ambient temperatures above 25 ºC (López-Gatius, 2012). Usman *et al*. (2013) mentions how global warming will continue to put pressure on dairy cattle and that selection for adaptability will be imperative in the future. High environmental temperatures will render parts of South Africa currently occupied by dairy producers unsuitable for milk production (Williams *et al*., 2016). Managerial inputs to alleviate heat stress in dairy cattle such as providing shade, fans, mist sprays and adequate nutrition to meet energy demands can artificially provide a suitable environment for dairy cattle to express their genetic potential (Muller *et al.*, 1994). The environment of pasture-based cattle can’t be altered to the same extend as cows that are housed, which presents a challenge to pasture-based producers in the future (Williams *et al*., 2016).

Greenhouse gas emission is causing global climatic changes, with the enteric methane production from dairy cattle being a contributor (Odongo *et al*., 2007). It is estimated that agriculture is responsible for the production of 5-10% of global greenhouse gas emission, of which livestock is believed to be accountable for 65% (CO_2 equivalent) (Scholtz *et al*., 2013). Consumer acceptance of dairy farming depends on lowering the negative effects on the environment (Boichard & Brochard, 2012).

The level of greenhouse gas emission per unit product produced will be reduced by selecting for more efficient dairy cows (Beukes *et al*., 2010; Scholtz *et al*., 2014). By scrutinizing recorded performance records in AMSs, breeders should be able to monitor and select animals with superior feed conversion, production, fertility, health and longevity, which promotes proficiency in the herd. The carbon footprint of cows managed in pasture-based and TMR systems are subject to management practices aimed at lowering carbon emission and endorsing carbon sequestration (Belflower *et al*., 2012). In addition to breeding efficient animals, management should consider manure, fertilization and forage supply in the strategy to alleviate greenhouse gas emission (Hörtenhuber *et al*., 2010).

2.6 Conclusion

The South African dairy industry is dynamic, with production becoming an exact science. It is an industry characterized by multiple and sometimes complex facets, from differences in production systems employed, to fluctuating markets. Most dairy producers are localized in the coastal regions of South Africa, where the implementation of pasture-based systems is permitted. The differences in production systems, herd size, production level and technology employed must be considered to accurately define future breeding objectives. With the expansion of South African dairy herds and an elevated level of output, producers are encouraged to consider fertility and health traits in breeding goals. Adoption of AMSs is a reality for producers and is expected to continue as herds enlarge. Economic pressure serves as incentive to strive for precision, in order to ensure economic viability and alleviate management challenges.

Chapter 3: Materials and methods

3.1 Introduction

The study involved two large herd dairy producers representing a TMR (producer A) and a pasture-based (producer B) production system. Both producers make use of an AMS, employing sensor-based computerized herd management technology. Consent for the analyses of data was provided by the individual producers and ethical approval for the use of external data was granted by the ethics committee of the faculty, Natural and Agricultural Science, University of Pretoria (EC 161209-0890). Producers installed the AfiMilk (Waikato, SA) herd management system from S.A.E Afikim, Kibbutz, Israel. Management principles and herd performance data were captured during a visit to the farms by the researcher. Historic production performance data on a herd, as well as individual animal level was analysed.

3.2 Materials

3.2.1 Particulars of the AfiMilk system

The principles of the AfiMilk system applies to both producers, regardless of differences in feeding and management. Cows are collected and brought into the parlour, during the milking session, physical treatment of udders and attachment of clusters are required. Premature cluster detachment is corrected manually and teat fore-stripping and disinfection is done by hand.

AfiMilk incorporates real time sensors to augment the AfiFarm management software. These include the AfiAct, AfiSort, AfiWeigh, AfiFeed and AfiLab components. AfiAct monitors animal activity via a pedometer (Miciński *et al*., 2010). AfiWeigh automatically weighs animals (Toshniwal *et al*., 2008). AfiSort detains animals based on parameter threshold deviations (Van den Berg & Howarth, 2014). AfiFeed is an automatic feeding system, which delivers feed to individual cows in the parlour. The software will deliver feed based on preset parameters. AfiLab which is an inline spectrophotometer, measures milk composition (Van den Berg & Howarth, 2014). AfiFarm serves as a central database for collection of data from these sensors during each milking session. The collected data is incorporated to execute pertinent alerts and reports (http://www.agromilk.hu/computerized-farm-management).

Cables running from the computer links the AfiFarm software with the parlour for documenting and saving real time data received from the Afi sensors. Parameters are stored within the heifer period (prior to first calving) or the respective lactation number during data capture. Fertility events such as insemination dates, calving dates, dry up dates and AI sire used are entered and saved for every animal on the system (Addendum A, Figure 1A; 2A). Daily milk yield, milk conductivity, milking time (minutes), activity level (steps taken) and body weight are some of the parameters automatically documented and saved each day during lactation (Addendum A, Figure 4A). Upon exit, the reason is recorded and logged (Addendum A, Figure 3A), BCS which is manually established can be entered and saved on an animal's event list (Addendum A, Figure 2A).

3.2.2 Producer A: Total mixed ration production system

Producer A is situated in the Durbanville area of the Western Cape as shown in Figure 3.1.

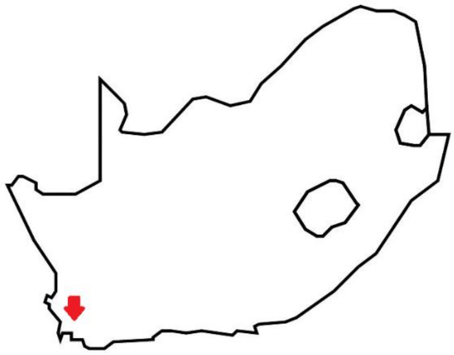


Figure 3.1 Geographical location of producer A

Durbanville is 174 meters above sea level and somewhat temperate. It forms part of the West Coast-Renosterveld bioregion (Rutherford *et al*., 2006), receiving predominantly winter rainfall and occasional rain in summer months. The mean daily temperature is 17 ºC with 444 mm precipitation per annum. February tends to be the warmest month and July the coldest. May, June, July and August are characterized with having the highest rainfall, peaking in June (Figure 3.2).

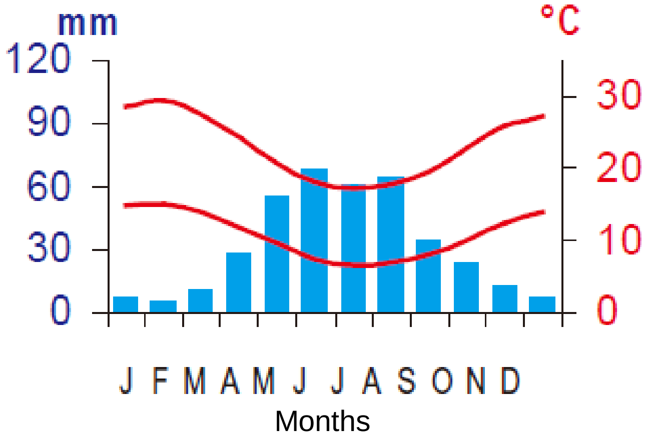


Figure 3.2 Median precipitation with mean daily minimum (lower line) and maximum (upper line) temperatures per month for the West Coast-Renosterveld bioregion (source, Rutherford *et al*., 2006)

The herd consists of roughly 4000 cows and heifers, with the lactating herd consisting of approximately 1650 Holsteins and 150 Ayrshires, milked three times a day. The AfiMilk system was installed in 2002, equipping the parlour with the AfiFarm herd management software version 3.076. The system operates at three intervals daily; 03:00 to 08:00; 10:00 to 15:00 and 18:00 to 22:00. A 64 point rotary system was installed in 2005 and the parlour was fitted with fans to alleviate heat stress. Animals are kept in roofed housing units with a deep litter surface area, where they receive a specially formulated diet.

Newborn calves are fetched daily and housed in individual hutches where they receive colostrum the first four days after birth. From day five calves receive 2 liters of milk replacer, mixed with tap water, twice a day. This ensures that the replacer is as uniform as possible in terms of nutritional composition and temperature, preventing metabolic problems. Calves receive starter pellets ad libitum by day 7 and are weaned from milk replacer by two months of age. Bull calves are sold within the first week from birth.

On this farm, the owner consults with nutritionists from a feed company to meet the requirements of all animals in the herd. There is no feeding in the parlour, lactating cows are grouped based on their level of production, receiving a diet according to their requirements. Animals are fed ad libitum twice a day to ensure optimal feed intake. Oats, maize silage and wheat straw are some of the raw materials produced to incorporate with a concentrate from the feed company.

Semen used for AI is primarily imported from, the USA, Canada and Europe. Cows are inseminated throughout the year. The producer works in collaboration with semen companies for selection of suitable AI bulls for his herd. Body weight and BCS is the determining factor at first insemination (56% of mature body weight and at least BCS of 3). Heifers receive a tag and pedometer between 13 and 15 months of age. When heifers reach the ideal weight for insemination, they enter the rotary system in the morning after the first milking session. This is done to familiarize them with the parlour and to observe their activity levels (measured by the pedometer). Heifers that have spikes in their activity will be inspected for heat and inseminated.

After insemination, heifers and cows are flagged and inspected if they show subsequent signs of heat (spike in activity) and are re-inseminated if heat is confirmed. Cows that don't show subsequent signs of elevated activity, receive a pregnancy diagnosis test by a veterinarian approximately 44 days after the last insemination. Upon calving, a cow will immediately enter the lactating herd.

3.2.3 Producer B: Pasture-based production system

Producer B is situated in the Tsitsikamma area of the Eastern Cape as shown in Figure 3.3, about 167 meters above sea level.

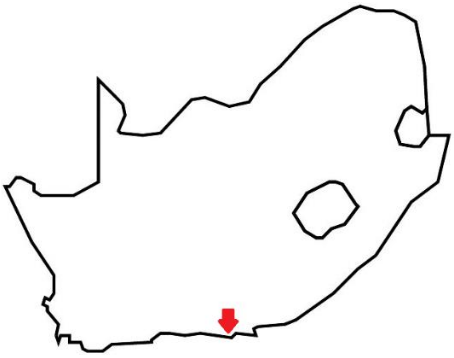


Figure 3.3 Geographical location of producer B

The farm is exposed to a cool Atlantic breeze, which diminishes ambient temperatures. This area forms part of the Eastern Fynbos-Renosterveld bioregion (Rutherford *et al*., 2006), which is temperate and receives rain year-round. The mean daily temperature and annual precipitation is 15.8 ºC and about 615 mm. February tends to be the warmest month and July the coldest (Figure 3.4).

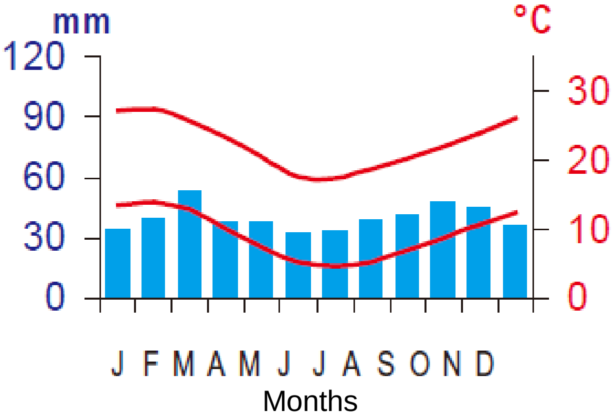


Figure 3.4 Median precipitation with mean daily minimum (lower line) and maximum (upper line) temperatures per month for the Eastern Fynbos-Renosterveld bioregion (source, Rutherford *et al*., 2006)

There are approximately 1700 cows and heifers in herd B, the lactating herd includes roughly 730 cows, milked twice a day. The breed composition of the herd is primarily Holsteins, with Holstein x Jersey crossbred animals. Holstein semen was used on Jerseys over the study period, and from 2010 onwards, only Holstein semen was used for AI. On this farm, the AgriMilk management software was used before installing AfiMilk in 2005. Data for animals enrolled on the AgriMilk system was transferred to AfiMilk, allowing extraction of data for animals born before 2005. A 64 point rotary system was installed in 2005 and the parlour was equipped with the AfiFarm herd management software version 4.1. The system operates at two intervals daily; 04:30 to 8:30 and from 14:30 to 17:30. Animals are kept on pasture and receive a supplementary ration in the milking parlour.

Newborn calves are fetched daily and put in individual hutches where they receive colostrum for the first two days. Bull calves are sold within the first week from birth. After colostrum feeding heifer calves are given 2 liters of whole milk, mixed with milk replacer, twice a day. Calves receive starter pellets ad libitum from day three and are weaned by three months of age. Calves are weighed every two weeks to ensure animals are on a desired growth plane. Weaned heifers are put on pasture with access to a roughage rich in protein, mainly Lucerne hay. By 13 months heifers receive a pedometer and enter the parlour after the first milking session, to monitor their weight and activity levels for heat detection. If a heifer has the desired body weight and condition with signs of heat (56% of mature body weight and BCS of at least 3), she will be inseminated.

The land used for pasture is divided into multiple camps, pasture species include perennial Ryegrass, Chicory and Kikuyu. Camps are examined, and foliage measured every week using a rising plate meter (RPM), to monitor growth. To maintain the health and nutritional status of pastures, animals are moved regularly to prevent over grazing. In addition to grazing, animals have access to a mineral lick mixed with apple pulp. In the parlour the AfiFeed system dispenses feed for each cow based on pre-set parameters. Raw materials fed in the parlour include maize, soy bean oil cake and a mineral pellet. Body weight and condition score, stage of lactation, days pregnant and fat corrected milk (FCM) production are parameters which are combined to determine the amount of feed to deliver. The AfiFarm system implements algorithms which are set manually to keep cows on a specific weight and production curve.

Only semen from established AI companies are considered, the producer scrutinizes the breeding values of AI bulls to ensure coherency with breeding objectives for his system. After insemination, heifers and cows will be flagged if their activity spikes (indicating heat), following manual observation, animals on heat will be re-inseminated. Cows that do not show subsequent signs of heat will receive a pregnancy diagnosis test by a veterinarian approximately 42 days after AI. Upon calving, a cow will immediately enter the lactating herd. Two breeding seasons per year ensure a constant supply of animals to the milking herd, cows calve down in autumn (March to May), with the majority calving down in spring (August to October). This is done to coincide excellent pasture growth with peak herd demand. Thus, the milking herd usually has its lowest numbers in January and July, allowing pasture recovery.

3.2.4 Constructing a template

The objective was to establish a practical procedure to obtain historical performance records for animals registered on AfiFarm. This undertaking could be realized by creating a software backup which was saved and removed from both systems (AfiMilk, 2000). The backup contains the entire database saved on the AfiFarm software, from the date of installation by the respective producers to the date of generating the backup. Producer A was visited in July 2016 and producer B in February 2017, AfiFarm versions 3.076 and 4.1 were installed by the researcher and both backups were successfully re-installed to access data. Comprehensive performance archives were available for all animals recorded.

Methods were developed for extracting required variables analysed in this study. Birth dates, calving dates and insemination dates saved during the heifer period (Addendum A, Figure 1A) and for cows within a respective lactation (Addendum A, Figure 2A) enabled the calculation of count and interval fertility traits. Daily milk yield and subsequent lactation milk yield together with the number of days in milk (Addendum A, Figure 4A) were mined to include in the analyses. Heifer and lactation one, two and three parameters extracted are shown in Table 3.1. Formulas (Addendum A, Table 1A) were constructed on AfiFarm to capture data logged within the heifer period and the first three lactations. These formulas were entered as commands to create reports retrieving the desired variables (Addendum A, Figure 5A).

Table 3.1 Animal parameters extracted

	Parameters	
	Production	Reproduction
All	Breed Lactation number[a] Days in herd[b] Lifetime milk yield[c] Exit reason	AI sire registration number
Heifer		AFS (months) AFConc (months) AFC (months) IN DFLI
Lactation 1,2 and 3	DIM LMY (kg) AMY (kg/day)	DIMFS IN DFLI ICP (days) DO DD

(a)The lactation number registered to an animal upon data extraction or upon exit from the herd; (b)The number of days from birth to the date of data extraction (for animals still in the herd) or exit date; (c)Total milk yield over all lactations in the herd; AFS=age at first service; AFConc=age at first conception; IN=insemination number; DFLI=days between first and last insemination; AFC=age at first calving; DIMFS=days in milk at first service; DFLI=days between first and last insemination; DO=days open; ICP=inter calving period; DD=days dry; DIM=days in milk; LMY=lactation milk yield; AMY=average daily milk yield

AfiFarm records the number of heifers, lactating cows, dry cows and the proportion of cows (lactating and dry) in lactation one, two and three and above on the system, for every day of the year. Herd parameters (Table 3.2) were extracted by constructing population summary reports (Addendum A, Figure 6A). Reports created on AfiFarm could be extracted to Microsoft Excel (2013) for editing.

Table 3.2 Herd parameters extracted

Variables	
Production traits	Herd numbers/structure
Total milk yield (kg)[a]	Cows
Average milk yield per cow (kg/day)	Heifers
	Lactating cows
	Dry cows
	Cows lactation 1[b]
	Cows lactation 2[b]
	Cows lactation 3+[b]

(a) The total milk produced by the lactating herd on a particular day; (b)Lactation number is defined as the period between consecutive calving events, animals in a specific lactation number is either in the lactating herd or in the dry group.

3.2.5 Evaluation of AI bulls

Analyses of AI bulls were performed for producer A, as documented sire registration numbers could be extracted from AfiFarm (Addendum A, Figure 5A). Registration numbers were applied to obtain 305-day milk yield and ICP estimated breeding values from the SADairyBulls platform

(Bernice Mostert, personal communication, e-mail: bernice@Stud Book.co.za). To minimize variation and strengthen the reliability of measured progeny performance, only Holstein AI sires with documented registration numbers and at least 40 daughters with a completed first lactation were considered. Daughters were required to have all-inclusive records for first LMY (all days in milk) and first ICP. A total of 48 registered sires and 3 047 daughters were analysed (Table 3.3).

Table 3.3 Descriptive statistics of sire's progeny and EBVs used in analyses

		Daughters/sire			LMY (kg)			ICP (days)		
	n	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Progeny	3047	63.50	40	113	12844.75	4054.20	29762.60	429.46	305	698
Sire EBV's	48				352.38	-670	1679	4.14	-23	31.7

LMY=lactation milk yield; ICP=inter calving period

3.3 Methods

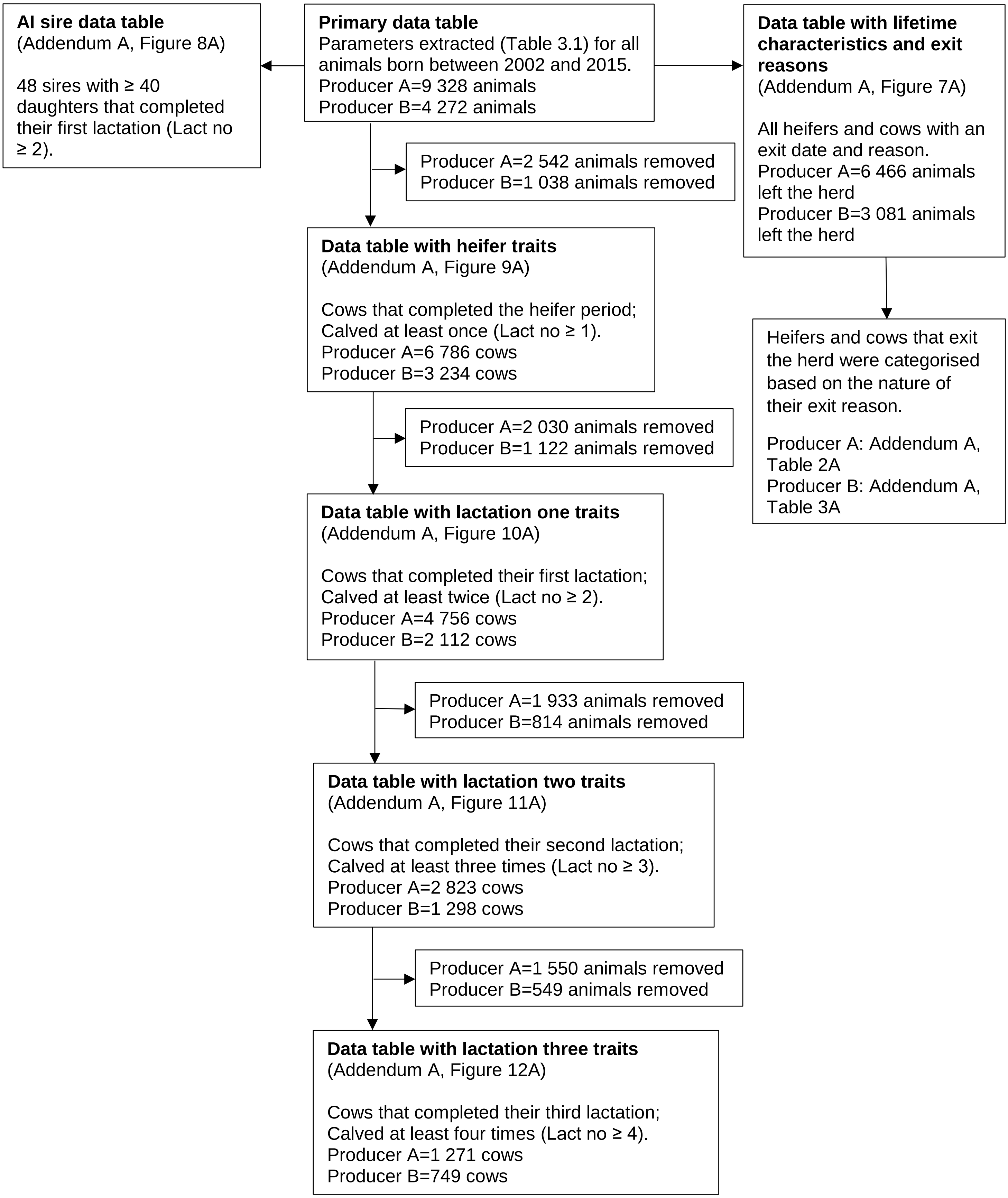
To ensure that reports were accurate and complete, a Waikato after-care technician was consulted (Anzel la Grange, personal communication, e-mail: anzel@waikato.co.za). Data was mined for female animals born between 2002 and 2015 with birth dates, calve dates, insemination dates and lactation milk yield data recorded on AfiFarm. Herd structure and performance data were extracted for the years 2004 to 2015 for producer A and from 2005 to 2015 for producer B.

3.3.1 Data editing

Population summary reports extracted data for all animals on the system, regardless of breed. When analysing cow parameters for producer A, only Holsteins were considered (n=9 328). For producer B Holsteins and Mixed (Holstein x Jersey cross) animals were analysed together (n=4 272). Primary data reports with all heifer and cow parameters (Table 3.1) were extracted from AfiFarm to Microsoft Excel, (2013). Subsequent data tables were built from the primary tables by removing animals based on the number of times they have calved (Figure 3.5). The lactation number (Lact no) assigned to animals in the primary data table revealed the parity of that animal at the time of data extraction or at the date of exit from the herd. The parameter proved suitable for eliminating heifers and cows from the data sets when analysing traits.

To ensure that records were complete for all traits, animals were required to have completed the corresponding production period to be included in the data set. Thus, only cows that completed the heifer period (calved at least once, Lact no ≥ 1) were considered when analysing heifer traits. The same principle applied when constructing tables for analysing lactation one, two and three traits. Lactation one traits were analysed for all cows that calved at least twice (Lact no ≥ 2). Cows in data sets with lactation two and lactation three traits were thus required to have calved at least three (Lact no ≥ 3) and four (Lact no ≥ 4) times respectively.

Further editing included the removal of animals with missing values when preparing data tables. There were no threshold restrictions placed on traits, extreme values considered detrimental to accurate analyses were removed. This was done to meticulously capture the mean performance of animals and scrutinize the association between traits. Tables with exit reasons were used to group heifers and cows based on their lactation number upon exit and the nature of their exit. An AI sire data table was built with the EBVs for ICP and LMY together with the mean first LMY and ICP of each sire's progeny, to analyse the association.



AI sire data table
(Addendum A, Figure 8A)

48 sires with ≥ 40 daughters that completed their first lactation (Lact no ≥ 2).

Primary data table
Parameters extracted (Table 3.1) for all animals born between 2002 and 2015.
Producer A=9 328 animals
Producer B=4 272 animals

Data table with lifetime characteristics and exit reasons
(Addendum A, Figure 7A)

All heifers and cows with an exit date and reason.
Producer A=6 466 animals left the herd
Producer B=3 081 animals left the herd

Heifers and cows that exit the herd were categorised based on the nature of their exit reason.

Producer A: Addendum A, Table 2A
Producer B: Addendum A, Table 3A

Producer A=2 542 animals removed
Producer B=1 038 animals removed

Data table with heifer traits
(Addendum A, Figure 9A)

Cows that completed the heifer period; Calved at least once (Lact no ≥ 1).
Producer A=6 786 cows
Producer B=3 234 cows

Producer A=2 030 animals removed
Producer B=1 122 animals removed

Data table with lactation one traits
(Addendum A, Figure 10A)

Cows that completed their first lactation; Calved at least twice (Lact no ≥ 2).
Producer A=4 756 cows
Producer B=2 112 cows

Producer A=1 933 animals removed
Producer B=814 animals removed

Data table with lactation two traits
(Addendum A, Figure 11A)

Cows that completed their second lactation; Calved at least three times (Lact no ≥ 3).
Producer A=2 823 cows
Producer B=1 298 cows

Producer A=1 550 animals removed
Producer B=549 animals removed

Data table with lactation three traits
(Addendum A, Figure 12A)

Cows that completed their third lactation; Calved at least four times (Lact no ≥ 4).
Producer A=1 271 cows
Producer B=749 cows

Figure 3.5 Data editing for analyses of heifer and cow parameters

3.3.2 Statistical analysis

Reports were constructed and extracted from AfiFarm to Microsoft Excel (2013) for editing. Data was imported and analysed using GenStat 18th edition software (GenStat®, Payne, 2015). Mean herd numbers and production output were regressed against the years of study to evaluate trends in herd composition and milk yield levels. Mean production and reproduction performance within lactation one, two and three were established for animals born over all the years studied. Birth year served as a contemporary group and the mean performance of heifers and cows were analysed accordingly. Generalized linear model analyses were used with either the Poisson or the Gamma distribution for count and continuous traits (GenStat®, Payne, 2015). Trait means were separated using Fisher's protected least significant difference test at the 5% level of significance (Snedecor & Cochran, 1980). Pearson correlation coefficients were calculated to evaluate the relationship between traits within the heifer period and within a given lactation.

Stepwise regression models were fitted to assess the association between lactation milk yield and non-production traits. Lactation milk yield was fixed as the response variate and all heifer and cow reproduction traits, days dry and differences across birth years (contemporary groups) as predictor variables. Models combined predictor variables explaining a minimum of 1% of variation in the response variate at the 0.1% level of significance, within a given lactation. Percentage distribution of exit reasons were analysed within the heifer period and across lactations. Lifetime characteristics were considered for heifers and cows that were culled by removing animals in the "Missing or Sold" group in herd A and the "Sold" category in herd B. Linear regression analyses were performed between an AI sire's EBVs for milk yield and the mean first lactation milk yield of his daughters, to evaluate the association between the genetic merit of an AI sire and the performance of his progeny. The analysis was repeated between the EBVs for inter calving period and the mean first inter calving period of each sire's progeny.

Chapter 4: Results

4.1 Introduction

Phenotypic performance variables documented by the AfiMilk system was investigated and a method to extract data was established. The AfiFarm management software permitted the extraction of data reports in a format that enabled accurate data editing and analyses. Reports constructed on AfiFarm can be saved and applied as a template for data extraction from similar systems in the future. Trends in herd size and production output were evaluated across the study period and indicated that herd numbers increased. The mean phenotypic performance of animals born between 2002 and 2015 were observed by assessing production and reproduction traits within the heifer period and the first three lactations. To establish the relationship between traits, correlations were determined and complimented by a stepwise regression analysis. The distribution of culling reasons were considered to scrutinize the primary convictions for removing animals from both production systems. Linear regression analyses between the estimated genetic merit of an AI sire and the mean performance of his progeny revealed the strength of a possible correlation.

4.2 Template construction

Reports constructed and saved in this study serve as a template for building data tables with multiple herd and individual cow parameters from systems employing the AfiFarm software. Herd numbers documented could be extracted in comprehensive reports (Addendum A, Figure 6A) to Microsoft Excel which allowed for analyses of mean herd composition over the study period. Formulas constructed on AfiFarm (Addendum A, Table 1A) permitted the researcher to calculate fertility traits from birth dates, insemination dates, dry up dates and calving dates saved for each animal (Addendum A, Figure 1A, 2A). Production traits such as LMY, DIM and AMY were calculated from data documented during each lactation (Addendum A, Figure 4A). The data table constructed from reports, included reasons for exit from the herd and lifetime production characteristics (Addendum A, Figure 7A) which represents lifetime efficiency of individual animals. Pedigree information, in the form of sire registration numbers could be obtained for individual animals (Addendum A, Figure 5A) in herd A. The template constructed in this study permitted a relatively simple method for obtaining data tables from a large data platform, tables were practical for editing and analysis.

4.3 Herd structure/composition

4.3.1 Producer A

The mature herd (lactating and dry cows) and the number of heifers, increased ($P<0.001$) in unison, except for the surge in the heifer herd in 2012 and 2013, which is explained by animals purchased. Cows in the mature herd increased at an annual rate of 6.7% from a mean of 999 cows in 2004 to 1989 cows in 2015, while the heifer group increased at an annual rate of 7.2% from 876 heifers in 2004 to 1793 heifers in 2015 (Figure 4.1).

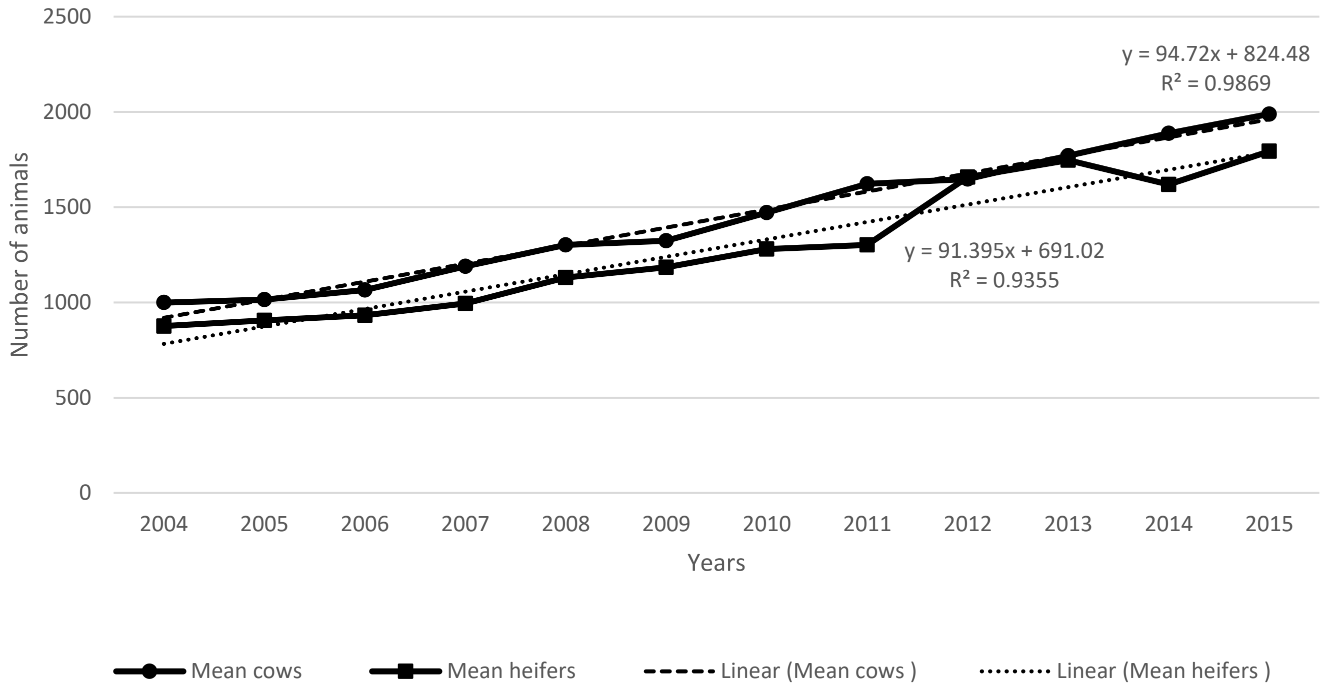


Figure 4.1 Mean number of cows and heifers from 2004 to 2015 in herd A

The lactating herd increased from a mean of 866 cows in 2004 to 1738 cows in 2015 (annual rate of 6.8%), while the mean number of dry cows increased from 133 cows in 2004 to 251 cows in 2015 (annual rate of 6.1%) (Figure 4.2).

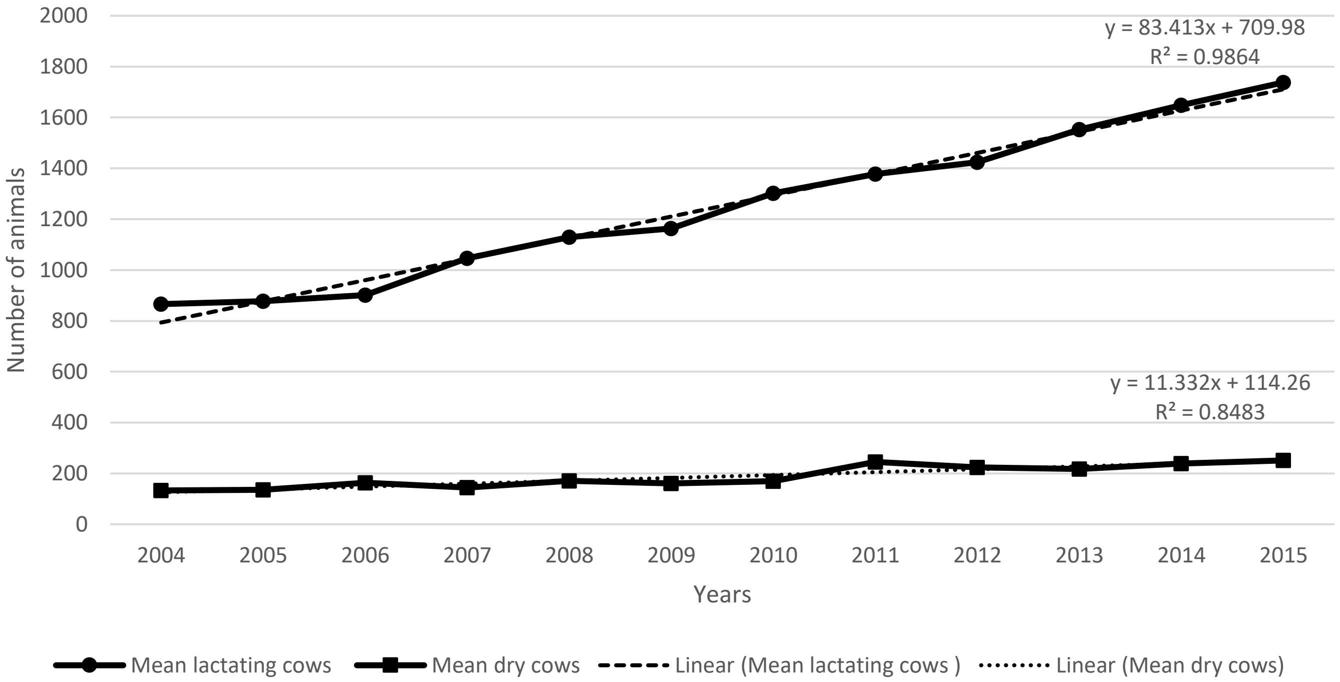


Figure 4.2 Mean number of lactating and dry cows from 2004 to 2015 in herd A

As seen in Figure 4.1, the proportion of heifers in Table 4.1 were highest throughout 2012 and 2013.

Table 4.1 Percentage distribution of lactating cows, dry cows and heifers from 2004 to 2015 in herd A

Year	Dry cows	Lactating cows	Heifers
2004	7.09	46.19	46.72
2005	7.09	45.75	47.16
2006	8.16	45.12	46.67
2007	6.59	47.87	45.54
2008	7.03	46.46	46.50
2009	6.42	46.37	47.21
2010	6.18	47.31	46.51
2011	8.38	47.11	44.51
2012	6.78	43.07	**50.15**
2013	6.20	44.14	**49.66**
2014	6.82	47.01	46.18
2015	6.64	45.95	47.41

The herd had a high percentage of first and second lactation cows, with the combined percentage peaking in 2015 at 75.36% (Table 4.2).

Table 4.2 Percentage distribution of lactation 1, 2 and 3+ cows from 2004 to 2015 in herd A

Year	Lactation 1	Lactation 2	Lactation 3+
2004	45.19	29.96	24.85
2005	42.00	31.92	26.09
2006	36.51	31.32	32.17
2007	36.82	28.64	34.54
2008	38.32	27.06	34.62
2009	40.64	28.01	31.35
2010	42.61	27.98	29.41
2011	42.37	29.03	28.60
2012	35.67	32.87	31.47
2013	42.59	25.74	31.67
2014	45.97	26.88	27.15
2015	**42.48**	**32.88**	24.64

The mean monthly milk yield increased ($P<0.001$) from 908 002 kg in 2004 to 2 010 912 kg in 2015 (annual rate of 7.9%). In 2004 the mean daily milk yield for the lactating herd was 34.40 kg which increased to 40.33 kg in 2012 (annual rate of 1.6%). The mean daily milk yield in 2013 (38.95 kg), 2014 (39.15 kg) and 2015 (38.19 kg) were slightly lower than levels in 2012, which can be explained by a higher percentage of primiparous cows in the lactating herd (Figure 4.3).

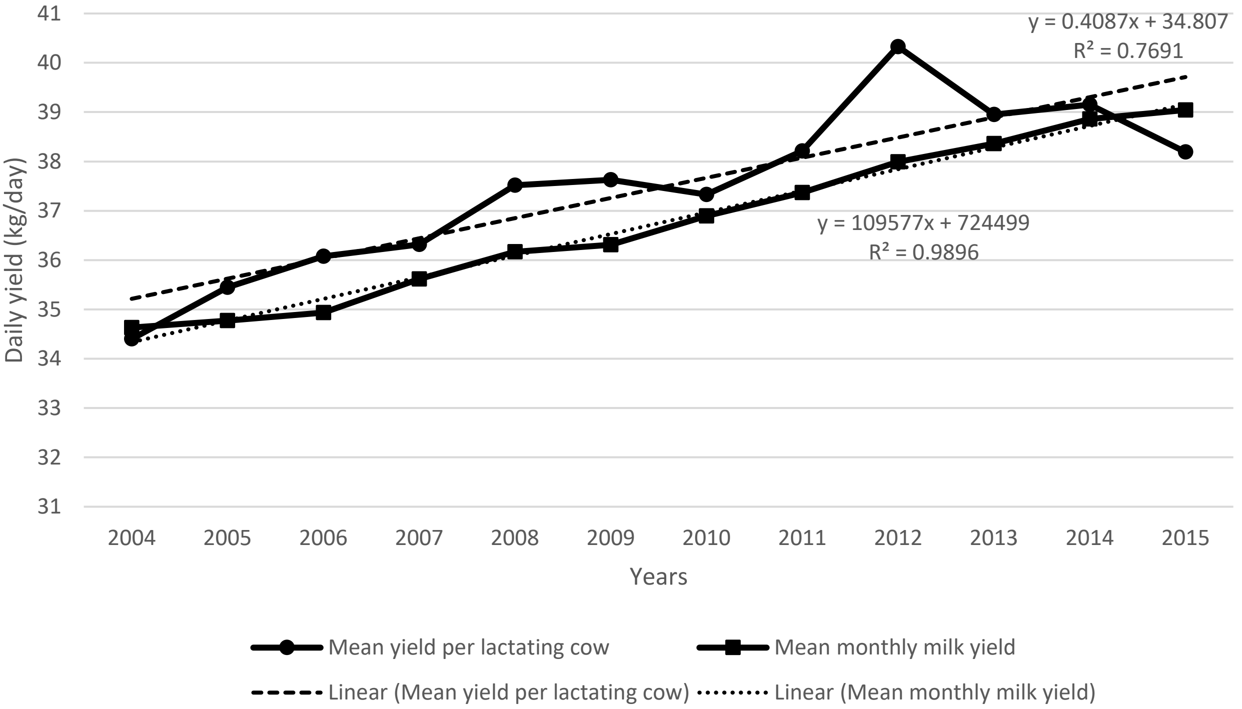


Figure 4.3 Mean daily milk yield per lactating cow and total monthly milk yield from 2004 to 2015 in herd A

4.3.2 Producer B

The mature herd (lactating and dry cows) size and the heifer herd size increased (*P*<0.001) from a mean of 495 heifers and 624 cows in 2005 to 788 heifers and 824 cows in 2015. After an initial decline in the mature herd from 2005 to 2006, the herd increased at an annual rate of 4%, while the heifer herd increased at an annual rate of 5% (Figure 4.4).

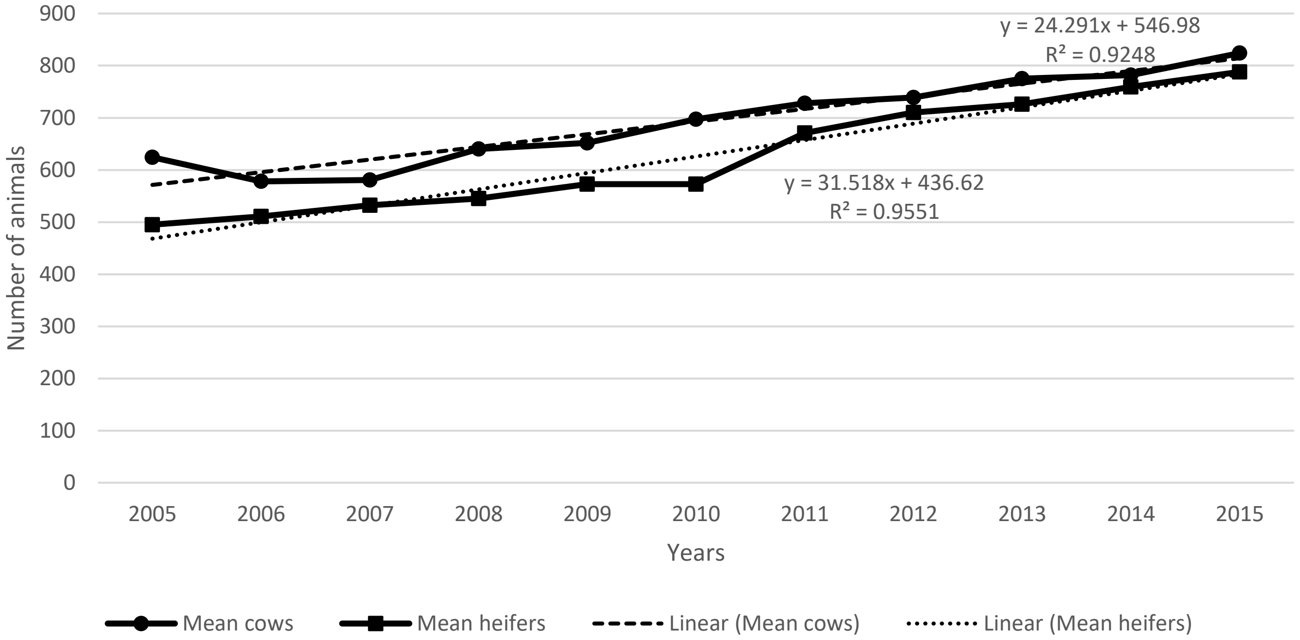


Figure 4.4 Mean number of cows and heifers from 2005 to 2015 in herd B

Proportional increase of the mature herd (Figure 4.5) show a similar trend seen in Figure 4.4. The lactating herd increased from a mean of 495 cows in 2006 to 725 cows in 2015 (annual rate of 4.3%). The mean dry herd remained fairly constant over the study period.

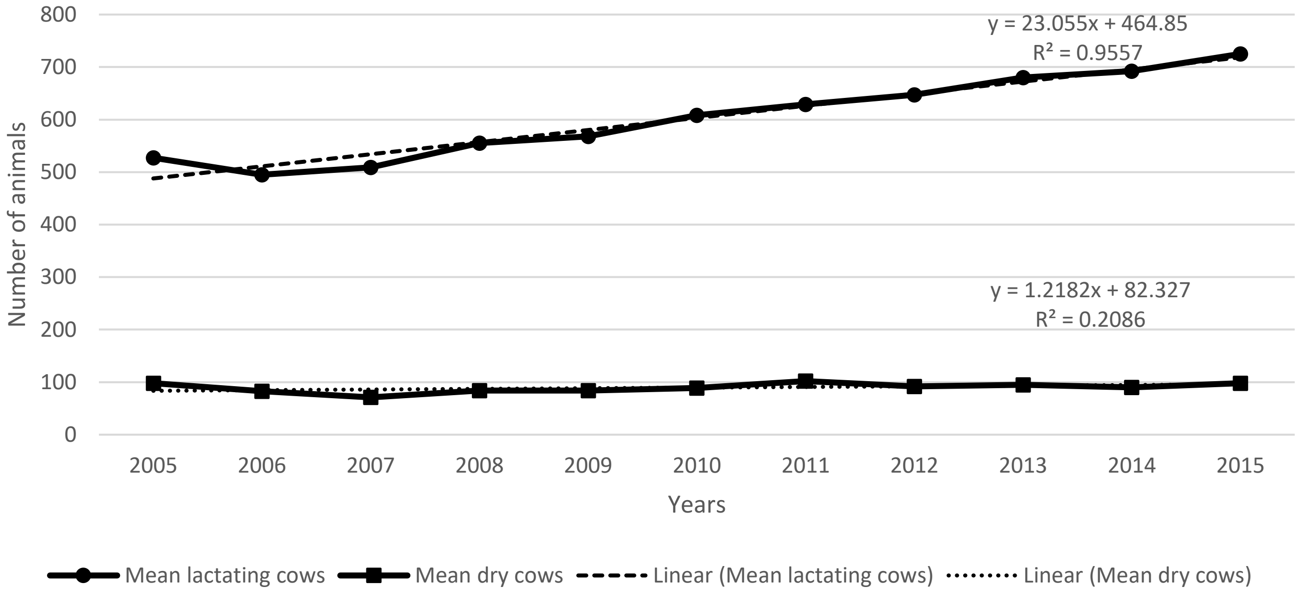


Figure 4.5 Mean number of lactating and dry cows from 2005 to 2015 in herd B

The proportion of heifers were high from 2011, lowering the percentage of lactating and dry cows in the herd (Table 4.3).

Table 4.3 Percentage distribution of lactating cows, dry cows and heifers from 2005 to 2015 in herd B

Year	Dry cows	Lactating cows	Heifers
2005	8.75	47.05	44.20
2006	7.62	45.45	46.92
2007	6.38	45.77	47.84
2008	7.09	46.88	46.03
2009	6.86	46.37	46.78
2010	7.01	47.87	45.12
2011	7.28	44.86	**47.86**
2012	6.35	44.65	**49.00**
2013	6.33	45.30	**48.37**
2014	5.84	44.91	**49.25**
2015	6.08	45.00	**48.91**

The combined percentage of first and second lactation cows were high from 2007, culminating in 2015 at 66.95% (Table 4.4).

Table 4.4 Percentage distribution of lactation 1, 2 and 3+ cows from 2005 to 2015 in herd B

Year	Lactation 1	Lactation 2	Lactation 3+
2005	26.40	22.08	51.52
2006	33.33	21.59	45.08
2007	38.38	24.27	37.35
2008	38.34	28.17	33.49
2009	36.25	27.19	36.56
2010	35.82	27.22	36.96
2011	36.31	25.58	38.10
2012	38.32	23.64	38.04
2013	40.00	24.52	35.48
2014	39.46	26.56	33.97
2015	**40.10**	**26.85**	33.05

Monthly milk yield ($P<0.001$) and daily milk yield for the lactating herd ($P<0.01$) increased at an annual rate of 5.7% and 1.9% respectively, from 2005 to 2015. From 2005 to 2007 there was a decrease in milk yield, the mean daily milk yield and monthly milk yield fell from 23.56 kg and 379 184 kg respectively to 20.96 kg and 325 665 kg in 2007. From 2007 to 2014 the mean daily milk yield increased at an annual rate of 3.52% to 26.51 kg. The mean monthly milk yield increased at an annual rate of 7.81% to 562 539 kg in 2014. In 2015, mean monthly milk yield (560 839 kg) and mean daily milk yield per lactating cow (25.38 kg) were slightly lower compared to values in 2014, which is explained by a higher percentage of primiparous cows in 2015 (Figure 4.6).

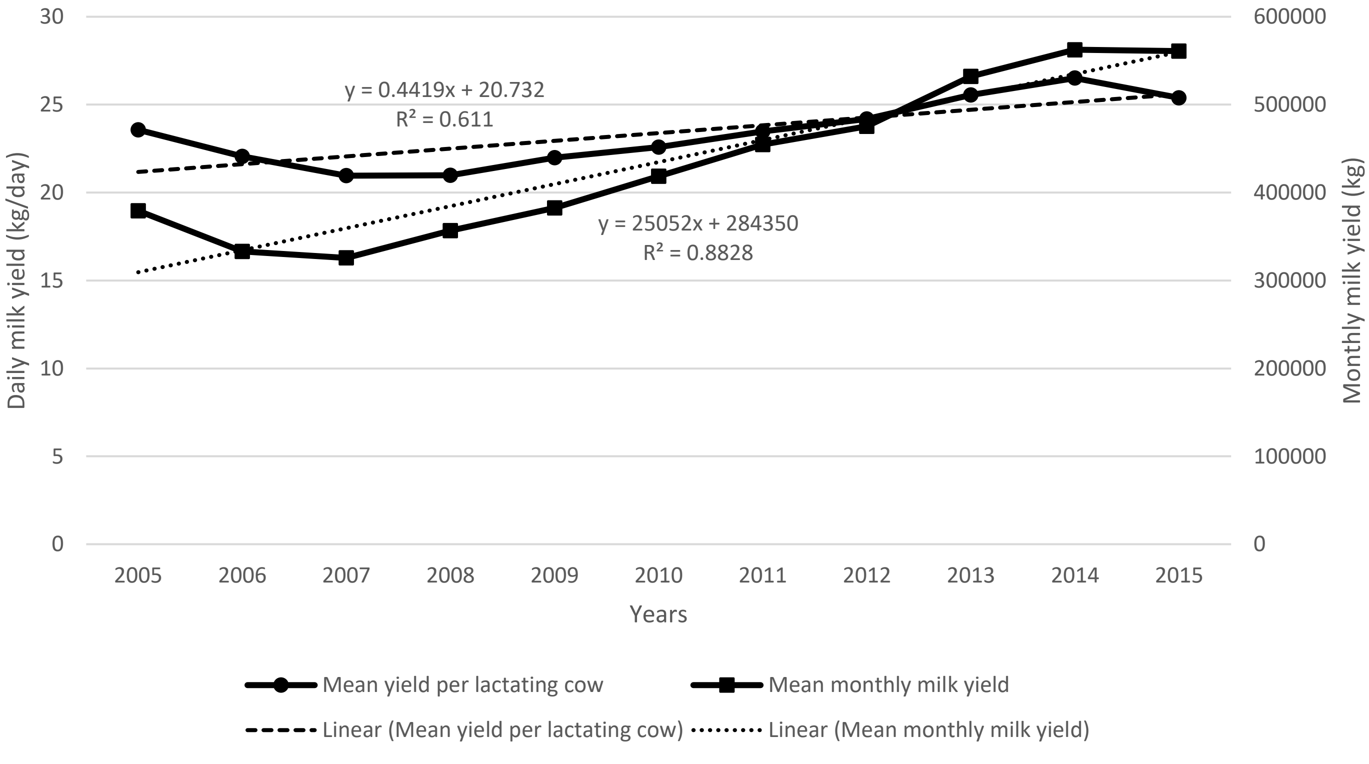


Figure 4.6 Mean daily milk yield per lactating cow and total monthly milk yield from 2005 to 2015 in herd B

4.4 Evaluation of production and reproduction traits

4.4.1 Producer A

Mean phenotypic performance for heifer and cow production and reproduction traits are presented in Table 4.5 and Table 4.6, respectively. Variation between birth years (Addendum B, Table 1B; 2B; 3B) and large standard deviations for traits measured confirm that the performance of animals were subject to change over the study period.

Table 4.5 Mean and standard deviation (SD) for heifer reproduction traits in herd A

	n	AFS	IN	DFLI	AFConc	AFC
Heifer	6786	15.83	1.69	30.17	16.83	25.86
		(2.16)	(1.03)	(63.63)	(2.99)	(3.00)

AFS=age at first service (months); AFConc=age at first conception (months); IN=insemination number; DFLI=days between first and last insemination; AFC=age at first calving (months)

Interval fertility traits (DIMFS, DO, ICP and DD) and milk yield traits (AMY and LMY) increased (*P*<0.05) across lactations (Table 4.6).

Table 4.6 Mean and standard deviation (SD) for cow production and reproduction traits in herd A

	n	DIMFS	IN	DFLI	DO	ICP	DD	DIM	LMY	AMY
Lactation 1	4756	110.20^c	2.20^b	46.42^b	156.60^c	433.90^c	64.05^c	369.80^a	12836^c	34.47^c
		(32.95)	(1.72)	(73.15)	(81.34)	(81.34)	(25.65)	(74.31)	(3231)	(4.57)
Lactation 2	2823	112.50^b	2.34^a	52.10^a	164.70^b	441.50^b	76.02^b	365.50^b	14702^b	40.09^b
		(31.81)	(1.73)	(72.87)	(79.99)	(79.68)	(36.52)	(70.48)	(3330)	(5.15)
Lactation 3	1271	120.20^a	2.32^a	51.69^a	171.90^a	448.60^a	78.01^a	370.70^a	15706^a	42.25^a
		(34.67)	(1.74)	(71.59)	(79.60)	(78.91)	(37.86)	(70.03)	(3510)	(5.49)

Means within column classification followed by different subscripts differ (*P*<0.05); DIMFS=days in milk at first service; IN=insemination number; DFLI=days between first and last insemination; DO=days open; ICP=inter calving period (days); DD=days dry; DIM=days in milk; LMY=lactation milk yield (kg); AMY=average daily milk yield (kg/day)

The relationship between AFS, AFConc and AFC is evident as the correlations between these traits were strong (Table 4.7).

Table 4.7 Pearson correlation coefficients for heifer traits in herd A

	AFS	AFConc	IN	DFLI	AFC
AFS	-				
AFConc	0.71	-			
IN	-0.03	0.45	-		
DFLI	-0.01	0.69	0.68	-	
AFC	0.71	0.99	0.45	0.68	-

AFS=age at first service; AFConc=age at first conception; IN=insemination number; DFLI=days between first and last insemination; AFC=age at first calving

Results in Table 4.8 indicate a strong correlation between lactation one reproduction traits. The relationship between production traits (DIM and LMY) and reproduction traits (IN, DFLI, DO and ICP) were moderate to strong, DO and ICP had the strongest correlation with DIM and LMY.

Table 4.8 Pearson correlation coefficients for first lactation traits in herd A

	DIMFS	IN	DFLI	ICP	DO	DD	DIM	LMY	AMY
DIMFS	-								
IN	0.02	-							
DFLI	0.04	0.85	-						
ICP	0.44	0.77	0.91	-					
DO	0.44	0.78	0.91	0.99	-				
DD	0.12	0.32	0.38	0.42	0.39	-			
DIM	0.44	0.74	0.86	0.95	0.95	0.12	-		
LMY	0.44	0.57	0.65	0.77	0.77	-0.02	0.85	-	
AMY	0.18	-0.03	-0.03	0.05	0.04	-0.21	0.12	0.62	-

DIMFS=days in milk at first service; IN=insemination number; DFLI=days between first and last insemination; DO=days open; ICP=inter calving period; DD=days dry; DIM=days in milk; LMY=lactation milk yield; AMY=average daily milk yield

The relationships observed in Table 4.8 is evident for second lactation traits, as seen in Table 4.9.

Table 4.9 Pearson correlation coefficients for second lactation traits in herd A

	DIMFS	IN	DFLI	ICP	DO	DD	DIM	LMY	AMY
DIMFS	-								
IN	-0.01	-							
DFLI	0.02	0.86	-						
ICP	0.41	0.78	0.91	-					
DO	0.41	0.78	0.92	0.99	-				
DD	0.16	0.38	0.42	0.47	0.45	-			
DIM	0.38	0.69	0.81	0.89	0.89	0.01	-		
LMY	0.38	0.47	0.54	0.65	0.65	-0.15	0.81	-	
AMY	0.13	-0.14	-0.15	-0.08	-0.08	-0.27	0.05	0.59	-

DIMFS=days in milk at first service; IN=insemination number; DFLI=days between first and last insemination; DO=days open; ICP=inter calving period; DD=days dry; DIM=days in milk; LMY=lactation milk yield; AMY=average daily milk yield

Lactation three traits (Table 4.10) had similar correlations between the mentioned production and reproduction traits.

Table 4.10 Pearson correlation coefficients for third lactation traits in herd A

	DIMFS	IN	DFLI	ICP	DO	DD	DIM	LMY	AMY
DIMFS	-								
IN	-0.01	-							
DFLI	0.01	0.88	-						
ICP	0.43	0.79	0.89	-					
DO	0.44	0.79	0.90	0.99	-				
DD	0.14	0.39	0.42	0.46	0.44	-			
DIM	0.41	0.68	0.78	0.88	0.88	-0.02	-		
LMY	0.38	0.45	0.52	0.63	0.63	-0.18	0.81	-	
AMY	0.09	-0.15	-0.17	-0.12	-0.12	-0.26	0.02	0.58	-

DIMFS=days in milk at first service; IN=insemination number; DFLI=days between first and last insemination; DO=days open; ICP=inter calving period; DD=days dry; DIM=days in milk; LMY=lactation milk yield; AMY=average daily milk yield

Stepwise regression models automatically assigned independent variables (predictor variables) with the strongest correlation to the response variate (LMY), within the prescribed level of significance (GenStat®, Payne, 2015). The effect of inter-correlation between traits does not influence the terms fitted. The coefficient of determination (adjusted R^2) values indicates the percentage of variation explained by a given range of independent variables. As seen in Table 4.11, the combined effect of prominent interval fertility traits (ICP and DO), DD and differences between birth years explained the majority of variation in lactation milk yield in herd A.

Table 4.11 Variation in lactation milk yield explained by non-production variables in herd A

Response variate	Lactation	n	Fitted terms[a]	Adjusted R^2	P value
	Lactation 1				
Y=LMY		4756	ICP	0.535	<0.001
		4756	ICP+DD	0.692	<0.001
		4756	ICP+DD+Year	0.714	<0.001
	Lactation 2				
Y=LMY		2823	ICP	0.383	<0.001
		2823	ICP+DD	0.651	<0.001
		2823	ICP+DD+Year	0.674	<0.001
		2823	ICP+DD+Year+DFLI	0.691	<0.001
	Lactation 3				
Y=LMY		1271	DO	0.359	<0.001
		1271	DO+DD	0.629	<0.001
		1271	DO+DD+ICP	0.65	<0.001
		1271	DO+DD+ICP+ICP.Year	0.667	<0.001
		1271	DO+DD+ICP+ICP.Year+DFLI	0.681	<0.001

(a)Terms were independently fitted based on the correlation strength with the response variate at the 0.1% level of significance; LMY=lactation milk yield; ICP=inter calving period; DD=days dry; DO=days open; DFLI=days between first and last insemination; ICP.Year=interaction between year and ICP

4.4.2 Producer B

Phenotypic performance for heifer reproduction traits is shown in Table 4.12, while cow reproduction and production traits are shown in Table 4.13. Variation between birth years (Addendum C, Table 1C; 2C; 3C) and large standard deviations for traits measured confirm that the performance of animals were subject to change over the study period.

Table 4.12 Mean and standard deviation (SD) for heifer reproduction traits in herd B

	n	AFS	IN	DFLI	AFConc	AFC
Heifer	3234	14.22	1.81	23.87	15.01	24.06
		(1.05)	(1.07)	(39.75)	(1.7)	(1.73)

AFS=age at first service (months); AFConc=age at first conception (months); IN=insemination number; DFLI=days between first and last insemination; AFC=age at first calving (months)

Milk yield traits (LMY and AMY) increased across lactations (*P*<0.05), while most reproduction traits remained stable (Table 4.13).

Table 4.13 Mean and standard deviation (SD) for cow production and reproduction traits in herd B

	n	DIMFS	IN	DFLI	ICP	DO	DD	DIM	LMY	AMY
Lactation 1	2112	78.03^a	1.95^a	29.56^b	386.80^a	107.60^a	64.25^b	322.60^a	6733^c	20.78^c
		(19.34)	(1.25)	(44.73)	(48.00)	(47.52)	(16.08)	(47.21)	(1453)	(3.17)
Lactation 2	1298	75.36^b	2.03^a	32.89^a	387.90^a	108.30^a	63.94^b	324.0^a	8345^b	25.62^b
		(18.24)	(1.28)	(45.65)	(48.21)	(47.77)	(20.52)	(47.32)	(1979)	(4.61)
Lactation 3	749	74.68^b	2.02^a	33.26^a	387.40^a	107.90^a	67.08^a	320.40^a	8665^a	26.86^a
		(18.22)	(1.28)	(46.39)	(48.70)	(48.31)	(22.99)	(47.72)	(2231)	(5.08)

Means within column classification followed by different subscripts differ (P<0.05); DIMFS=days in milk at first service; IN=insemination number; DFLI=days between first and last insemination; DO=days open; ICP=inter calving period (days); DD=days dry; DIM=days in milk; LMY=lactation milk yield (kg); AMY=average daily milk yield (kg/day)

AFC had strong correlations with all other heifer reproduction traits (Table 4.14).

Table 4.14 Pearson correlation coefficients for heifer traits in herd B

	AFS	AFConc	IN	DFLI	AFC
AFS	-				
AFConc	0.63	-			
IN	0.01	0.63	-		
DFLI	0.02	0.79	0.81	-	
AFC	0.62	0.98	0.61	0.77	-

AFS=age at first service; AFConc=age at first conception; IN=insemination number; DFLI=days between first and last insemination; AFC=age at first calving

Lactation one reproduction traits were strongly correlated, while production traits (DIM and LMY) had medium to strong correlations with reproduction traits (IN, DFLI, DO and ICP), DO and ICP showed the strongest correlation with DIM (Table 4.15).

Table 4.15 Pearson correlation coefficients for first lactation traits in herd B

	DIMFS	IN	DFLI	ICP	DO	DD	DIM	LMY	AMY
DIMFS	-								
IN	-0.05	-							
DFLI	-0.07	0.85	-						
ICP	0.34	0.77	0.90	-					
DO	0.34	0.78	0.91	0.98	-				
DD	0.07	0.10	0.11	0.22	0.13	-			
DIM	0.32	0.75	0.88	0.94	0.96	-0.12	-		
LMY	0.22	0.50	0.59	0.64	0.64	-0.17	0.70	-	
AMY	0.01	-0.01	-0.01	0.00	-0.01	-0.13	0.04	0.73	-

DIMFS=days in milk at first service; IN=insemination number; DFLI=days between first and last insemination; DO=days open; ICP=inter calving period; DD=days dry; DIM=days in milk; LMY=lactation milk yield; AMY=average daily milk yield

Correlations in Table 4.16 and Table 4.17 illustrate a similar relationship between production and reproduction traits, as seen in Table 4.15.

Table 4.16 Pearson correlation coefficients for second lactation traits in herd B

	DIMFS	IN	DFLI	ICP	DO	DD	DIM	LMY	AMY
DIMFS	-								
IN	-0.06	-							
DFLI	-0.08	0.85	-						
ICP	0.29	0.78	0.92	-					
DO	0.30	0.79	0.92	0.99	-				
DD	0.00	0.19	0.21	0.26	0.21	-			
DIM	0.30	0.71	0.84	0.91	0.92	-0.17	-		
LMY	0.26	0.38	0.46	0.53	0.54	-0.26	0.66	-	
AMY	0.11	-0.08	-0.07	-0.03	-0.03	-0.23	0.07	0.79	-

DIMFS=days in milk at first service; IN=insemination number; DFLI=days between first and last insemination; DO=days open; ICP=inter calving period; DD=days dry; DIM=days in milk; LMY=lactation milk yield; AMY=average daily milk yield

Table 4.17 Pearson correlation coefficients for third lactation traits in herd B

	DIMFS	IN	DFLI	ICP	DO	DD	DIM	LMY	AMY
DIMFS	-								
IN	-0.05	-							
DFLI	-0.09	0.86	-						
ICP	0.28	0.80	0.92	-					
DO	0.29	0.81	0.93	0.99	-				
DD	-0.03	0.26	0.27	0.28	0.25	-			
DIM	0.30	0.69	0.81	0.89	0.89	-0.20	-		
LMY	0.24	0.36	0.47	0.55	0.55	-0.24	0.67	-	
AMY	0.09	-0.06	-0.02	0.02	0.02	-0.19	0.11	0.80	-

DIMFS=days in milk at first service; IN=insemination number; DFLI=days between first and last insemination; DO=days open; ICP=inter calving period; DD=days dry; DIM=days in milk; LMY=lactation milk yield; AMY=average daily milk yield

The combined effect of differences between birth years (contemporary groups), primary reproduction traits (DO and ICP) and DD explained most of the variation in lactation milk yield across lactations (Table 4.18).

Table 4.18 Variation in lactation milk yield explained by non-production variables in herd B

Response variate	n	Fitted terms[a]	Adjusted R^2	P value
Lactation 1				
	2112	DO	0.384	< 0.001
Y=LMY	2112	DO+DD	0.452	< 0.001
	2112	DO+DD+Year	0.502	< 0.001
	2112	DO+DD+Year+ICP	0.529	< 0.001
	2112	DO+DD+Year+ICP+DD.Year	0.539	< 0.001
	2112	DO+DD+Year+ICP+DD.Year+AFC	0.548	< 0.001
Lactation 2				
Y=LMY	1298	Year	0.291	< 0.001
	1298	Year+DO	0.501	< 0.001
	1298	Year+DO+DD	0.613	< 0.001
	1298	Year+DO+DD+ICP	0.630	< 0.001
Lactation 3				
Y=LMY	749	Year	0.353	< 0.001
	749	Year+ICP	0.584	< 0.001
	749	Year+ICP+DD	0.681	< 0.001

(a) Terms were independently fitted based on the correlation strength with the response variate at the 0.1% level of significance; LMY=lactation milk yield; ICP=inter calving period; DD=days dry; DO=days open; DFLI=days between first and last insemination; AFC=age at first calving; DD.Year=interaction between year and DD

4.5 Evaluation of lifetime characteristics and culling reasons

4.5.1 Producer A

Lifetime milk yield increased with lactation number and milk yield as a function of the number of days a cow was on the farm stabilized ($P>0.05$) from the fourth lactation (Table 4.19).

Table 4.19 Mean and standard deviation (SD) for lifetime characteristics of heifers and cows culled in herd A

		Days on farm		Lifetime milk yield (kg)		Milk yield (kg)/days on farm	
Lactation^{a}	n^{b}	Mean	SD	Mean	SD	Mean	SD
0	1079	420^{h}	317.5				
1	1244	1052^{g}	270.1	8163^{e}	8148	6.55^{d}	5.67
2	1421	1479^{f}	237.3	22031^{d}	8331	14.52^{c}	3.83
3	1204	1891^{e}	254.1	36061^{c}	9769	18.85^{b}	3.29
4	691	2325^{d}	264.6	51507^{b}	11566	22.00^{a}	3.36
5	301	2742^{c}	263.4	64936^{ab}	12588	23.60^{a}	3.56
6	110	3141^{b}	231.8	78309^{a}	10206	24.94^{a}	2.77
7	34	3501^{a}	328.8	85624^{a}	21270	24.40^{a}	5.16
8	4	3827^{a}	208.5	95563^{a}	8962	24.97^{a}	1.81

(a)Animals born between 2002 and 2015 were grouped based on their lactation number upon exit; (b)Animals in the “Missing or Sold” category was removed; Means within column classification followed by different subscripts differ (P<0.05)

Most animals were culled due to reasons related to poor production, together with reproduction and mastitis complications (Figure 4.7). Heifers culled due to poor production or mastitis is probably due to incorrect allocation of exit reasons, with the reasons possibly pertaining to poor fertility or other health related problems.

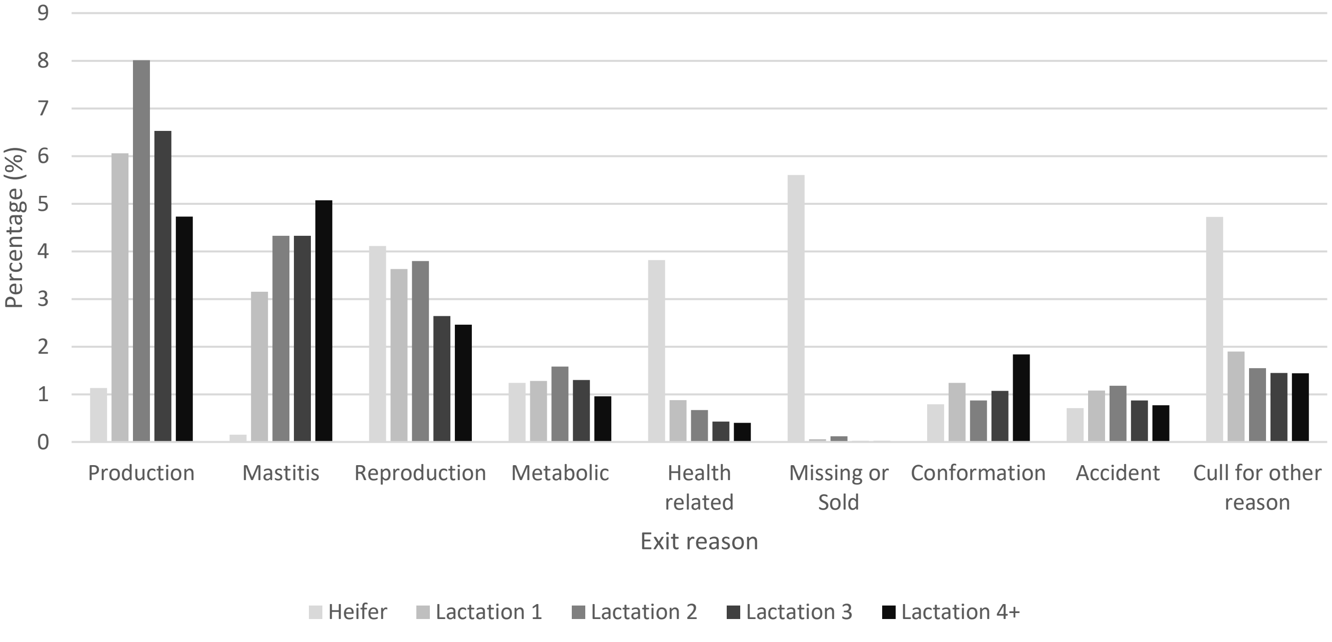


Figure 4.7 Percentage distribution of exit reasons for heifers and cows in herd A (Addendum B, Table 5B)

4.5.2 Producer B

Milk yield as a function of the number of days on the farm increased as animals culled in later lactations produced more milk, reaching an optimum from lactation four onwards (*P*>0.05) (Table 4.20).

Table 4.20 Mean and standard deviation (SD) for lifetime characteristics of heifers and cows culled in herd B

		Days on farm		Lifetime milk yield (kg)		Milk yield (kg)/days on farm	
Lactation[a]	n[b]	Mean	SD	Mean	SD	Mean	SD
0	676	384^{i}	266.3				
1	748	1011^{h}	228.6	5509^{e}	4746	4.73^{d}	3.50
2	557	1401^{g}	190.5	13356^{d}	5192	9.27^{c}	2.62
3	411	1757^{f}	182.7	21209^{c}	5779	11.95^{b}	2.47
4	284	2135^{e}	182.8	30342^{b}	6522	14.16^{a}	2.49
5	182	2471^{d}	197.2	36590^{a}	7861	14.76^{a}	2.63
6	105	2836^{c}	186.4	42881^{a}	7044	15.10^{a}	2.11
7	41	3145^{b}	137.8	49854^{a}	7185	15.84^{a}	2.12
8	11	3620^{a}	287.7	59746^{a}	8610	16.47^{a}	1.44

(a)Animals born between 2002 and 2015 were grouped based on their lactation number upon exit; (b)Animals in the "Sold" category was removed; Means within column classification followed by different subscripts differ (P<0.05)

The majority of animals were culled due to fertility reasons (Figure 4.8).

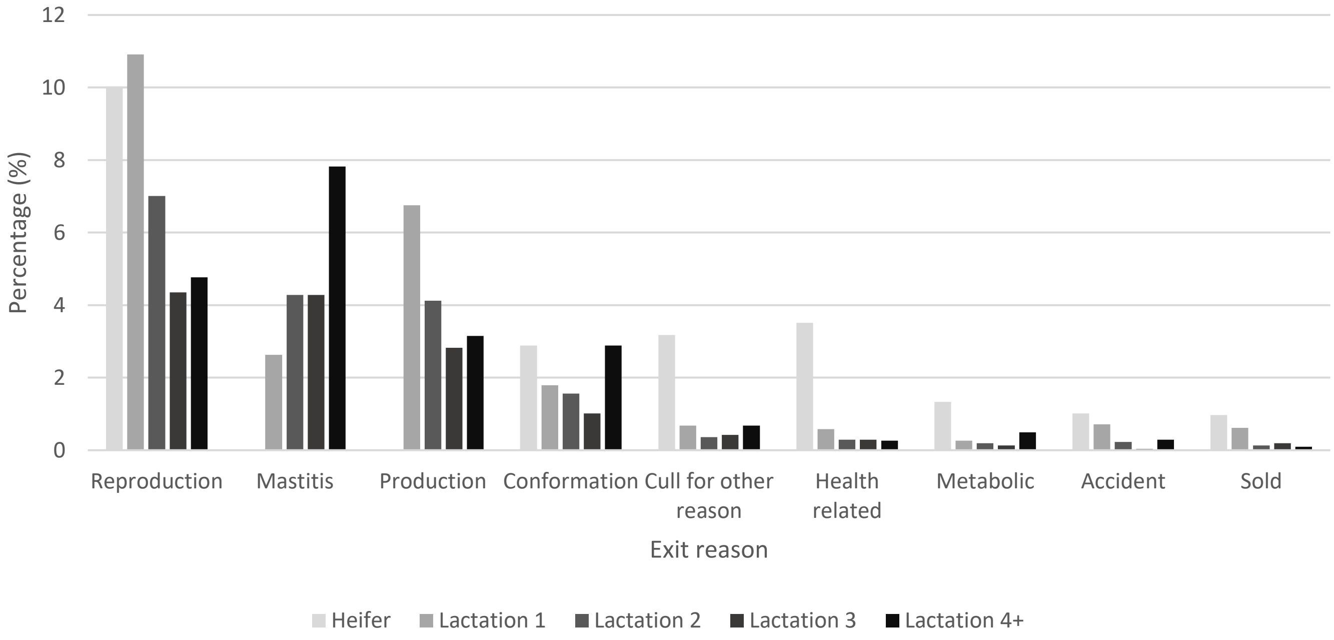


Figure 4.8 Percentage distribution of exit reasons for heifers and cows in herd B (Addendum C, Table 5C)

4.6 Evaluation of AI Bulls

The association between the genetic merit for milk yield and the mean first lactation milk yield of a given sire's progeny (Figure 4.9) had a linear relationship (*P*<0.001). The moderate linear relationship (R^2=0.5422) can be attributed to variation in the number of progeny per sire available for analysis. Changes in the management environment could have contributed to the observed variance in progeny performance over the study period.

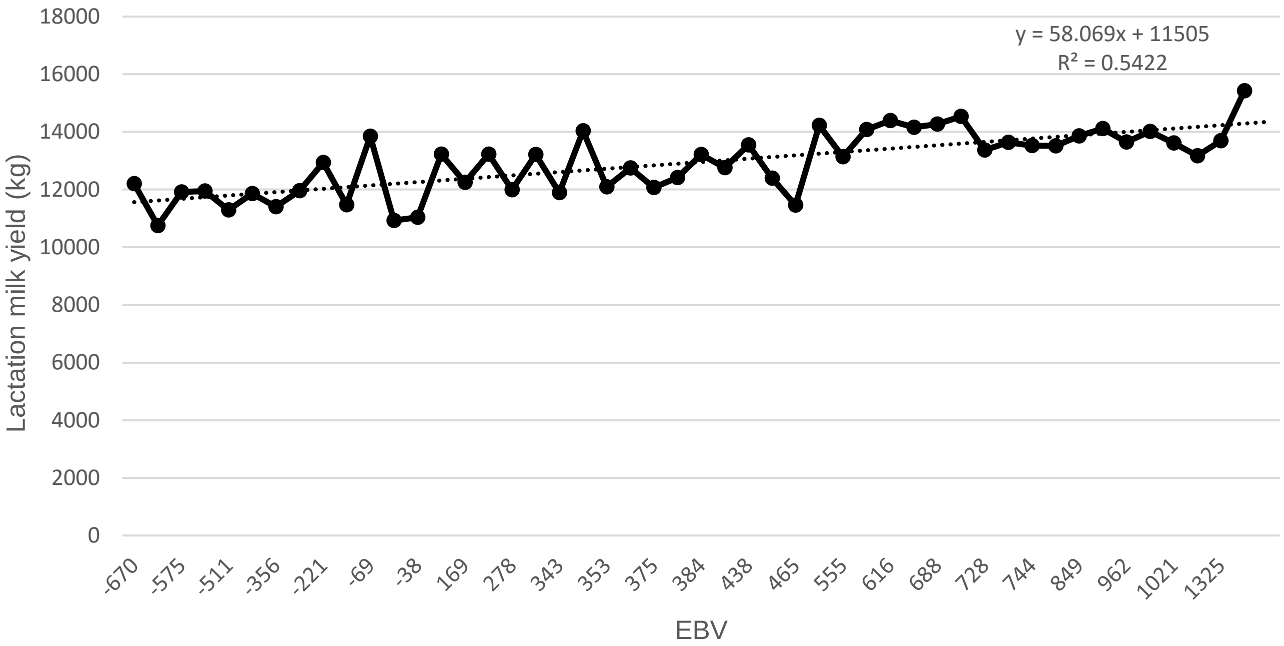


Figure 4.9 Relationship between sire EBV for milk yield and the mean first LMY of daughters

The linear relationship (*P*<0.01) between the EBV for ICP and the mean first ICP of a sire's progeny (Figure 4.10) was weaker compared to milk yield in Figure 4.9.

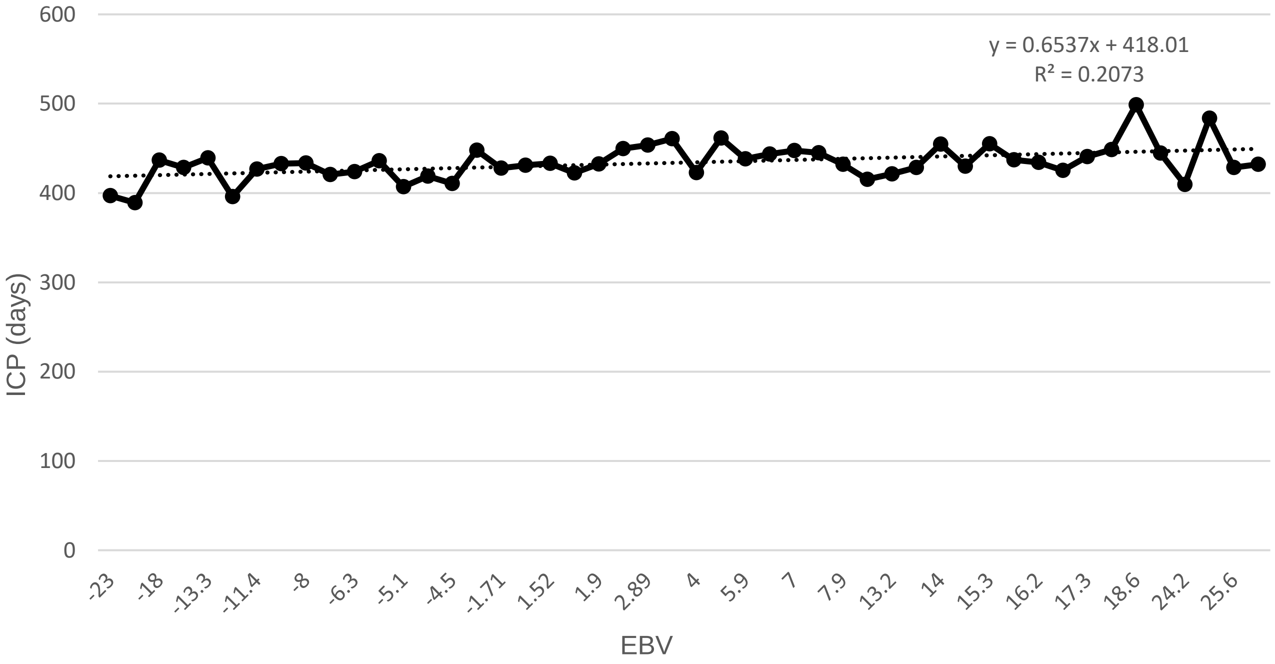


Figure 4.10 Relationship between sire EBV for ICP and the mean first ICP of daughters

Chapter 5: Discussion

5.1 Introduction

Producers often focus on real time animal performance records for short and medium-term monitoring and management decisions in their herd, while not considering the potential of historic performance data. Records documented on AfiFarm that were analysed in the present study allowed evaluation of herd and individual cow parameters. That provided insight into production performance of animals and the management protocols implemented by the respective producers. Proportional increase in herd size showed that replacement heifers and young cows dominated herd composition. A strong correlation between reproduction traits and between production and reproduction traits was observed. Production, reproduction and mastitis limitations were primary reasons for culling animals in both production systems. Results suggest that low milk yield was a major motivation for removing animals in herd A, while infertility was the principal reason in herd B. The regression between a sire's EBVs and the mean performance of his daughters designated a stronger relationship between the genetic merit of sires and mean LMY of progeny, compared to mean ICP of progeny.

5.2 Template construction

The analyses executed from data captured in the template served to investigate the management principles pertaining to production and fertility in the respective production systems. Population summary reports (Addendum A, Figure 6A) extracted from AfiFarm, comprised all required figures of the mature and heifer herd, together with milk yield data. The reports served to evaluate historic herd management reflected in changing herd numbers and production output. The analysis can be repeated to profile historic patterns in herd size and milk yield levels on a daily, monthly and yearly basis for other producers employing AfiFarm.

Comprehensive routine data capture by the Afi sensors and storage capabilities on AfiFarm permitted extraction of multiple parameters saved during the productive and non-productive periods of an animal's lifetime, for scientific research. Parameters documented within the heifer period and within the respective lactations for each animal allowed access to multiple production and reproduction traits. The unique features of a TMR and pasture-based system could be explained by coupling reproductive traits with production traits such as DIM, LMY and AMY. Traits extracted in the template were sufficient for the present study, although AfiFarm permit extraction of additional traits, to consider in future analyses.

5.3 Herd structure/composition

Herd A has surpassed mean herd numbers estimated from a statutory survey both nationally (354 cows and 277 heifers) and in the Western Province (294 cows and 198 heifers) (MPO, 2017). The herd size has increased to form part of an estimated 14.4% of South African herds exceeding 1000 cows (milk and dry cows) (Milk SA, 2018). Results designated herd A as one of the premier South African herds in terms of numbers and yield, forming part of an estimated 3.9% of national herds producing more than 35 kg per cow per day (Milk SA, 2018). Trends in herd composition indicated that the herd will probably continue to increase in number and production output. Infrastructure, feeding and managerial capacity will most likely determine the saturation point for expansion.

The number of heifer calves born in the herd increased, as the number of mature cows (breeding stock) increased over the study period. Heifers purchased explain the rise in numbers observed in 2012 and 2013. Producer A incorporated the use of sexed semen which augmented the progression in the heifer herd. During herd expansion, the proportional composition of dry cows, lactating cows and heifers remained relatively stable, except for the spike in the percentage of heifers in 2012 and 2013.

In an expanding herd the percentage of young cows (lactation one and two) will be higher when likened to a stable (not expanding) herd (Steward, 2010). It is postulated that in a stable herd the proportion of first, second and third and above lactation cows will comprise 25%, 20% and 55% of the mature herd. The comparatively higher percentage of first and second lactation cows seen in the present herd substantiates that herd A was enlarging. Findings suggest that the mean lactation number of cows in the mature herd fluctuated but remained below three, which is in accordance with national estimates (Scholtz & Grobler, 2009; Logix Milk Annual Report 2015/2016).

At the time of data collection, the mean lactation number for all cows in the herd was 2. This is lower than the mean 2.4 and 2.7 lactations for registered and commercial Holstein cows reported in the Logix Milk Annual Report 2015/2016, which includes cows from both TMR and pasture-based systems. The mean lactation number for registered cows in the Western Cape was 2.1, which is similar to that observed in herd A. The continuous supply of replacement heifers most likely facilitated strict culling of cows before their third lactation (Hare *et al*., 2006b). Muller & de Waal, (2016) found that South African Holstein herds with a combined percentage of first and second lactation cows of 69% enforced a replacement rate of 40% and the mean lactation number in that herd was 2.16. Based on the similarities with herd A it is presumed that a replacement rate of close to 40% was maintained in herd A. Maintaining a high replacement rate with genetically superior replacement heifers entering as first parity cows (assuming superior sire genes were selected), might have been beneficial in reducing the genetic lag (De Vries, 2017).

Production trends suggest that the herd maintained high milk yield, considering that most of the milking herd consisted of first and second lactation cows, the increase in yield is commendable. The high rate of increase in kilogram milk produced can be explained by herd growth together with a rise in daily milk production for cows in the lactating herd. The improvement in mean daily milk yield can be ascribed to genetic selection for superior milk yield (AI sires used), better nutrition, identification of metabolic ailments and early intervention, infrastructure supporting cow comfort and management of cows based on their production level. Lower mean daily milk yield levels in 2013, 2014 and 2015 can be explained by the entry of first lactation cows and a subsequent reduction in the proportion of older cows compared to 2012.

In herd B the mean number of cows and heifers increased over the study period and exceeded mean herd numbers estimated both nationally (354 cows and 227 heifers) and in the Eastern Cape (658 cows and 404 heifers) (MPO, 2017), forming part of 6% of South African herds having between 751 and 1000 cows (Milk SA, 2018). Production levels placed herd B with an estimated 28.3% of South African herds producing between 21 and 25 kg per cow per day (Milk SA, 2018). The implementation of individualized feeding through AfiFeed in the parlour has the potential to facilitate and maintain production efficiency in the emerging herd.

The initial decrease in the mature herd from 2005 to 2006 can be attributed to probable feed and management limitations. Adaptation of the AfiMilk system from 2005 possibly restricted the accuracy of measurements recorded on the system, contributing to lower herd numbers observed. From 2007 the composition of the mature herd was exceeding percentages postulated for an expanding herd (Steward, 2010), explaining the large percentage of heifers and lactation one and two cows observed.

The higher rate of increase for the heifer herd can be explained by a raised throughput of replacement heifers born in the herd each year. Producer B did not rely on outside purchase to the same extend as producer A but in 2011 the heifer group was supplemented with animals purchased. Entry of heifers from outside the herd and the advanced use of sexed semen in 2010 subsidized a higher percentage of heifers from 2011. The trend is amplified by a reduced proportion of older cows (lactation three and up) in the herd from 2011.

The percentage of first lactation cows increased from 2013 as the large heifer group in 2011 was entering the milking herd. Results suggest that the mean lactation number of the mature herd was below three over most of the study period. At the time of data extraction, the mean lactation number for cows was 2.2 in herd B. This is lower compared to registered and commercial Holstein cows that participated in Logix Milk Recording (2015/2016). The mean lactation number for registered cows in the Eastern Cape was 2.9. A lower lactation number in herd B therefore suggests cows were exposed to strict culling regimes before reaching their third lactation. The expanding herd and a large replacement heifer group enabled the high replacement rate (Hare *et al*., 2006b).

From 2005 to 2007 the mean monthly milk yield and daily milk yield decreased, which can be explained partly by a reduction in the lactating herd and possible adaptation time for incorporating AfiMilk from 2005. The rise in daily milk production from 2007 suggests enhanced pasture and supplementary feed management to meet the nutritional demands of lactating cows. Higher production can also be attributed to using Holstein semen on Jersey and Jersey x Holstein crossbred cows. Lower mean monthly milk yield and daily milk yield in 2015 can be explained by a marginally higher percentage of first lactation cows in the herd.

The value of population summary reports (Addendum A, Figure 6A) extracted from AfiFarm must be stressed, analyses of herd numbers and composition over time, clearly illustrated the emphasis on large heifer herds in both systems and a high culling rate of older cows. The increase in herd size confirmed that both producers were promoting more animals in the total herd and as a result more cows in a producing state, which increased the production output of both herds, allowing producers to optimize economic return.

5.4 Evaluation of production and reproduction traits

Heifer and cow traits extracted from AfiFarm in the TMR herd elucidated mean performance of animals managed in production system A over the study period. Results showed that most heifers calved down after 24 months and that cows were inseminated late in lactation, extending DIM and LMY as high producing animals were able to maintain lactation persistency.

The large standard deviations and differences ($P<0.05$) across birth years (Addendum B, Table 1B, 2B and 3B), confirm the variation in performance of animals. Studies on dairy cattle performance over time indicated that changing environment and management protocols will influence performance of herds (Atashi *et al*., 2012; Muller *et al*., 2014; Allah, 2015). Thus, several factors could have contributed to the observed variation, including implementation and refinement of the AfiMilk system, changes in climate, fertility management (extending VWP), infrastructure, herd size, nutritional composition of the TMR, hormonal administration and feeding practices. Future research could refine the analyses by correcting for these effects. However, the researcher acknowledges the contribution of these factors to variation in the results.

Mean DIM (369.8±74.31, 365.5±70.48 and 370.7±70.03 days) across lactations, was higher than the conventional 305 days, which is explained by producer A managing cows to maintain lactation persistency. Studies suggest that high yielding and persistent dairy cows can maintain lactations over 400 days (Maciel *et al*., 2016). Producer A made use of recombinant bovine somatotropin (rBST) to maintain persistency (Dohoo *et al*., 2003) and extend DIM during the study period. However, its implementation varied and was no longer enforced during data extraction. Producer A further maintained persistency in his herd by feeding specialized high energy rations and frequently stimulating mammary glands by employing three milking sessions per day (Sørensen *et al*., 2008; Mellado *et al*., 2011).

The increase in mean AMY together with mean LMY ($P<0.05$) from lactation one to three is in accordance with previous studies (Kuhn *et al*., 2006a; Makgahlela *et al*., 2007; Yamazaki *et al.*, 2014). Differences in secretory tissue utilisation and endocrine structure in first parity cows may limit the partitioning of nutrients for milk synthesis (Mellado *et al*., 2011). The increase in production capacity over lactations can thus be attributed to the fact that younger cows were still growing and developing mammary tissue. As cows aged, higher feed intake facilitated growth in body size and development of the udder, which amassed the number of secretory cells.

Mean AMY (34.47±4.57 kg, 40.09±5.15 kg and 42.24±5.49 kg per cow per day) levels across lactations can be compared to high yielding Holstein cows managed in TMR systems in the USA. Herds in North America typically sustained AMY levels of 40 kg per cow per day (Weigel, 2006). Holstein cows from Pennsylvania State University, managed with AfiMilk produced a mean AMY of 37.1±11.2 kg per cow per day (Toshniwal *et al*., 2008). The high LMY observed in herd A was probably a function of persistent high AMY and more DIM.

Results indicate that heifers were inseminated at a mean age of 15.83±2.16 months with a mean IN of 1.69±1.03 inseminations, conceiving on average at 16.83±2.99 months and calving on average at 25.86±3 months in herd A, which was lower compared to other studies on herds in South Africa. Records analysed from South African Holstein cows presented a mean AFC of 28±4 months (Makgahlela *et al*., 2007). Neser *et al*. (2014) found a mean AFC of 27±3.8 months from cattle managed in a TMR system. The higher AFC in both studies can be attributed to breed differences and presumably not all cows in the data sets were exposed to automatic fertility management. The mean AFS and IN found in a South African TMR Holstein herd studied by Muller *et al*. (2013) was

16.0±2.1 months and 1.86±1.21 inseminations, while the AFC was 26.4±2.4 months, which is similar to herd A. Heifers (n=115) in the latter study were placed in an AI group from 13 months of age where regular oestrus inspection was performed by a veterinarian. Similar trait measurements between the large data set in the present study and the smaller herd in the study by Muller *et al*. (2013), clarifies the precision of individualized fertility monitoring through sensor-based heat detection (Nebel *et al*., 2000) in a large herd.

Various studies across the globe reported an AFC value proximate to or above 26 months of age (Wathes *et al*., 2014). Holstein heifers in the USA had a mean AFC of 26.9±3.2 months (Hare *et al*., 2006a). Heise *et al*. (2018) observed heifer performance from a data set with German Holstein heifers, a mean AFS of 16.23 months and AFC of 25.97 months was found, which is comparable to herd A. Japanese Holsteins had a mean AFS of 17.1±2.8 months, IN of 1.45±1.52 inseminations and AFConc of 17.9±3.37 months. By assuming a gestation period of 280 days in Holstein cattle (Nogalski & Piwczyński, 2012) a mean AFC of 27.11 months can be estimated. Competent Holstein heifer rearing in Israel is evident as an AFC of 24.4±1.7 months was reported by Weller & Ezra, (2015). Findings in the latter study proposes that the mean AFC in herd A can be lowered. Although the AFC observed in the present study was upward of the suggested 24 months, it was on par or lower than most studies mentioned.

Heifer rearing and timing of AI with desirable BCS and BW was possible by means of automatic documentation of body weight and detection of oestrus, which contributed to a conception rate (estimated by the inverse of IN) of 59.2% in herd A. The observed conception rate is higher than the number (53.76%) calculated from the mean IN reported by Muller *et al*. (2013) for South African Holstein heifers. The conception rate in USA heifers peaked at 57% between 15 and 16 months of age (Kuhn *et al*., 2006b). These findings suggest that oestrus detection by the AfiMilk system was relatively efficient, inseminators proficient and heifers fertile, facilitating successful first insemination.

Mean DFLI observed (30.17±63.63 days) was higher than estimates from Holstein heifers in Norway (18.5±36.5 days; Muuttoranta, 2015) and Germany (17.94 days; Heise *et al*., 2018). The higher DFLI for some heifers in herd A can be attributed to possible reproduction complications such as abortions, stillbirths and delayed recycling (Ettema & Santos, 2004). The choice to allow heifers with reproduction difficulties to be re-inseminated can be motivated by pedigree, keeping daughters of high producing cows. The cost of rearing heifers probably served as an incentive to get heifers into calf, considering that replacement heifers were required for increasing herd numbers. Continuous monitoring of heifer health, body weight and body condition by means of the AfiMilk system and ongoing selection for fertile animals is recommended to improve the mean AFS, IN and DFLI in future measurements, which will subsidize a lower mean AFC in herd A.

In herd A the VWP changed over the study period, but it was confirmed that it was 100 days or more over the study period, which subsequently extended the mean DIMFS, DO and consequently ICP. Mean ICP observed in herd A was higher than 365 days, indicating that component fertility traits (DIMFS, IN, DFLI and DO) were all extended beyond the conventional thresholds. The comparatively longer interval fertility traits measured in herd A can be attributed to producer A capitalizing on the persistency of high yielding cows. In modern herds, there might be an economic advantage to extending the ICP by prolonging the VWP beyond 60 days (Lehmann *et al*., 2016; Maciel *et al*., 2016). The principle suggests that the number of cows calving per year will be lower, reducing the risk of dystocia and post-partum metabolic challenges, while saving on insemination costs in the herd. The ability of the AfiMilk system to monitor the DIM and automatically detect oestrus expression, enabled producer A to set a target DIM for breeding cows. By breeding cows after the expected limitations in reproduction traits brought forward by a negative energy balance, the success rate of first insemination could be maximized (Inchaisri *et al.,* 2010; 2011).

Results from South African studies show that herd A had comparatively longer fertility intervals but superior conception rates. South African TMR Holsteins, studied by Muller *et al*. (2013) had a mean DIMFS of 91±31 days, IN of 2.33±1.51 inseminations and DO of 149±72 days. Mean DIMFS, DO and IN from a study conducted on South African Holstein herds managed in TMR and pasture-based systems dispersed over the Western Cape, Eastern Cape and Kwazulu-Natal was 77.3±29.9 days, 133.9±74.3 days and 2.55±1.79 inseminations (Muller *et al*., 2014). Makgahlela *et al*. (2007) observed a mean ICP of 396±58 days in South African Holsteins.

Fertility traits in high yielding herds overseas were similar to measurements in herd A and suggest that producers were inclined to prolong the VWP. Trends in Holstein cows in the USA showed an increase in LMY (De Vries & Risco 2005), subsequently DIMFS, DO, and ICP increased and peaked at 103.7±1.9, 167.3±2.0 and 429±2 days respectively. A large survey on 250 Holstein herds in the USA found a mean DIMFS of 100.2±31.4 days, DO of 163±31.4 days, ICP of 441±30.72 days and IN of 2.8±1.58 inseminations (Kellogg *et al*., 2001). Tunisian Holsteins had a mean DIMFS of 93.2±80.2 days, DO of 150.9±75.7 days, ICP of 444.2±101.5 days and mean IN of 2.55±1.7 inseminations (Aloulou *et al*., 2010). Yamazaki *et al.* (2014) measured fertility traits in Japanese Holstein cows in lactation one, two and three. Mean DIMFS increased from 83.1±31.9 days in lactation one to 84.6±32.3 days in lactation two and 85.8±32.2 days in lactation three. Mean IN and DO across lactations were 2.5±1.9, 2.6±1.9 and 2.6±1.9 inseminations and 144±80, 151±83 and 153±83 days respectively. Housed Japanese Holstein cows had a mean DIMFS of 90.6±22.1 days, DO of 151.3±55.8 days and mean IN of 2.8±1.4 inseminations (Dochi *et al*., 2010).

The comparatively higher DIMFS seen in herd A (110.2±32.95, 112.5±31.81 and 120.2±34.67 days across lactations) and the studies discussed was due to producer A enforcing a longer VWP. Assuming that the VWP remained constant over lactations, the rise in DIMFS suggest that cows were being inseminated later in lactation, indicating that animals might have had delayed oestrus expression in second and third parities. Mean DO (156.6±81.34, 164.7± 79.99 and 171.9±79.60 days) and ICP (433.9±81.34, 441.5±79.68 and 448.6±78.91 days) observed in herd A is comparable to some of the studies mentioned (Kellogg *et al*., 2001; De Vries & Risco 2005; Aloulou *et al*., 2010). Higher DO and ICP values, especially in second and third lactations can be explained by the extended VWP and animals conceiving later in lactation.

Mean IN (2.2±1.72, 2.34±1.73 and 2.32±1.74 inseminations) in herd A was analogous or lower, compared to studies mentioned. Comparable or superior conception rates in herd A can be attributed to the success of the AfiMilk system in identifying cows on heat (Nebel *et al*., 2000; Wojcik & Rudzinski, 2014) and monitoring body weight and body condition in order to breed cows when energy levels permit greater conception. However, variation between cows in the data set and a moderately lower mean IN observed in some studies (Abe *et al*., 2009; Pritchard *et al*., 2013a) proposes that herd A can improve conception rates across lactations. The effect of health disorders such as lameness, mastitis, endometritis, milk fever and preceding calving difficulties (Dobson *et al*., 2008) were possibly contributing to variation in IN and DFLI.

Poor body condition and high milk yield on the day of insemination could have disrupted conception (Stádník *et al*., 2002). Variation in heat detection due to defective pedometers are rare but could have contributed to additional inseminations and DFLI (Nir, 2010; Saint-Dizier & Chastant-Maillard, 2012; Wojcik & Rudzinski, 2014). Sexed semen is known to be less fertile, possibly contributing to conception restrictions, producer A could address the constraint by only considering heifers and above average fertile cows for insemination with sexed semen (Mccullock *et al*., 2013). Apart from semen quality, maintaining proficient insemination techniques and monitoring the nutritional requirements of high producing cows will support optimum fertility at breeding (LeBlanc, 2010).

Limitations in successful oestrus expression and conception was potentially increased by high production levels (Lucy, 2001; Inchaisri *et al*., 2010). Long term selection for high milk yield possibly amplified the concentrations of circulating somatotropin and prolactin, but suppressed hormones such as insulin, which supports growth and development of the ovary (Sawa & Krężel-czopek, 2009). Findings by Lopez *et al*. (2004) support the notion, by observing lower levels of circulating oestradiol concentrations in cows that were producing more than 39.5 kg/day. In addition, the effect of nutrient partitioning to sustain a high AMY probably supressed reproductive hormone secretion, decreasing conception and maintenance of pregnancy by the uterine environment (Walsh *et al*., 2011). As the level of production increased across lactations in the present herd, the effect of milk yield on reproductive functioning probably intensified.

The rise in mean DD (64.06±25.65, 76.02±36.52 and 78.01±37.86 days) across lactations (*P*<0.05) in herd A can be attributed to lower lactation persistency, with increasing parity. Sub-fertile cows with additional DO probably had to be dried up with more days to calving, increasing DD. A minimum of 55 days dry is expected to maximize subsequent LMY, while more than 70 days could be detrimental to LMY as cows may build up too much body reserves (Kuhn *et al*., 2006a). The optimum dry period is dependent on the production system and especially DIM and LMY facilitated in a herd. It is likely that producer A didn't condone the long dry periods, especially in lactation two and three, but found it more profitable to extend DIM and maximize lifetime milk yield.

The relationship between the measured reproduction and production traits for heifers and cows within the first three lactations were evaluated with Pearson correlations and stepwise regression analyses. Results validated the necessity to measure multiple traits in a herd. Producers employing AMSs have access to birth and insemination dates, which can be applied to determine traits early in life for heifers or early in lactation for cows. Since Pearson correlations reflect the linear association between a pair of traits, marginal correlations may be due to a small portion of measurements showing a given association. When scrutinizing correlations and interpreting relationships, moderate (3-5) to strong (>5) correlations should be deliberated. If one considers that AFS and AFConc were components of AFC, then the strong positive correlations (0.68-0.99) between these traits were anticipated (Abe *et al*., 2009; Heise *et al*., 2018). The moderate to strong relationship (0.45-0.68) between IN, DFLI and AFC suggest that AFC can be lowered by increasing conception rate. The strong correlation (0.99) between AFConc and AFC can be explained by the fixed gestation period for Holstein cows (Nogalski & Piwczyński, 2012). Findings support the concept of striving to breed heifers at a lower AFS, while minimizing IN in order to lower AFC.

Associations (0.41-0.99) between ICP and its component traits (DIMFS, IN, DFLI and DO) across lactations were evident. The strong positive correlation (0.99) between DO and ICP can be attributed to a fixed gestation period. Multiple studies support these findings with strong positive genetic and phenotypic correlations between fertility traits (Yamazaki *et al*. 2014; Ben Zaabza *et al*., 2016). Monitoring component traits (DIMFS, IN, DFLI and DO) could enable producers to predict ICP for individual cows and project the mean ICP for the herd. Establishing benchmark values for reproduction traits within a given parity and level of production could aid producers in identifying cows with sub-optimal performance early in lactation.

Strong positive correlations between production traits (DIM and LMY) and primary reproduction traits (DO and ICP) were reported in previous studies in South Africa and abroad (Makgahlela *et al*., 2007; Riecka & Candrák, 2011; Osman *et al*., 2013). It is evident that DIM and subsequently LMY were positively associated (0.63-0.95) with DO and ICP across all three lactations in herd A. Stepwise regression results confirm this association, as ICP and DO were primary prediction variables explaining the largest fraction of variation in LMY, extending DIM for high milk producing cows by delaying insemination is a feasible explanation (Lehmann *et al*., 2016). The antagonistic effect of high production on fertility undoubtedly contributed to more DO and a prolonged ICP, especially in second and third lactations.

Interestingly the moderate positive correlations (0.39-0.47) between DD and interval reproduction traits (DO and ICP) across lactations suggest that sub-fertile cows had a subsequent longer dry period (Kuhn *et al*., 2005). Cows conceiving late in lactation and unable to maintain production persistency were probably dried up with more days to calving (Kuhn *et al*., 2006a). The marginal and negative correlations, ranging from -0.21 to -0.27 between AMY and DD propose that there was a portion of cows with low daily milk yield levels that were dried up before the optimum DIM was achieved, resulting in extended dry periods. The contribution of DD to variation in LMY observed in the stepwise regression models can be explained by the same concept discussed for the Pearson correlations; dry periods were extended due to low producing cows or cows with conception difficulties. In both cases DIM was altered, which in turn affected LMY. Cows with low production levels were probably dried up before realizing the ideal DIM (resulting in decreased LMY) and cows conceiving late had extended DIM (resulting in increased LMY).

Disparity ($P<0.05$) across birth years (contemporary groups) were evident (Addendum B, Table 2B; 3B), explaining the inclusion of years in all three stepwise regression models. Coefficients of determination (adjusted R^2) indicate that 71.4%, 69.1% and 68.1% of lactation one two and three variation in LMY is explained by correcting for reproduction performance, DD and differences across birth years.

The analyses of traits extracted from AfiFarm in the pasture-based system disclosed mean heifer and cow performance that suggest producer B maintained strict and uniform fertility management, while upholding optimum production levels. Variation ($P<0.05$) across birth years (Addendum C; Table 1C; 2C; 3C) and large standard deviation values for traits measured, confirm that cows were exposed to changing management environments over the study period. Changes in climate, herd size, herd composition, fertility protocols, hormonal administration, pasture management, application of AfiMilk and refinement of AfiFeed probably contributed to variation. The proportion of Holstein calves born were high from 2007 onwards, explaining the increase ($P<0.05$) in AMY and LMY (Addendum C, Table 3C). As the breed composition of the herd changed towards more Holsteins, the genetic merit for high AMY and LMY increased.

Mean AMY across lactations in herd B agree with studies conducted on cows managed in pasture-based systems in South Africa and abroad. First lactation Holstein cows in Ireland were producing 19.54±0.02 kg per cow per day (Cummins *et al*., 2012), which is comparable to lactation one AMY (20.78±3.17 kg per cow per day) in herd B. Holsteins managed in New Zealand, receiving supplementary concentrates were producing 6 996 kg/300 DIM (23.32 kg per cow per day) (Kolver *et al*., 2007). High yielding pasture-based Holstein herds in South Africa were producing 7 820 kg/305 DIM (25.64 kg per cow per day; Williams *et al*., 2016) which is similar to levels for lactation two and three cows (25.62±4.61 kg and 26.86±5.08 kg per cow per day, respectively) in herd B. These findings propose that producer B was managing cows at optimum production levels for a South African pasture-based system. The rise in AMY ($P<0.05$) across lactations in herd B is expected as cows were growing and developing mammary tissue (Haworth *et al*., 2008; Mellado *et al*., 2011). Recovering from the first calving event probably contributed to lower first lactation AMY.

Energy is a limiting factor which challenges milk yield in pasture-based cows (Bargo *et al*., 2002). Satisfactory production levels in herd B suggest that the nutrient contribution from supplementary concentrate feeding by AfiFeed in the parlour abridged the challenge. Feeding cows based on individual requirements (Van den Berg & Howarth, 2014) probably facilitated an increase ($P<0.05$) in AMY across lactation one to three and can assist in increasing production levels in the future. Concentrates dispensed to maintain a cow’s production curve possibly contributed to more DIM (Haile-Mariam *et al*., 2003), extending the mean DIM in herd B (322.60±47.21, 324±47.32 and 320±40 days across lactations) above 305 days.

In a seasonal calving herd, breeding dates, calving dates, DIM, and DD must be relatively synchronized (Cordoba & Fricke, 2002) to ensure cows calve and initiate a lactation with optimum pasture growth. Birth dates, automatic oestrus detection and insemination dates documented by the AfiMilk system provided information to manage breeding seasons. Hormone treatment practices were developed to induce oestrus, ensuring a fixed time AI (Bisinotto *et al*., 2014). Producer B employed multiple treatments of which the Ovsynch protocol (Galvão & Santos, 2010) was prevalent. Esteemed heifer traits and diminutive disparity in reproduction traits across lactations observed in herd B attest to the implementation of strict fertility management. The contribution of Jersey genotypes, which is presumably more fertile than Holsteins (Auldist *et al*., 2007) in mixed cows possibly contributed to virtuous reproductive performance in this herd.

Optimum economic return is generally achieved when heifers calve down between 23 and 24.5 months (Ettema & Santos, 2004; Weller & Ezra, 2015), which was achieved in herd B. Producer B enforced rearing practices that monitored heifer body weight, body condition and health by means of automatic weighing and activity meters, indicating poor growth or health problems, based on deviations. Precision heifer rearing supported heifers to be physically receptive to breeding by 14.22±1.05 months, ensuring a mean AFC of 24.06±1.73 months in herd B, which is lower than findings from South African pasture-based cattle. Muller *et al*. (2015) observed a mean AFS, AFConc and AFC of 16.1±2.3, 17.5±2.9 and 26.5±2.9 months respectively for Holstein heifers. Heifers in the latter study were placed in an AI group from 13 months of age where regular examination for signs of oestrus was done by a veterinarian.

The mean AFC for cattle in a large South African pasture-based data set was 28.21±3.6 months (Neser *et al*., 2014). Breed variation and inclusion of heifers not exposed to automatic fertility management possibly explain the higher value in the latter study. Internationally, Berry *et al*. 2013 found the mean$\pm\sigma_g$ (genetic standard deviation) for AFC in Irish Holsteins to be 26.2±1.19 months. Findings suggest that heifer fertility traits in herd B were maintained at optimum thresholds and that animals were exposed to a minimum rearing time, saving costs and maximising an animal's productive lifetime.

The mean heifer IN (1.81±1.07) in herd B was similar to the 1.86±1.30 inseminations found in the study by Muller *et al*. (2015). Herd B had an estimated first conception rate of 55.2%, which agrees with the >53% recommended by the Australian InCalf (2017) project for pasture-based herds. The small difference (5.37 days) between mean heifer DFLI (23.87±39.75 days) observed in herd B and Holstein heifers in Norway (18.5±36.5 days; Muuttoranta, 2015) suggests that heifers were successfully recycling, conceiving from subsequent inseminations and maintaining pregnancy. Producer B can potentially lower DFLI by continuously removing heifers with conception difficulties.

The uniformity in cow fertility traits across lactations (*P*>0.05) are in part explained by hormonal treatments and lower production pressure on cows in herd B, compared to TMR herds. To enforce seasonal calving regimes, cows were required to have early post-partum recycling and good conception rates (Cordoba & Fricke, 2002). The mean DIMFS observed across lactations (78.03±19.34, 75.36±18.24 and 74.68±18.22 days) suggest that producer B enforced a VWP approximate to 60 days. Mean DIMFS were highest for first lactation cows (*P*<0.05), which is supported by literature (Berry *et al*., 2013). Higher DIMFS can be attributed to young cows requiring more recovering time following their first calving event. South African pasture-based Holstein cows studied by Muller *et al*. (2015) were inseminated by 88±27 days in milk with a mean IN of 2.19±1.41 inseminations. The latter herd was exposed to a VWP of 60 days and tail-markers were implemented to observe heat, animals with extended anoestrus were subjected to hormonal treatment. Mean DIMFS, DO and IN from a study by Muller *et al*. (2014) on 14 South African Holstein herds was 77.3±29.9 days, 133.9±74.3 days and 2.55±1.79 inseminations respectively. The lower DIMFS and IN observed in herd B was probably due to producer B implementing precision automatic feeding and monitoring of oestrus expression and cow health, promoting high conception rates.

The estimated conception rate for first (51.3%), second (49.3%) and third lactation (49.5%) cows were below the >53% suggested by the Australian InCalf (2017) project. Marginally better conception rates observed in studies abroad (Berry *et al*., 2013; Shalloo *et al*., 2014; Kelleher *et al*., 2016) suggest herd B can improve mean IN and DFLI. Cow and management factors that possibly contributed to conception challenges include preceding calving difficulties, metabolic and reproduction related disorders (Dobson *et al*., 2008), semen quality, sexed semen and inseminator proficiency. Although unlikely, incorrect application of pedometers could have reduced observed heats and timing of insemination (Nir, 2010; Saint-Dizier & Chastant-Maillard, 2012; Wojcik & Rudzinski, 2014). Continued application of health and fertility monitoring with precision feeding practices will potentially reduce the trivial difference seen in mean IN between herd B and the studies mentioned.

Stable (*P*>0.05) mean DO (107.6±47.52, 108.3±47.77 and 107.9±48.31 days) and ICP (386.8±48, 387.9±48.21 and 387.4±48.7 days) values observed across lactations in herd B confirmed a static VWP and fixed AI management. Mean DO observed in herd B was lower than the 139±62 days reported by Muller *et al*. (2015). Mean ICP in herd B was lower than the 398.3±71.5 and 394.9±68.8 days reported by Haile-Mariam *et al*. (2003) for first and second lactation Australian Holsteins. The longer intervals in the latter study was probably due to cows not exposed to automatic feeding and fertility management. Comparable ICP values were reported for Irish Holstein cattle (383±65 days; Shalloo *et al*., 2014 and 390±72.9 days; Berry & Cromie, 2009). Mean DD in herd B (64.25±16.08, 63.94±20.52 and 67.08±22.99) remained relatively stable, suggesting that as cows were conceiving at a fixed DIM and maintained a constant lactation period across lactations (*P*>0.05) they were dried up at a parallel interval before calving. Producer B will benefit from maintaining the mean DD within the limits proposed by Kuhn *et al*. (2006a) (55-70 days) in order to prime cows for optimum performance in the subsequent lactation.

Correct implementation of AfiMilk components and synchronization protocols allowed producer B to regulate fertility management. Supplementary feed based on individual body weight, body condition and production levels (Van den Berg & Howarth, 2014) probably reduced the risk of anoestrus and conception challenges brought forward by a negative energy balance at breeding. Activity meters (AfiAct) identified heifers and cows on heat (Wojcik & Rudzinski, 2014) in this large herd, which increased precision of fixed breeding seasons. In addition to identifying cows to breed or dry, the central management component, AfiFarm could sort cows experiencing ailments, which permitted pre-emptive treatment before breeding.

As expected, AFC had strong positive correlations (0.61-0.98) with its component traits in herd B, which is supported by literature (Heise *et al*., 2018). Once more the strong positive relationship (0.98) between AFConc and AFC is explained by a fixed gestation period. It was clear that DFLI influenced AFC as the trait had the second strongest correlation (0.77) with AFC. Thus, increasing first insemination success rate will decrease discrepancy in AFC and increase the precision of fixed first calving dates (Berry & Cromie, 2009).

The positive correlations (0.77-0.99) between IN, DFLI, DO and ICP was evident across lactations, signifying that these traits hinged on one another. The strong correlations (0.98-0.99) between DO and ICP is explained by the reasonably fixed gestation period of cows (Holsteins and mixed). In herd B where control over insemination and calving dates are closely managed, traits measured early in lactation (DIMFS, IN, DFLI and DO) could serve as waypoints to ensure cows calve down within the designated breeding seasons (Berry *et al*., 2013; Kelleher *et al*., 2016). The strong positive correlations (0.77-0.93) between IN, DFLI and interval reproduction traits (DO and ICP) support the notion that by striving to improve conception rates, producer B may exert more control over calving dates.

The marginal positive relationships (0.13-0.28) between DD and reproduction traits (DO and ICP) across lactations suggest that cows with extended fertility traits had longer dry periods. The marginal negative correlations (between -0.13 and -0.26) amid DD and production traits (DIM, AMY and LMY) proposes that a number of cows with low AMY levels had less DIM and more DD. Variation explained by DD in stepwise regression models supports the concept and can be attributed to deviation in dry periods due to cows conceiving late in lactation (possibly increasing DIM) and poor milk producers dried up before the optimum DIM was achieved.

Associations between fertility and production traits in pasture-based cows have been reported in literature (Haile-Mariam *et al*. 2003; Berry *et al*., 2013). In this study, the strong positive correlations (0.69-0.96) between DIM and reproduction traits (IN, DFLI, DO and ICP) across lactations illustrates that cows with extended reproduction intervals had more DIM. Even though pertinent control over fertility traits were enforced to allow a fixed DIM and DD, correlations suggest that there were cows with reproduction difficulties, albeit anoestrus or abortions, resulting in extended lactations. The correlation can be explained in part by allowing sub-fertile cows to have more DIM as the animal will probably be culled, maximizing DIM and production potential should be more economical than removing the animals directly (Shalloo *et al*., 2014). Hormonal treatments administered, possibly facilitated an extended lactation period (Ribeiro *et al*., 2010). Cows in the data sets had subsequent calving events, thus the conviction was possibly to maximize milk yield and retain a calf from these cows.

Findings across all three lactations propose that cows with conception challenges had extended lactation periods and as a result higher LMY. The positive correlations (0.66-0.71) between LMY and DIM suggest that as DIM increased, the escalation in LMY was not as drastic compared to the correlation between fertility traits and DIM. The inclination could be explained by a reduced production persistency late in lactation (Haile-Mariam *et al*., 2003), lowering AMY with increased DIM. The physiological pressure from an extended production period and maintaining pregnancy possibly contributed to lower yield late in lactation. A similar relationship was observed from the correlations (0.36-0.64) between fertility traits and LMY as they were lower compared to the correlations between fertility traits and DIM.

Stepwise regression models support the association between fertility traits and production traits, with primary reproduction traits (DO and ICP) and differences across birth years (Addendum C, Table 2C; 3C), explaining most of the variation in LMY across all three lactations in herd B. Uniformity in reproduction traits across lactation two and three possibly explicate why differences across birth years were primary predictor variables in the respective models. The trivial contribution of AFC to variation in model one can be explained by several heifers calving at an older age having more body reserves and producing more milk in the first lactation (Haworth *et al*., 2008). Coefficients of determination (adjusted R^2) indicate that 54.8%, 63% and 68.1% of variation in lactation one, two and three respectively, can be explained by correcting for reproductive performance, differences in birth years and DD. Once more, the uniform management of fertility traits and DIM limited the contribution of these traits to LMY variation. Considering that the data set included Holsteins and mixed cows and that seasonal breeding practices were implemented; the unexplained variation can be attributed to dissimilarity between individual production capacities and seasonal differences.

The data captured from the reports constructed on AfiFarm were insightful, animals removed from data sets based on missing values for traits or values considered unnatural, were negligible for both production systems. The production and reproduction traits calculated from the records documented on AfiFarm, expressed the mean performance, as well as associations between traits accurately, as the maximum number of records were considered for analyses in this study.

5.5 Evaluation of lifetime characteristics and culling reasons

The data available from AfiFarm in herd A clearly indicated that 63.67% of animals were removed as heifers or during the first two lactations, thus only 36.33% of cows that left the herd commenced a third lactation. This clarification is supported as first, and second lactation cows dominated the mature herd during the study period. Lifetime milk yield increased with the lactation number upon exit. Evaluating lifetime yield as a function of the number of days since birth indicates the return from rearing, feeding, breeding and veterinary costs.

Lifetime milk yield is a direct indication of the efficiency of a given animal, representing revenue from the days on the farm (Haworth *et al*., 2008; Kelleher *et al*., 2015). In this study, days on farm was calculated from the day of birth to the date of exit, thus representing true herd life (Ducrocq *et al*., 1998). Lifetime profit as determined by the offset between input costs and milk yield, required a high producing cow that was fertile and healthy (Pérez-Cabal & Alenda *et al*., 2003). Thus, milk yield as a function of days on the farm represented the production capacity of a cow and the ability to avert voluntary and involuntary culling. The parameter increased (P<0.05) from the first lactation but at a lower rate (P>0.05) from the fourth parity onwards. Studies on dairy cows in South Africa (Muller & De Waal, 2016; De Waal *et al*., 2017) and abroad (Shalloo *et al*., 2014) confirmed that cows tend to reach their optimum milk production capability by the fourth lactation, explaining the inclination. Maximising AMY and maintaining lactation persistency enabled producer A to take full advantage of milk yield within the first three lactations.

Motives for removing animals from the herd was evaluated from exit reasons assigned upon removal. Allocating the reason on AfiFarm rests on the operator and human error, therefore probably influencing the data. Communication between the veterinarian or stockman and the program operator could be distort or if the ailment was uncertain, an incorrect alternative could have been assigned. The relatively high percentage of cases assigned as “Cull for other reason” (11.06%; Addendum B, Table 5B) suggest that producer A could have refined recording of departure details.

In this study, findings based on exit reasons remain valuable as the principle motivations for culling heifers and cows were investigated. The proportion of animals culled due to poor production, fertility or mastitis explained 60.52% of exit events in herd A. The increasing percentage of animals culled due to mastitis and reproduction across lactations one and two suggest that high producing cows were challenged with ailments pertaining to fertility and udder infections. Mastitis described an increasing percentage of cows culled past the third parity, indicating that older cows were more exposed to user infections.

High milk yield has become synonymous with the Holstein breed, however, decreasing survivability is a concern (Heins *et al*., 2012). Results suggest that persistent, high AMY was the primary management goal, as the highest proportion of removals (26.46%) were attributed to low production across lactations (Addendum B, Table 5B). This category must be interpreted with caution, the herd manager might record the culling reason as poor production, but the primary reason for culling was hoof problems or subclinical mastitis or sub-acute acidosis for example, which lead to low production. Cows dominating others at the feed bunk could result in some animals not consuming enough feed for high production. This could result in the manager focusing on the wrong aspects to correct.

Data collected from Holstein cows in Iran designated a similar proportion to voluntary culling (27.11%) primarily due to poor production (Ghaderi-Zefrehei *et al.*, 2017). Voluntary culling of sub-optimal producers was a principal reason for decreasing survivability in USA Holsteins (Hare *et al*., 2006b). Removing cows based on low production sanctioned 27.11% of culls in Canadian cattle (Denis-Robichaud *et al*., 2018). Sub-optimum production served as motivation for the highest proportion of first, second and third lactation cows exiting herd A (Addendum B, Table 5B). A large replacement heifer group supplied a constant influx of first lactation cows and supported the emphasis on efficient production within the first three lactations. However, driving high yield in young cows probably predisposed animals to health and fertility constraints (Sawa & Krężel-czopek, 2009). As milk production increases with parity, so does the risk of involuntary culling (Amirpour Najafabadi *et al*., 2016), which was evident in herd A.

Reproduction (16.66% of total removals) and mastitis (17.04% of total removals) complications were the principal motivation for involuntary culling in herd A (Addendum B, Table 5B). Internationally, the percentage of animals involuntarily culled within a category fluctuated between studies, as categories were demarcated by different methods. It was however clear that cows were culled for impaired fertility, mastitis, metabolic disorders, digestive problems, numerous infections, udder conformation, poor locomotion and accidents (Olechnowicz *et al*., 2011; Chiumia *et al*., 2013; Ghaderi-Zefrehei *et al*., 2017; Denis-Robichaud *et al*., 2018). Infertility and mastitis difficulties explained the majority of animals involuntarily culled in the studies mentioned, confirming that optimum reproduction and udder health promoted longevity.

The rising incidence of udder infections across lactations in herd A was in agreement with a study on South African cattle (Dube *et al*., 2008), which reported increasing levels of SCC across the first three lactations. Miciński *et al*. (2009) measured levels of mastitis incidents between lactations one to three (32.62%, 37.37% and 36.78% for lactation one two and three respectively) in German Holstein cows. Mastitis incidents in lactation two and three in the latter study had similar percentages, which is in accordance with cows culled due to mastitis in herd A. A survey on UK dairy cattle found that mastitis cases increased across the first three lactations and accounted for 13.97%, 20.86% and 25.88% of health incidents, the overall percentage across the three parities was 17.40% (Pritchard *et al*., 2013a) which was similar to the 17.04% of mastitis-based culls in herd A (Addendum B, Table 5B). Cows in herd A, exposed to three milking sessions per day and extended days in milk were presumably more vulnerable to udder infections with increasing lactation number, explaining the high proportion of mastitis-based culls in the lactation four and above group.

A study on German Holsteins found the all-inclusive proportion of cows removed due to reproduction to be 20.4% (Heise *et al*., 2016), which is 3.74% higher than herd A but nonetheless comparable. Infertile cows in herd A were primarily culled for anoestrus, poor conception, abortions and dystocia. The proportion of infertile animals culled were high for heifers and cows in the first two lactations. Thereafter it decreased, suggesting that cows culled from lactation three were fertile but were vulnerable to mastitis, metabolic disorders, injury or udder and limb conformation difficulties. Mastitis and infertility often mount up to a culling event, Schneider *et al*. (2007) found that cows with mastitis infections and more DO were at higher risk. The cumulative effect of multiple ailments could thus have contributed to the culling reason assigned. Fertility and udder health challenges probably shadowed high AMY and more DIM in herd A, particularly in the first two lactations.

Cows culled for metabolic and digestive problems, infectious diseases, accidents and poor hoof and udder conformation in herd A ranged between 6.36% and 4.61% of total removals (Addendum B, Table 5B). Ghaderi-Zefrehei *et al.* (2017) observed 6.36% of culls due to feet and legs, 7.82% for metabolic and digestive problems and 23.46% for infectious diseases in Iranian Holstein cattle. The proportion of cows culled for lameness, body conformation, health problems and injury were 3.5% 4.2%, 5.2% and 4.2% respectively, also in Iranian Holsteins (Ansari-Lari *et al*., 2012). German Holsteins with feet and leg problems attributed to 12.2% of culls (Heise *et al*., 2016). The high percentage in the latter study could be attributed to housing systems that don’t permit enough resting time, resulting in cows standing longer, which increases the stress on their feet. Producer A presumembly supressed these categories by providing sufficient bunk-space, monitoring herd health through the AfiMilk system and administering preventative treatments and scheduled vaccination programs. Considering conformation traits, especially udder traits more strongly in future breeding goals, could prolong herd life (Du Toit *et al*., 2012c).

Heifers comprised 22.27% of the animals that were removed from the system (Addendum B, Table 5B). A wrongful cull reason was probably assigned to heifers that were culled due to production

(1.13% of total removals) or mastitis (1.15% of total removals). The cases attributed to production was probably due to infertility. A large fraction of heifers was assigned to either “Missing or Sold” (5.60% of total removals) or “Cull for other reason” (4.72% of total removals). Heifer calves that were transferred to another herd, sold or that died without defining the cause facilitated the high proportion within these categories. Refining the allocation of exit reasons for heifers should increase precision in future analyses. Heifers, with a confirmed cull reason were predominantly infertile or suffered from infectious diseases (mostly Pneumonia), which agrees with literature (Ettema & Santos, 2004; Wathes *et al*., 2008; Ghaderi-Zefrehei *et al.*, 2017). Infertile heifers in the present study were culled primarily for conception difficulties, abortions and dystocia.

Applying sensor-based detection to address animal constraints mentioned is recommended to reduce future involuntary culling levels (Norton & Berckmans *et al*., 2017) in herd A. Activity meters identify heifers and cows experiencing anoestrus or delayed recycling due to possible health and welfare restrictions (Denis-Robichaud *et al*., 2018), allowing managerial intervention to treat and possibly recover animals at risk. Producer A can monitor herd SCC levels by means of the automatic conductivity processes (Kamphuis *et al*., 2010), which could be used to identify, treat and suppress udder infections. Optimal quality and nutritional composition of the ration delivered, together with safe feeding practices can contest metabolic and digestive challenges. It is assumed that producer A enforced these processes, however, refining inputs while continuously removing sub-optimal animals can lower culling rates in the future. Selecting AI sires promoting functional traits could contribute to upholding cow health and welfare.

By confirming an accurate diagnosis of ailments and assigning a correct exit reason for animals culled, precise future tracking of culling patterns will be possible. The process can refine the data received by management to identify and administer pre-emptive treatment and biosecurity measures. Herd numbers, heifer and cow performance, together with health and culling reasons saved on AfiFarm could serve as welfare predictors. Sandgren *et al*. (2009) found that herd welfare can be measured and monitored by documenting multiple fertility and production traits (similar to those in the present study) in combination with herd structure, calf mortalities, culling rate and reasons for culling animals. Combining these measurements assessed herds based on a golden standard, promoting herd health and decreasing involuntary culling levels.

Data recorded on AfiFarm in herd B indicated that heifers and cows in lactation one and two comprised 66.02% of animals that left the herd, consequently only 33.98% of cows survived to initiate a third lactation. These results are supported by the large fraction of lactation one and two cows observed in the herd over the study period. Heifers and young cows were thus most vulnerable to being culled. Cows that completed subsequent lactations had higher lifetime milk yield. As a result, milk yield as a function of days on the farm increased with lactation number ($P<0.05$) but stabilized from lactation four and onwards ($P>0.05$). The disposition is explained by cows generally reaching their optimum milk yield in their fourth lactation (Shalloo *et al*., 2014; Muller & De Waal, 2016; De Waal *et al*., 2017).

Cows that were able to avoid voluntary and involuntary culling were the most profitable, considering the increase in lifetime milk yield. However, in pasture-based systems input costs for veterinarians and inseminations must be maintained at a minimum. Production levels are lower compared to TMR based cows, thus animals in herd B were expected to be fertile and healthy, without the pressure for high AMY.

The motivation for enforcing a high culling rate on heifers and cows in herd B was primarily related to infertility. In herd B reproduction explained 37.07% of total exit reasons followed by mastitis (19.02%) and production (16.85%) (Addendum C, Table 5C). The large fraction of animals culled based on reproduction difficulties clarify the emphasis on a fixed time conception. Animals leaving the herd within the “Cull for other reason” category was only 5.32% of cases, which propose that producer B maintained accurate record of removals from the herd. Heifers contributed the largest fraction to this category, which was mostly animals that died without a documented reason.

As discussed, pasture-based systems necessitate fertile cows to ensure fixed breeding seasons (Berry *et al*., 2013; Kelleher *et al*., 2016) and as a result a high percentage of cows tend to be culled based on infertility (Mayne *et al*., 2002). Infertile cows in herd B were culled primarily due to anoestrus, poor conception, abortions and dystocia, which is similar to previous studies (Mayne *et al*., 2002; Bell *et al*., 2010; Chiumia *et al*., 2013). Studies varied in their methods of measuring exit reasons and assigning categories, however infertility was the principle motive for removing animals from pasture-based systems. A survey on 19 Irish Holstein herds found that 26.8% of cows were culled for infertility, 22.2% as a general management decision (presumably low production) while mastitis accounted for 9.5% of removals (Mayne *et al*., 2002). The primary reasons for removing cows in a Holstein herd from Scotland was infertility (27.4%) and udder difficulties (26.9%) (Chiumia *et al*., 2013). Similar culling patterns were observed in Swedish Holsteins, with 25.9% culled for infertility, 20.65% for poor udder health and 8.8% for production (Ahlman *et al*., 2011). Cows in lactation four and above in herd B had the highest percentage of culls for mastitis, illustrating the strain multiple lactations placed on udder integrity.

In herd B, primiparous cows explicated the largest proportion (24.93%) of cows that left the herd (Addendum C, Table 5C). Studies have found that first lactation cows on pasture were more at risk of being culled, especially for infertility (Frelich *et al*. 2010; Chiumia *et al*., 2013). Primiparous cows have smaller rumen capacity (still growing), which could extend the negative energy balance, resulting in infertility. In addition to infertility (10.91% of total removals), first lactation cows were culled for low milk yield (6.75% of total removals) and mastitis (2.63% of total removals) (Addendum C, Table 5C). The high percentage of first parity cows culled for low AMY could be explained by the fact that cows were still growing and experiencing a possible physiological strain from the first calving event. Cows were nevertheless required to meet minimum production thresholds and were removed if not on par. Low producing first parity cows tend to have low second and third lactation production levels (Haworth *et al*., 2008), supporting the movement towards eliminating these animals from the herd.

By promoting heifer fertility, it certifies that healthy and fertile cows enter the herd (Wathes *et al*., 2008). In the present study, 10.03% of animals removed were infertile heifers (Addendum C, Table 5C), heifer infertility was primarily attributed to poor conception, abortions and calving difficulties. The high fraction of culls based on poor conception was possibly due to producer B implementing a minimum service protocol for heifers. The large replacement heifer group observed, clarifies how producer B could have facilitated high culling rates on heifers not up to standard.

Claw and leg health were essential in a system where cows were required to walk from paddocks to the parlour on a daily basis. The high percentage of animals removed (10.13%) within the “Conformation” category in this study clarifies the emphasis on this trait. Irish Holsteins with locomotor difficulties explained 14.3% of removals (Mayne *et al*., 2002). Scottish Holsteins with claw and leg problems described 12.6% of culls (Chiumia *et al*., 2013). In addition to locomotion, cows culled for poor udder conformation had a primary contribution to culls in herd B, supporting the findings of Du Toit *et al*. (2012c), which postulated that a sound udder promotes longevity. Animals culled for health-related reasons, accidents, metabolic and digestive problems explained between 4.92% and 2.27% of exits in herd B. In studies abroad, these categories were not well described but were in all instances higher than percentages observed in herd B (Mayne *et al*., 2002; Frelich *et al*., 2010; Chiumia *et al*., 2013).

In addition to protocol vaccination programs, multiple automatic sensors measuring daily body weight, milk yield levels, milk conductivity (SCC), and activity levels (long lying bouts) facilitated a healthy herd, especially in grazing cows where visual observation was limited. Real time algorithms set on AfiFarm incorporated measurements and recognized possible ailments based on daily deviations (Norton & Berckmans, 2017). Accurate implementation of AfiMilk should thus have facilitated early managerial intervention, which suppressed culls in the “Health related” and “Metabolic” categories in herd B. Maintaining accurate daily measurements and continuously removing uneconomical or sickly animals should lower the future percentage of culls within all categories. Herd welfare can be evaluated on a routine bases by combining herd structure, milk yield and reproduction performance of heifers and cows together with health-related incidents, culling rates and the proportional distribution of culling reasons (Sandgren *et al*., 2009) documented on AfiFarm.

5.6 Evaluation of AI bulls

The AfiFarm software makes provision for pedigree information (sire and dam records) and in herd A the number of bulls registered on the software with progeny born between 2002 and 2015 was 161 bulls with between 1 and 326 daughters. Only 48 sires had a sufficient number of progeny that completed their first lactation for analyses in the present study. Producers are encouraged to document sire registration numbers to facilitate larger data sets for future analyses.

The simple linear relationships between sire EBVs and daughter performance served to exemplify that the long-term genetic contribution of AI sires corresponded with phenotypic progeny performance. Findings illustrated that the relationship between sire EBVs for milk yield and mean first lactation milk production levels of daughters (R^2=0.5422) was stronger than the relationship between EBVs for ICP and mean ICP of progeny (R^2=0.2073). The higher correlation with milk yield could be explained by the management environment in herd A. The backdrop for optimum expression of milk yield potential was facilitated by feeding specialized rations high in energy and protein, employing three milking sessions per day and promoting longer lactation periods (Sørensen *et al*., 2008; Mellado *et al*., 2011).

Cows in herd A were thus inclined to produce at levels representing their genetic merit. High AMY and LMY levels observed in herd A confirm that cows were genetically predisposed to high milk yield levels. Selection of superior AI sires probably expedited the fixation of high yielding cows in the herd over time. Results in the present study propose that superior sires produced progeny inclined to have higher LMY, despite variation in the number of progeny per bull available for analyses and the effect of a changing management environment on progeny performance.

The EBV's obtained from SADairyBulls for this study were recently estimated with BLUP techniques. The reliability of values representing the genetic merit of bulls should be high, as progeny were available to be evaluated under South African conditions. Thus, breeding values obtained for analyses in this study possibly represented the genetic merit of bulls more accurately. Sires in this study with low genetic merit for milk yield (minimum EBV of -670 kg) suggest that some bulls selected did not transmit superior milk yield genes. The breeding values considered for initial selection of bulls in herd A might not have had negative EBVs for milk yield. Sire EBVs used for selection probably changed as BLUP methodology is refined over time (Van Doormaal & Kistemaker, 2003). The breeding values considered for sire selection by producer A might have been estimated overseas and thus under management and climatic environments that vary from South African conditions.

Production levels of daughters from inferior sires were possibly enhanced by the cumulative effect of superior maternal genes for high milk yield and the management environment, encouraging persistent AMY. Daughters culled due to low production during their first lactation were not included in this study, however, considering the proportion of progeny removed due to low milk yield before commencing a second lactation, could further clarify variation between sires. Future selection accuracy can be increased by considering GEBVs estimated from a reference population representing South African herds.

Animal variables documented on AfiFarm could possibly refine performance measurements of cows participating in genetic evaluation schemes. Routine phenotypic evaluation of progeny performance against sire EBVs could highlight the effect of the AI sire selected in the herd. This methodology could in turn increase the accuracy of selection in systems applying automatic management. The potential of progeny records for genetic evaluation of sires in automatic systems was confirmed by Zwald *et al*. (2005). They found that automatic recorded milking duration data could be applied in genetic evaluation and selection of dairy sires.

Chapter 6: Conclusion and recommendations

Historic phenotypic performance data was successfully extracted from both a TMR and pasture-based system and the methodology established can serve as a template for parameter extraction from similar systems in the future. The AfiMilk system documented herd and cow variables that permitted evaluation of animal performance and management decisions over the study period. Data saved on the AfiFarm herd management software could be extracted with minimal inconvenience to producers. A backup was obtained within minutes to be re-installed for data capture. Reports constructed to recover data were extracted to Microsoft Excel in a format that was practical for editing and analysis.

The linear trend in herd numbers over the study period was facilitated by the heifer herd supplying a constant influx of first parity cows, enabling strict culling regimes of infertile, sickly or sub-optimal milk producing animals between the heifer period and the third lactation. Despite a high culling rate, both herds exhibited an annual increase in numbers and production output, which is expected to continue. The capacity for future increase in herd numbers is facilitated by the AfiMilk system supporting precise management of large herds, but remain subject to limitations in infrastructure, feed costs, pasture availability (producer B) and labour restrictions.

Associations between reproduction and production traits were evident in both systems. Cows in herd A were charactrised by high daily milk yield levels and extended lactation periods. Findings suggest that AI in herd A was delayed beyond the initial negative energy balance to maximise conception rates and to exploit lactation persistency. Producer A exploited lifetime milk yield, as opposed to days on the farm, finding it profitable to have a young herd with extended lactations, as opposed to older cows with less DIM. Seasonal breeding patterns explained the uniform mean fertility traits observed across lactations in herd B. Heifers and cows were expected to be fertile as fixed conception was required for cows to calve down within the seasonal thresholds. Lactation periods in herd B were constant and production levels considered optimal for a pasture-based system in South Africa.

In both systems where most animals were removed before initiating a third lactation, older cows, avoiding voluntary culling due to low milk yield or involuntary culling based on infertility, health problems, metabolic or conformation difficulties, were perceived more economical. The return from lifetime milk yield increased with lactation number, supporting the notion to strive for longevity. Animals were removed from both systems primarily due to low production levels, infertility and mastitis. The proportional distribution of exit reasons illustrated that high milk yield was the primary goal in herd A as opposed to optimum fertility in herd B. Results suggest that producer A was probably inclined to re-inseminate high producing cows, where producer B would not tolerate infertility. Challenges with mastitis, contributed to a large portion of involuntary culling in both systems.

It will be useful to investigate the days in milk when cows were culled for the different reasons. For example, if a high percentage of cows are culled within the first 60 days post-partum, it might indicate poor feeding and management during the transition phase. By refining the reasons for culling animals and considering both the age of animals, together with days in milk when culled, could increase the accuracy of identifying limitations. In addition, sensors that measure rumen pH (rumen health) and body temperature (general health) should be considered by managers. These sensors alert managers and ensure early intervention, reducing culling rates.

Phenotypic performance captured by the AfiMilk system could be applied in evaluating AI sires by comparing progeny performance values with EBVs of bulls. Linear relationships suggest that sires with superior milk yield EBVs produced progeny inclined to have a higher first lactation milk yield. Producers are encouraged to document sire registration numbers to build larger data tables and improve future comparative analyses between the genetic merit of an AI bull and the phenotypic performance of his progeny.

The “large data” at the disposal of producers holds great potential, of which they should be informed. The findings from analyses performed in the present study should be communicated back to producers. Mutual trust between animal scientists and AMS producers can facilitate multiple large herd producers providing access to their data in the future. Researchers can aid producers in tracking performance of the herd as well as cows grouped based on parity, production levels or health status. Benchmark values for multiple economically important production, reproduction and health traits can potentially be established for producers with similar systems i.e. similarities in the geographical location, feeding systems employed, herd size and breeds used. By comparing results, herds that were unable to reach benchmark threshold values for traits measured can be identified.

Multiple specialists could be consulted and limitations in management identified. Production efficiency can be managed, allowing producers to exploit maximum return from production output in an industry exposed to a tight profit margin. Animal health and welfare would be promoted in the process, since unhealthy cows can be identified, the cause established and treatments administered. By measuring and monitoring multiple traits, balanced breeding goals can be established based on the particular requirements of a given producer. The average lactation number in herds can potentially be increased in due course, as cows should be bred and managed in a manner that promotes longevity.

Future research is suggested to include milk composition, milking time, body weight and lactation curve parameters such as peak milk yield and days in milk at peak yield not considered in this study. Data on documented diagnosis and treatments administered is available on AfiFarm, it could be insightful to evaluate disease incidents and medical treatment patterns within production systems and across geographical borders in South Africa. Ailments documented for animals with extended reproduction traits could explain conception challenges.

The present study was the first production analyses in both a TMR and pasture-based automatic management system in South Africa. Results provided insight into the possibilities for extracting data from automatic management software and should serve as a platform for administering future research on documented animal records. A production analyses performed on historic data can provide added value to producers by tracking the performance of animals and management decisions, which can be continuously updated by comparing previous results with findings from present-day data.

References

Abe, H., Masuda, Y. & Suzuki, M., 2009. Relationships between reproductive traits of heifers and cows and yield traits for Holsteins in Japan. J. Dairy Sci. 92, 4055–4062.

Abin, S., Visser, C. & Banga, C.B., 2018. Comparative performance of dairy cows in low-input smallholder and high-input production systems in South Africa. Trop. Anim. Health. Prod.1-6.

AfiMilk., 2000. AfiFarm Basic user manual. Kibbutz, Isreal, S.A.E Afikim.

Ahlman, T., Berglund, B., Rydhmer, L. & Strandberg, E.M., 2011. Culling reasons in organic and conventional dairy herds and genotype by environment interaction for longevity. J. Dairy Sci. 94, 1568–1575.

Allah, E.F., 2015. Genetic and non-genetic analysis for milk production and reproductive traits in Holstein cattle in Egypt. J. Ilmu Ternak dan Vet. 20, 10–17.

Aloulou, R., Brar, S.K., Bouallegue, M. & Ben Hamouda, M., 2010. Phenotypic and genetic parameters of reproductive traits in Tunisian Holstein cows. Biotechnol. Anim. 26, 297–307.

Amirpour Najafabadi, H., Ansari Mahyari, S., Ali Edriss, M. & Strapakova, E., 2016. Genetic analysis of productive life length in Holstein dairy cows using Weibull proportional risk model. Arch. Anim. Breed. 59, 387–393.

Annen, E.L., Collier, R.J., McGuire, M.A. & Vicini, J.L., 2004. Effects of Dry Period Length on Milk Yield and Mammary Epithelial Cells. J. Dairy Sci. 87, 66–76.

Ansari-Lari, M., Mohebbi-Fani, M. & Rowshan-Ghasrodashti, A., 2012. Causes of culling in dairy cows and its relation to age at culling and interval from calving in Shiraz, Southern Iran. Vet. Res. Forum. Int. 3, 233–237.

Atashi, H., Zamiri, M.J., Sayyadnejad, M.B. & Akhlaghi, A., 2012. Trends in the reproductive performance of Holstein dairy cows in Iran. Trop. Anim. Health Prod. 44, 2001–2006.

Auldist, M.J., Pyman, M.F.S., Grainger, C. & Macmillan, K.L., 2007. Comparative Reproductive Performance and Early Lactation Productivity of Jersey × Holstein Cows in Predominantly Holstein Herds in a Pasture-Based Dairying System. J. Dairy Sci. 90, 4856–4862.

Bach, A. & Ahedo, J., 2008. Record Keeping and Economics of Dairy Heifers. Vet. Clin. North Am. - Food Anim. Pract. 24, 117–138.

Banga, C.B., Neser, F.W.C., Van der Westhuizen, J. & Garrick, D.J., 2009. Economic values for dairy production traits under different milk payment systems in South Africa. S. Afr. J. Anim. Sci. 39, 112-115.

Banga, C.B., Neser, F.W.C., Van der Westhuizen, J. & Garrick, D.J., 2010. Economic Value of Live Weight in South African Dairy Cattle. Proc. Tenth World Congress on Genetics Applied to Livestock Production.

Banga, C.B., Neser, F.W.C. & Garrick, D.J., 2014a. The economic value of somatic cell count in South African Holstein and Jersey cattle. S. Afr. J. Anim. Sci. 44, 173-177.

Banga, C.B., Neser, F.W.C. & Garrick, D.J., 2014b. Breeding objectives for Holstein cattle in South Africa. S. Afr. J. Anim. Sci. 44, 199-214.

Banhazi, T.M., Lehr, H., Black, J.L., Crabtree, H., Schofield, P., Tscharke, M. & Berckmans, D., 2012. Precision livestock farming: An international review of scientific and commercial aspects. Int. J. Agric. & Biol. Eng. 5, 1-9.

Bargo, F., Muller, L.D., Delahoy, J.E. & Cassidy, T.W., 2002. Performance of High Producing Dairy Cows with Three Different Feeding Systems Combining Pasture and Total Mixed Rations. J. Dairy Sci. 85, 2948–2963.

Barkema, H.W., von Keyserlingk, M.A.G., Kastelic, J.P., Lam, T.J.G.M., Luby, C., Roy, J.P., LeBlanc, S.J., Keefe, G.P. & Kelton, D.F., 2015. Invited review: Changes in the dairy industry affecting dairy cattle health and welfare. J. Dairy Sci. 98, 7426–7445.

Belflower, J.B., Bernard, J.K., Gattie, D.K., Hancock, D.W., Risse, L.M. & Rotz, C.A., 2012. A case study of the potential environmental impacts of different dairy production systems in Georgia. Agr. Syst. 108, 84-93.

Bell, M.J., Wall, E., Russell, G., Roberts, D.J. & Simm, G., 2010. Risk factors for culling in Holstein-Friesian dairy cows. Vet. Rec. 167, 238–240.

Ben Zaabza, H., Ben Gara, A., Hammami, H., Jemmali, B., Amine Ferchichi, M. & Rekik, B., 2016. Genetic parameters of reproductive traits in Tunisian Holsteins. Arch. Anim. Breed. 59, 209–213

Berry, D.P., Buckley, F., Dillon, P., Evans, R.D., Rath, M. & Veerkamp, R.F., 2003. Genetic relationships among body condition score, body weight, milk yield, and fertility in dairy cows. J. Dairy Sci. 86**,** 2193-2204.

Berry, D.P., Buckley, F., Dillon, P., Evans, R.D. & Veerkamp, R.F., 2004. Genetic relationships among linear type traits, milk yield, body weight, fertility and somatic cell count in primiparous dairy cows. Irish. J. Agr. Food. Res. 43, 161-176.

Berry, D.P. & Cromie, A.R., 2009. Associations between age at first calving and subsequent performance in Irish spring calving Holstein-Friesian dairy cows. Livest. Sci. 123, 44–54.

Berry, D.P., Kearney, J.F., Twomey, K. & Evans, R.D., 2013. Genetics of reproductive performance in seasonal calving dairy cattle production systems. Irish J. Agric. Food Res. 52, 1–16.

Berry, D.P., 2015. Breeding the dairy cow of the future: What do we need?. Anim. Prod. Sci. 55, 823-837.

Berry, D.P., Friggens, N.C., Lucy, M. & Roche, J.R., 2016. Milk Production and Fertility in Cattle. Annu. Rev. Anim. Biosci. 4, 269–290

Beukes, P.C., Gregorini, P., Romera, A.J., Levy, G. & Waghorn, G.C., 2010. Improving production efficiency as a strategy to mitigate greenhouse gas emissions on pastoral dairy farms in New Zealand. Agr. Ecosyst. Environ. 136, 358-365.

Bisinotto, R.S., Ribeiro, E.S. & Santos, J.E.P., 2014. Synchronisation of ovulation for management of reproduction in dairy cows. Animal. 8, 151–159.

Boichard, D. & Brochard, M., 2012. New phenotypes for new breeding goals in dairy cattle. Animal. 6**,** 544-550.

Brotherstone, S. & Goddard, M., 2005. Artificial selection and maintenance of genetic variance in the global dairy cow population. Philosophical Transactions of the Royal Society of London B: Biol. Sci. 360,1479-1488.

Buckley, F., O'sullivan, K., Mee, J.F., Evans, R.D. & Dillon, P., 2003. Relationships among milk yield, body condition, cow weight, and reproduction in spring-calved Holstein-Friesians. J. Dairy Sci. 86**,** 2308-2319.

Byrne, T.J., Santos, B.F.S., Amer, P.R., Martin-Collado, D., Pryce, J.E. & Axford, M., 2016. New breeding objectives and selection indices for the Australian dairy industry. J. Dairy Sci. 99, 8146–8167.

Cabrera, V.E., 2014. Economics of fertility in high-yielding dairy cows on confined TMR systems. Animal. 8, 211–221.

Chang, Y.M., Weigel, K.A. & Fricke, P.M., 2007. Genetic Analysis of the Twenty-One-Day Pregnancy Rate in US Holsteins Using an Ordinal Censored Threshold Model with unknown voluntary waiting period. J. Dairy Sci. 90, 1987–199.

Chiumia, D., Chagunda, M.G.G., MacRae, A.I. & Roberts, D.J., 2013. Predisposing factors for involuntary culling in Holstein-Friesian dairy cows. J. Dairy Res. 80, 45–50.

Clark, C.E.F., Farina, S.R., Garcia, S.C., Islam, M.R., Kerrisk, K.L. & Fulkerson, W.J., 2016. A comparison of conventional and automatic milking system pasture utilization and pre- and post-grazing pasture mass. Grass Forage Sci. 71, 153–159.

Coetzee, K., 2018. Suid-Afrikaanse Melkprodusente speel in die superliga. The Dairy Mail. 25, 10-13.

Cordoba, M.C. & Fricke, P.M., 2002. Initiation of the Breeding Season in a Grazing-Based Dairy by Synchronization of Ovulation. J. Dairy Sci. 85, 1752–1763.

Crowe, M.A., Hostens, M. & Opsomer, G., 2018. Reproductive management in dairy cows - The future. Ir. Vet. J. 71, 1–13.

Cummins, S.B., Lonergan, P., Evans, A.C.O., Berry, D.P., Evans, R.D. & Butler, S.T., 2012. Genetic merit for fertility traits in Holstein cows: I. Production characteristics and reproductive efficiency in a pasture-based system. J. Dairy Sci. 95, 1310–1322.

DAFF., 2017. A profile of the South African Dairy Market value chain. Directorate: Marketing, Department of Agriculture, Forestry and Fisheries, Pretoria.

Dohoo, I.R., Leslie, K., DesCôteaux, L., Fredeen, A., Dowling, P., Preston, A. & Shewfelt, W., 2003. A meta-analysis review of the effects of recombinant bovine somatotropin. 1. Methodology and effects on production. Can. J. Vet. Res. 67, 241–51.

Dejarnette, J.M., Sattler, C.G., Marshall, C.E. & Nebel, R.L., 2007. Voluntary Waiting Period Management Practices in Dairy Herds Participating in a Progeny Test Program. J. Dairy Sci. 90, 1073–1079.

De Ponte Bouwer, P., Mostert, B.E. & Visser, C., 2013. Genetic parameters for production traits and somatic cell score of the SA Dairy Swiss population. S. Afr. J. Anim. Sci. 43, 113-122.

De Rensis, F. & Scaramuzzi, R.J., 2003. Heat stress and seasonal effects on reproduction in the dairy cow—a review. Theriogenology. 60, 1139-1151.

De Vries, A. & Risco, C.A., 2005. Trends and Seasonality of Reproductive Performance in Florida and Georgia Dairy Herds from 1976 to 2002. J. Dairy Sci. 88, 3155–3165.

De Vries, A., 2017. Economic trade-offs between genetic improvement and longevity in dairy cattle. J. Dairy Sci. 100, 4184–4192.

De Waal, H.L., Muller, C.J.C., van der Rijst, M. & Scholtz, M.M., 2017. Productive lifetime and lifetime efficiency in Holstein cows as affected by non-genetic factors. In: Proc. Of the 50th Annual SASAS Congress, Port Elizabeth, 18-20 September 2017.

Denis-Robichaud, J., Cerri, R.L.A., Jones-Bitton, A. & LeBlanc, S.J., 2018. Dairy producers' attitudes toward reproductive management and performance on Canadian dairy farms. J. Dairy Sci. 101, 850–860.

Diepersloot, E.J., 2011. The use of technology for improved cow health to increase production and reproduction. In Proceedings of 47th Florida Dairy Production Conference, 30-34.

Dobson, H., Walker, S.L., Morris, M.J., Routly, J.E. & Smith, R.F., 2008. Why is it getting more difficult to successfully artificially inseminate dairy cows? Animal. 2, 1104–1111.

Dochi, O., Kabeya, S. & Koyama, H., 2010. Factors affecting reproductive performance in high milk-producing Holstein cows. J. Reprod. Dev. 56, 61-5.

Dodzi, M.S. & Muchenje, V., 2011. Avoidance-related behavioural variables and their relationship to milk yield in pasture-based dairy cows. Appl. Anim. Behav. Sci. 133, 11-17.

Dohoo, I.R., Leslie, K., DesCôteaux, L., Fredeen, A., Dowling, P., Preston, A. & Shewfelt, W., 2003. A meta-analysis review of the effects of recombinant bovine somatotropin. 1. Methodology and effects on production. Can. J. Vet. Res. 67, 241–51.

Douphrate, D.I., Hagevoort, G.R., Nonnenmann, M.W., Lunner Kolstrup, C., Reynolds, S.J., Jakob, M. & Kinsel, M., 2013. The dairy industry: A brief description of production practices, trends, and farm characteristics around the world. J. Agromedicine. 18, 187-197.

Ducrocq, V., Quaas, R.L., Pollak, E.J. & Casella, G., 1998. Length of productive life of dairy cows. Justification of a Weibull Model. J. Dairy Sci., 71, 61–70.

Du Toit, J., Van Wyk, J.B. & Maiwashe, A., 2009. Genetic parameter estimates for functional herd life for the South African Jersey breed using a multiple trait linear model. S. Afr. J. Anim. Sci. 39, 40-44.

Du Toit, J., Van Wyk, J.B. & Maiwashe, A., 2012a. Assessment of inbreeding depression for functional herd life in the South African Jersey breed based on level and rate of inbreeding. S. Afr. J. Anim. Sci. 42, 55-62.

Du Toit, J., Van Wyk, J.B. & Maiwashe, A., 2012b. Correlated response in longevity from direct selection for production in the South African Jersey breed. S. Afr. J. Anim. Sci. 42, 38-46.

Du Toit, J., Van Wyk, J.B. & Maiwashe, A., 2012c. Relationships between functional herd life and conformation traits in the South African Jersey breed. S. Afr. J. Anim. Sci. 42, 47–54.

Dube, B., Dzama, K. & Banga, C.B., 2008. Genetic analysis of somatic cell score and udder type traits in South African Holstein cows. S. Afr. J. Anim. Sci. 38, 1–11.

Egger-Danner, C., Cole, J.B., Pryce, J.E., Gengler, N., Heringstad, B., Bradley, A. & Stock, K.F., 2015. Invited review: Overview of new traits and phenotyping strategies in dairy cattle with a focus on functional traits. Animal. 9, 191–207.

Elahi Torshizi, M., 2016. Effects of season and age at first calving on genetic and phenotypic characteristics of lactation curve parameters in Holstein cows. J. Anim. Sci. Technol. 58, 8.

El-Tarabany, M.S., 2015. Effects of non-lactating period length on the subsequent calving ease and reproductive performance of Holstein, Brown Swiss and the crosses. Anim. Reprod. Sci. 158, 60–67.

Ettema, J.F. & Santos, J.E.P., 2004. Impact of Age at Calving on Lactation, Reproduction, Health, and Income in First-Parity Holsteins on Commercial Farms. J. Dairy Sci. 87, 2730–2742.

FAO., 2006. Livestock's long shadow.

Fouché, N., 2010. Milk SA support participation in the National Milk Recording Scheme. National Milk Recording and Improvement Scheme Newsletter Nº15: November. p 5.

Frelich, J., Šlachta, M. & Kobes, M., 2010. Reasons for the culling of dairy cows on low-input mountain farms. J. Agrobiol. 27, 41–48.

Galvão, K.N. & Santos, J.E.P., 2010. Factors affecting synchronization and conception rate after the ovsynch protocol in lactating Holstein cows. Reprod. Domest. Anim. 45, 439–446.

Gay, K.D., Widmar, N.J.O., Nennich, T.D., Schinckel, A.P., Cole, J.B. & Schutz, M.M., 2014. Development of a Lifetime Merit-based selection index for US dairy grazing systems. J. Dairy Sci. 97, 4568–4578.

Ghaderi-Zefrehei, M., Rabbanikhah, E., Baneh, H., Peters, S.O. & Imumorin, I.G., 2017. Analysis of culling records and estimation of genetic parameters for longevity and some production traits in holstein dairy cattle. J. Appl. Anim. Res. 45, 524–528.

Ghiasi, H., Pakdel, A., Nejati-Javaremi, A., Mehrabani-Yeganeh, H., Honarvar, M., González-Recio, O., Carabaño, M.J. & Alenda, R., 2011. Genetic variance components for female fertility in Iranian Holstein cows. Livest. Sci. 139, 277–280.

González-Recio, O., de Maturana, E.L. & Gutiérrez, J.P., 2007. Inbreeding depression on female fertility and calving ease in Spanish dairy cattle. J. Dairy Sci. 90, 5744-5752.

Gray, L., 2014. Alpro, The dairy pro. The Dairy Mail. 21, 88-93.

Haile-Mariam, M., Bowman, P.J. & Goddard, M.E., 2003. Genetic and environmental relationship among calving interval, survival, persistency of milk yield and somatic cell count in dairy cattle. Livest. Prod. Sci. 80, 189–200.

Haskell, M.J., Rennie, L.J., Bowell, V.A., Bell, M.J. & Lawrence, A.B., 2006. Housing system, milk production, and zero-grazing effects on lameness and leg injury in dairy cows. J. Dairy Sci. 89, 4259-4266.

Hammoud, M.H., El-Zarkouny, S.Z. & Oudah, E.Z.M., 2010. Effect of sire, age at first calving, season and year of calving and parity on reproductive performance of Friesian cows under semiarid conditions in Egypt. Archiva Zootechnica. 13, 60-82.

Hare, E., Norman, H.D. & Wright, J.R., 2006a. Trends in calving ages and calving intervals for dairy cattle breeds in the United States. J. Dairy Sci. 89, 365-370.

Hare, E., Norman, H.D. & Wright, J.R., 2006b. Survival Rates and Productive Herd Life of Dairy Cattle in the United States. J. Dairy Sci. 89, 3713–3720.

Haworth, G.M., Tranter, W.P., Chuck, J.N., Cheng, Z. & Wathes, D.C., 2008. Relationships between age at first calving and first lactation milk yield, and lifetime productivity and longevity in dairy cows. Vet. Rec. 162, 643–647.

Heins, B.J., Hansen, L.B. & De Vries, A., 2012. Survival, lifetime production, and profitability of Normande × Holstein, Montbéliarde × Holstein, and Scandinavian Red × Holstein crossbreds versus pure Holsteins. J. Dairy Sci. 95, 1011–1021.

Heise, J., Liu, Z., Stock, K.F., Rensing, S. & Reinhardt, F., 2016. The genetic structure of longevity in dairy cows. J. Dairy Sci. 99, 1253–1265.

Heise, J., Stock, K.F., Reinhardt, F., Ha, N.T. & Simianer, H., 2018. Phenotypic and genetic relationships between age at first calving, its component traits, and survival of heifers up to second calving. J. Dairy Sci. 101, 425–432.

Heringstad, B., Klemetsdal, G. & Steine, T., 2003a. Selection responses for clinical mastitis and protein yield in two Norwegian dairy cattle selection experiments. J. Dairy Sci. 86, 2990-2999.

Heringstad, B., Rekaya, R., Gianola, D., Klemetsdal, G. & Weigel, K.A., 2003b. Genetic change for clinical mastitis in Norwegian cattle: A threshold model analysis. J. Dairy Sci. 86, 369-375.

Hörtenhuber, S., Lindenthal, T., Amon, B., Markut, T., Kirner, L. & Zollitsch, W., 2010. Greenhouse gas emissions from selected Austrian dairy production systems—model calculations considering the effects of land use change. Renew. Agr. Food. Syst. 25, 316-329.

Hossein-zadeh, N.G., 2011. Estimation of genetic and phenotypic relationships between age at first calving and productive performance in Iranian Holsteins. Trop. Anim. Health. Prod. 43, 967–973.

Imbayarwo-Chikosi, V.E., Dzama, K., Halimani, T.E., Van Wyk, J.B., Maiwashe, A. & Banga, C.B., 2015. Genetic prediction models and heritability estimates for functional longevity in dairy cattle. S. Afr. J. Anim. Sci. 45, 106-121.

ICAR., 2016. Yearly survey on the situation of MILK RECORDING SYSTEMS (Years 2014 and 2015) in ICAR member countries for cow, sheep and goats.

InCalf Farm case studies., 2017. Dairy Australia.

Inchaisri, C., Hogeveen, H., Vos, P.L.A.M., van der Weijden, G.C. & Jorritsma, R., 2010. Effect of milk yield characteristics, breed, and parity on success of the first insemination in Dutch dairy cows. J. Dairy Sci. 93, 5179–5187.

Inchaisri, C., Jorritsma, R., Vernooij, J.C.M., Vos, P.L.A.M., van der Weijden, G.C. & Hogeveen, H., 2011. Cow effects and estimation of success of first and following inseminations in Dutch dairy cows. Reprod. Domest. Anim. 46, 1043–1049.

Jensen, J., 2001. Genetic evaluation of dairy cattle using test-day models. J. Dairy Sci. 84, 2803-2812.

Joubert, R., 2018. DGP update. The Dairy Mail. 25, 77-79.

Kahi, A.K. & Nitter, G., 2004. Developing breeding schemes for pasture based dairy production systems in Kenya. I. Derivation of economic values using profit functions. Livest. Prod. Sci. 88, 161-177.

Kamphuis, C., Mollenhorst, H., Heesterbeek, J.A.P. & Hogeveen, H., 2010. Detection of clinical mastitis with sensor data from automatic milking systems is improved by using decision-tree induction. J. Dairy Sci. 93, 3616–3627.

Kargo, M., Hjortø, L., Toivonen, M., Eriksson, J.A., Aamand, G.P. & Pedersen, J., 2014. Economic basis for the Nordic Total Merit Index. J. Dairy Sci. 97, 7879–7888.

Keeper, D.M., Kerrisk, K.L., House, J.K., Garcia, S.C. & Thomson, P., 2017. Demographics, farm and reproductive management strategies used in Australian automatic milking systems compared with regionally proximal conventional milking systems. Aust. Vet. J. 95, 325–332.

Kellogg, D.W., Pennington, J.A., Johnson, Z.B. & Panivivat, R., 2001. Survey of Management Practices Used for the Highest Producing DHI Herds in the United States. J. Dairy Sci. 84, 120–127.

Kelleher, M.M., Amer, P.R., Shalloo, L., Evans, R.D., Byrne, T.J., Buckley, F. & Berry, D.P., 2015. Development of an index to rank dairy females on expected lifetime profit. J. Dairy Sci. 98, 4225–4239.

Kelleher, M.M., Buckley, F., Evans, R.D. & Berry, D.P., 2016. Additive genetic, non-additive genetic and permanent environmental effects for female reproductive performance in seasonal calving dairy females. Irish J. Agric. Food Res. 55, 10–23.

Klungland, H., Sabry, A., Heringstad, B., Olsen, H.G., Gomez-Raya, L., Våge, D.I., Olsaker, I., Ødegård, J., Klemetsdal, G., Schulman, N. & Vilkki, J., 2001. Quantitative trait loci affecting clinical mastitis and somatic cell count in dairy cattle. Mamm. Genome. 12, 837-842.

Koeck, A., Miglior, F., Kelton, D.F. & Schenkel, F.S., 2012. Alternative somatic cell count traits to improve mastitis resistance in Canadian Holsteins. J. Dairy Sci. 95, 432–439.

Kolmodin, R., Strandberg, E., Madsen, P., Jensen, J. & Jorjani, H., 2002. Genotype by environment interaction in Nordic dairy cattle studied using reaction norms. Acta. Agr. Scand. A-An. 52, 11-24.

Kolver, E.S., Roche, J.R., Burke, C.R., Kay, J.K. & Aspin, P.W., 2007. Extending Lactation in Pasture-Based Dairy Cows: I. Genotype and Diet Effect on Milk and Reproduction. J. Dairy Sci. 90, 5518–5530.

Kuhn, M.T., Hutchison, J.L. & Norman, H.D., 2005. Characterization of days dry in US Holsteins. J. Dairy Sci. 88, 1147–1155.

Kuhn, M.T., Hutchison, J.L. & Norman, H.D., 2006a. Dry period length to maximize production across adjacent lactations and lifetime production. J. Dairy Sci. 89, 1713–22.

Kuhn, M.T., Hutchison, J.L. & Wiggans, G.R. 2006b. Characterization of Holstein Heifer Fertility in the United States. J. Dairy Sci. 89, 4907–4920.

Lassen, B., 2012. Dairy production in South Africa. Agri. Benchmark 2, 730.

LeBlanc, S., 2010. Assessing the association of the level of milk production with reproductive performance in dairy cattle. J. Reprod. Dev. 56, 1–7.

Lehmann, J.O., Fadel, J.G., Mogensen, L., Kristensen, T., Gaillard, C. & Kebreab, E., 2016. Effect of calving interval and parity on milk yield per feeding day in Danish commercial dairy herds. J. Dairy Sci. 99, 621–633.

Logix Milk Annual Report., 2015/16, SA Stud Book.

Lopez, H., Satter, L.D. & Wiltbank, M.C., 2004. Relationship between level of milk production and estrous behavior of lactating dairy cows. Anim. Reprod. Sci. 81, 209–223.

López-Gatius, F., 2012. Factors of a noninfectious nature affecting fertility after artificial insemination in lactating dairy cows. A review. Theriogenology. 77, 1029–1041.

Lucy, M.C., 2001. Reproductive loss in high-producing dairy cattle: where will it end? J. Dairy Sci. 84, 1277-1293.

Lyons, N.A., Kerrisk, K.L. & Garcia, S.C., 2013. Comparison of 2 systems of pasture allocation on milking intervals and total daily milk yield of dairy cows in a pasture-based automatic milking system. J. Dairy Sci. 96, 4494-4504.

Macdonald, K.A., Penno, J.W., Lancaster, J.A.S. & Roche, J.R., 2008. Effect of stocking rate on pasture production, milk production, and reproduction of dairy cows in pasture-based systems. J. Dairy Sci. 91, 2151-2163.

Maciel, G.M., Poulsen, N.A., Larsen, M.K., Kidmose, U., Gaillard, C., Sehested, J. & Larsen, L.B., 2016. Good sensory quality and cheesemaking properties in milk from Holstein cows managed for an 18-month calving interval. J. Dairy Sci. 99, 8524–8536.

Maiwashe, A., Nephawe, K.A., Van der Westhuizen, R.R., Mostert, B.E. & Theron, H.E., 2006. Rate of inbreeding and effective population size in four major South African dairy cattle breeds. S. Afr. J. Anim. Sci. 36, 50-57.

Maiwashe, A., Nephawe, K.A. & Theron, H.E., 2008. Estimates of genetic parameters and effect of inbreeding on milk yield and composition in South African Jersey cows. S. Afr. J. Anim. Sci. 38, 119-125.

Makgahlela, M.L., Banga, C.B., Norris, D., Dzama, K. & Ng'ambi, J.W., 2007. Genetic correlations between female fertility and production traits in South African Holstein cattle. S. Afr. J. Anim. Sci. 37, 180-188.

Makgahlela, M.L., Mostert, B.E. & Banga, C.B., 2009. Genetic relationships between calving interval and linear type traits in South African Holstein and Jersey cattle. S. Afr. J. Anim. Sci. 39, 90-92.

Mayne, C.S., Mackey, D.R., Verner, M., McCaughey, W.J., Gordon, F. J., McCoy, M.A., Lennox, S.D., Catney, D.C., Wylie, A.R.G. & Kennedy, B.W., 2002. Fertility of dairy cows in Northern Ireland. Vet Rec. 150, 707–713.

Mccullock, K., Hoag, D.L.K., Parsons, J., Lacy, M., Jr, G.E.S. & Wailes, W., 2013. Factors affecting economics of using sexed semen in dairy cattle. J. Dairy Sci. 96, 6366–6377.

Mee, J.F., 2012. Reproductive Issues Arising from Different Management Systems in the Dairy Industry. Reprod. Domest. Anim. 47, 42–50.

Meissner, H.H., Scholtz, M.M. & Palmer, A.R., 2013. Sustainability of the South African livestock sector towards 2050 Part 1: Worth and impact of the sector. South African J. Anim. Sci. 43, 282–297.

Mellado, M., Antonio-Chirino, E., Meza-Herrera, C., Veliz, F.G., Arevalo, J.R., Mellado, J. & de Santiago, A., 2011. Effect of lactation number, year, and season of initiation of lactation on milk yield of cows hormonally induced into lactation and treated with recombinant bovine somatotropin. J. Dairy Sci. 94, 4524–4530.

Miciński, J., Pogorzelska, J., Barański, W. & Kalicka, B., 2009. Effect of disease incidence on the milk performance of high-yielding cows in successive lactations. Polish J. Nat. Sci. 24, 102–112.

Miciński, J., Zwierzchowski, G., Barański, W., Gołębiowska, M. & Maršálek, M., 2010. Locomotor activity and daily milk yield of dairy cows during the perioestrous period in successive lactations. J. Agrobiol. 27, 111–119.

Miglior, F., Muir, B.L. & Van Doormaal, B.J., 2005. Selection Indices in Holstein Cattle of Various Countries. J. Dairy Sci. 88, 1255–1263.

Milk SA., 2018. Statistics, LACTO DATA, Vol. 21, May 2018, a Milk SA publication compiled by the MPO, Pretoria.

Miller, R.H., Norman, H.D., Kuhn, M.T., Clay, J.S. & Hutchison, J.L., 2007. Voluntary Waiting Period and Adoption of Synchronized Breeding in Dairy Herd Improvement Herds. J. Dairy Sci. 90, 1594–1606.

MPO., 2017. Report on a survey conducted during October and November 2016 in respect of information supplied by milk producers in terms of the requirements as published in Regulation 42 and 46 of 22 January 2016 in terms of the Marketing of Agricultural Products Act, 1996, Act No. 47 of 1996.

Mohammadi, G.R. & Sedighi, A., 2009. Reasons for culling of Holstein dairy cows in Neishaboor area in northeastern Iran. Iran. J. Vet. Res. 10, 278–282.

Mostert, B.E., Banga, C.B., Groeneveld, E. & Kanfer, F.H.J., 2004a. Breeding value estimation for somatic cell score in South African dairy cattle. S. Afr. J. Anim. Sci. 34, 32-34.

Mostert, B.E., Groeneveld, E. & Kanfer, F.H.J., 2004b. Testday models for production traits in dairy cattle. S. Afr. J. Anim. Sci. 34, 35-37.

Mostert, B.E., Theron, H.E., Kanfer, F.H.J. & Van Marle-Köster, E., 2006. Test-day models for South African dairy cattle for participation in international evaluations. S. Afr. J. Anim. Sci. 36, 58-70.

Mostert, B.E., Van der Westhuizen, R.R. & Theron, H.E., 2008. Procedures for estimation of genetic persistency indices for milk production for the South African dairy industry. S. Afr. J. Anim. Sci. 38, 224-230.

Mostert, B.E., Van der Westhuizen, R.R. & Theron, H.E., 2010. Calving interval genetic parameters and trends for dairy breeds in South Africa. S. Afr. J. Anim. Sci. 40, 156-162.

Mulder, H.A., Veerkamp, R.F., Ducro, B.J., Van Arendonk, J.A.M. & Bijma, P., 2006. Optimization of dairy cattle breeding programs for different environments with genotype by environment interaction. J. Dairy Sci. 89, 1740-1752.

Muller, C.J.C., Botha, J.A. & Smith, W.A., 1994. Effect of shade on various parameters of Friesian cows in a Mediterranean climate in South Africa 1. Feed and water intake, milk production and milk composition. S. Afr. J. Anim. Sci. 24, 49-49.

Muller, C.J.C., Du Toit, F.J., Singhapol, C. & Botha, J.A., 2000. The effect of milk yield on some reproductive parameters of the Elsenburg Holstein and Jersey herds. S. Afr. J. Anim. Sci. 30, 34–35.

Muller, C.J.C., Potgieter, J.P., Cloete, S.W.P. & Botha, J.A., 2013. Reproductive performance of Holstein and Fleckvieh x Holstein heifers and cows in a total mixed ration feeding system. Proc. Assoc. Advmt. Anim. Breed. Genet. 20, 439-443.

Muller, C.J.C., Potgieter, J.P., Cloete, S.W.P. & Dzama, K., 2014. Non-genetic factors affecting fertility traits in South African Holstein cows. S. Afr. J. Anim. Sci. 44, 54-63.

Muller, C.J.C., Potgieter, J.P., Cloete, S.W.P. & Botha, J.A., 2015. Reproductive performance of Holstein and Jersey heifers and cows in a pasture-based system in South Africa. Proc. Assoc. Advmt. Breed. Genet. 21, 290-293.

Muller, C.J.C. & de Waal, H.L., 2016. The effect of herd structure on the performance of dairy herds. ARC News Letter Article, Western Cape.

Muuttoranta, K., 2015. Genetic parameters for female fertility in Nordic dairy cattle. Proc. 2015 Interbull Meet. 49, 32–35.

Nayeri, S., Sargolzaei, M., Abo-Ismail, M.K., May, N., Miller, S.P., Schenkel, F., Moore, S.S. & Stothard, P., 2016. Genome-wide association for milk production and female fertility traits in Canadian dairy Holstein cattle. BMC Genet. 17, 1–11.

Nayeri, S., Sargolzaei, M., Abo-Ismail, M.K., Miller, S., Schenkel, F., Moore, S.S. & Stothard, P., 2017. Genome-wide association study for lactation persistency, female fertility, longevity, and lifetime profit index traits in Holstein dairy cattle. J. Dairy Sci. 100, 1246–1258.

Nebel, R.L., Dransfield, M.G., Jobst, S.M. & Bame, J.H., 2000. Automated electronic systems for the detection of oestrus and timing of AI in cattle. Anim. Reprod. Sci. 60–61, 713–723.

Neerhof, H.J., Madsen, P., Ducrocq, V.P., Vollema, A.R., Jensen, J. & Korsgaard, I. R., 2000. Relationship between mastitis and functional longevity in Danish Black and White dairy cattle estimated using survival analysis. J. Dairy Sci. 83, 1064–1071.

Němečková, D., Stádník, L. & Čítek, J., 2015. Associations between milk production level, calving interval length, lactation curve parameters and economic results in Holstein cows. MLJEKARSTVO. 65, 243–250.

Neser, F.W.C., Van Wyk, J.B. & Ducrocq, V., 2014. A preliminary investigation into genotype x environment interaction in South African Holstein cattle for reproduction and production traits. S. Afr. J. Anim. Sci. 44, 75-79.

Nir, O., 2010. Achieving Optimal Cow Performance with the Aid of Information Systems. Proc. High Plains Dairy Conference. Amarillo, Texas.

Nogalski, Z. & Piwczyński, D., 2012. Association of length of pregnancy with other reproductive traits in dairy cattle. Asian-Australas. J. Anim. Sci, 25, 22.

Norton, T. & Berckmans, D., 2017. Developing precision livestock farming tools for precision dairy farming. Anim. Front. 7, 18-23.

Odongo, N.E., Bagg, R., Vessie, G., Dick, P., Or-Rashid, M.M., Hook, S.E., Gray, J.T., Kebreab, E., France, J. & McBride, B.W., 2007. Long-term effects of feeding monensin on methane production in lactating dairy cows. J. Dairy Sci. 90, 1781-1788.

Olechnowicz, J. & Jaskowski, J.M., 2011. Reasons for culling, culling due to lameness, and economic losses in dairy cows. Med. Weter. 67, 618–621.

Oltenacu, P.A. & Algers, B., 2005. Selection for Increased Production and the Welfare of Dairy Cows: Are New Breeding Goals Needed? AMBIO A J. Hum. Environ. 34, 311–315.

Oltenacu, P.A. & Broom, D.M., 2010. The impact of genetic selection for increased milk yield on the welfare of dairy cows. Anim. Welfare. 19, 39-49.

Osman, M.M., El-bayomi, K.M. & Moawed, S.A., 2013. Genetic trends for production and reproduction traits of Holstein-Friesian dairy cattle using sire model. SCVMJ. 18, 115–128.

Payne, R.W. © 2015 (Ed.). Introduction to GenStat® for Windows™ 18th Edition Introduction. VSN International, UK.

Pérez-Cabal, M.A. & Alenda, R., 2003. Lifetime profit as an individual trait and prediction of its breeding values in Spanish Holstein cows. J. Dairy Sci. 86, 4115-4122.

Pinedo, P.J., De Vries, A. & Webb, D.W., 2010. Dynamics of culling risk with disposal codes reported by Dairy Herd Improvement dairy herds. J. Dairy Sci. 93, 2250–2261.

Potgieter, J.P., Muller, C.J.C., Cloete, S.W.P., Zishiri, O.T. & Dzama, K., 2011. Exploring fertility traits other than calving interval for inclusion in a national genetic evaluation for South African Holstein cows. In Proc. Assoc. Advmt. Anim. Breed. Genet. 19, 482-485.

Pritchard, T., Coffey, M., Mrode, R. & Wall, E., 2013a. Genetic parameters for production, health, fertility and longevity traits in dairy cows. Animal. 7, 34–46.

Pritchard, T., Coffey, M., Mrode, R. & Wall, E., 2013b. Understanding the genetics of survival in dairy cows. J. Dairy Sci. 96, 3296–3309.

Pryce, J.E., Veerkamp, R.F., Thompson, R., Hill, W.G. & Simm, G., 1997. Genetic aspects of common health disorders and measures of fertility in Holstein Friesian Dairy cattle. Anim. Sci. 65, 353-360.

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

Pryce, J.E., Royal, M.D., Garnsworthy, P.C. & Mao, I.L., 2004. Fertility in the high-producing dairy cow. Livest. Prod. Sci. 86, 125-135.

Ptak, E., Jagusiak, W., Zarnecki, A. & Otwinowska-Mindur, A., 2011. Heritabilities and genetic correlations of lactational and daily somatic cell score with conformation traits in Polish Holstein cattle. Czech J. Anim. Sci. 56, 205–212.

Ramatsoma, N.I., Banga, C.B., MacNeil, M.D. & Maiwashe, A., 2014. Evaluation of genetic trends for traits of economic importance in South African Holstein cattle. S. Afr. J. Anim. Sci. 44, 85-89.

Randolph, T.F., Schelling, E., Grace, D., Nicholson, C.F., Leroy, J.L., Cole, D.C., Demment, M.W., Omore, A., Zinsstag, J. & Ruel, M., 2007. Invited Review: Role of livestock in human nutrition and health for poverty reduction in developing countries. J. Anim. Sci. 85, 2788–2800.

Ribeiro, P., Freitas, C., Coelho, S.G., Rabelo, E., Maria, Â., Lana, Q., Alexandra, M., Artunduaga, T., Saturnino, H. M. & Freitas., 2010. Artificial induction of lactation in cattle. Rev. Bras. Zootec. 39, 2268–2272.

Riecka, Z. & Candrák, J., 2011. Analysis of Relationship between Production and Reproduction Traits of Holstein Cattle Population in the Slovak Republic. J Anim Sci Biotechnol. 44, 332–336.

Roche, J.R., Dillon, P.G., Stockdale, C.R., Baumgard, L.H. & VanBaale, M.J., 2004. Relationships among international body condition scoring systems. J. Dairy Sci. 87, 3076-3079.

Roche, J.R., Berry, D.P. & Kolver, E.S., 2006. Holstein-Friesian strain and feed effects on milk production, body weight, and body condition score profiles in grazing dairy cows. J. Dairy Sci. 89, 3532-3543.

Rodenburg, J., 2017. Robotic milking: Technology, farm design, and effects on work flow. J. Dairy Sci. 100, 7729–7738.

Rutherford, M., Mucina, L. & Powrie, L., 2006. Chapter 3: Biomes and bioregions of southern Africa. Veg. South Africa Lesotho Sawzil., 31–51.

Saint-Dizier, M. & Chastant-Maillard, S., 2012. Towards an Automated Detection of Oestrus in Dairy Cattle. Reprod. Domest. Anim. 47, 1056–1061.

Sandgren, C.H., Lindberg, A. & Keeling, L.J., 2009. Using a national dairy database to identify herds with poor welfare. Anim. Welf. 18, 523–532.

Sawa, A. & Krężel-czopek, S., 2009. Effect of first lactation milk yield on efficiency of cows in herds with different production levels. Archiv. Tierzucht. 52, 7–14.

Sawa, A., Kręzel-Czopek, S. & Bogucki, M., 2015. Dry period length as related to milk yield and SCC during the first month of subsequent lactation. Ann. Anim. Sci. 15, 155–163.

Schaeffer, L.R., 2006. Strategy for applying genome-wide selection in dairy cattle. J. Anim. Breed. Genet. 123, 218-223.

Schneider, M. del P., Strandberg, E., Emanuelson, U., Grandinson, K. & Roth, A., 2007. The effect of veterinary-treated clinical mastitis and pregnancy status on culling in Swedish dairy cows. Prev. Vet. Med. 80, 179–192.

Scholtz, M.M. & Grobler, S.M., 2009. A systems approach to the South African dairy industry. S. Afr. J. Anim. Sci. 39, 121-125.

Scholtz, M.M., Van Ryssen, J., Meissner, H. & Laker, M., 2013. A South African perspective on livestock production in relation to greenhouse gases and water usage. S. Afr. J. Anim. Sci. 43, 247-254.

Scholtz, M.M., Du Toit, J. & Neser, F.W.C., 2014. Antagonism in the carbon footprint between beef and dairy production systems. S. Afr. J. Anim. Sci. 44, 17-20.

Sewalem, A., Kistemaker, G.J., Miglior, F. & Van Doormaal, B.J., 2006a. Analysis of inbreeding and its relationship with functional longevity in Canadian dairy cattle. J. Dairy Sci. 89, 2210-2216.

Sewalem, A., Miglior, F., Kistemaker, G.J. & Van Doormaal, B.J., 2006b. Analysis of the relationship between somatic cell score and functional longevity in Canadian dairy cattle. J. Dairy Sci. 89, 3609-3614.

Sewalem, A., Miglior, F., Kistemaker, G.J., Sullivan, P. & Van Doormaal, B.J., 2008. Relationship between reproduction traits and functional longevity in Canadian dairy cattle. J. Dairy Sci. 91, 1660-1668.

Shalloo, L., Cromie, A. & McHugh, N., 2014. Effect of fertility on the economics of pasture-based dairy systems. Animal. 8, 222–231.

Singh, S., Ghosh, S., Lakhani, G.P., Jain, A. & Roy, B., 2014. Precision Dairy Farming: The Next Dairy Marvel. J. Veterinar. Sci. Technolo. 5, 164-166.

Smith, J., Sones, K., Grace, D., MacMillan, S., Tarawali, S. & Herrero, M., 2013. Beyond milk, meat, and eggs: Role of livestock in food and nutrition security. Anim. Front. 3, 6–13.

Snedecor, G.W. & Cochran, W.G., 1980. Statistical methods (7th Ed.). Iowa State University Press, 234.

Sölkner, J., Grausgruber, H., Okeyo, A.M., Ruckenbauer, P. & Wurzinger, M., 2008. Breeding objectives and the relative importance of traits in plant and animal breeding: a comparative review. Euphytica. 161, 273-282.

Sørensen, A.C., Sørensen, M.K. & Berg, P., 2005. Inbreeding in Danish dairy cattle breeds. J. Dairy Sci. 88, 1865-1872.

Sørensen, A., Muir, D.D. & Knight. C.H., 2008. Extended lactation in dairy cows: effects of milking frequency, calving season and nutrition on lactation persistency and milk quality. J. Dairy Res. 75, 90–97.

Stádník, L., Louda, F. & Ježková, A., 2002. The effect of selected factors at insemination on reproduction of Holstein cows. Czech J. Anim. Sci. 47, 169–175.

Steeneveld, W., Schukken, Y.H., van Knegsel, A.T.M. & Hogeveen, H., 2013. Effect of different dry period lengths on milk production and somatic cell count in subsequent lactations in commercial Dutch dairy herds. J. Dairy Sci. 96, 2988–3001.

Steward, P.G., 2010. Dairy Herd Structure / Dairy Herd Dynamics. Cedara Agricultural Development Institute.

Theron, H.E. & Mostert, B.E., 2009. Production and breeding performance of South African dairy herds. S. Afr. J. Anim. Sci. 39, 206-210.

Thompson, J.R., Everett, R.W. & Hammerschmidt, N.L., 2000a. Effects of inbreeding on production and survival in Holsteins. J. Dairy Sci. 83, 1856-1864.

Thompson, J.R., Everett, R.W. & Wolfe, C.W., 2000b. Effects of inbreeding on production and survival in Jerseys. J. Dairy Sci. 83, 2131-2138.

Tiezzi, F., Maltecca, C., Cecchinato, A., Penasa, M. & Bittante, G., 2012. Genetic parameters for fertility of dairy heifers and cows at different parities and relationships with production traits in first lactation. J. Dairy Sci. 95, 7355–7362.

Toshniwal, J.K., Dechow, C.D., Cassell, B.G., Appuhamy, J.A.D.R.N. & Varga, G.A., 2008. Heritability of Electronically Recorded Daily Body Weight and Correlations with Yield, Dry Matter Intake, and Body Condition Score. J. Dairy Sci. 91, 3201–3210.

Tse, C., Barkema, H.W., DeVries, T.J., Rushen, J. & Pajor, E.A., 2016. Effect of transitioning to automatic milking systems on producers' perceptions of farm management and cow health in the Canadian dairy industry. J. Dairy Sci. 100, 2404–2414.

Useni, B.A., Muller, C.J.C. & Cruywagen, C.W., 2014. Milk production of dairy cows as affected by the length of the preceding dry period. S. Afr. J. Anim. Sci. 44, 21–24.

Usman, T., Qureshi, M.S., Yu, Y. & Wang, Y., 2013. Influence of various environmental factors on dairy production and adaptability of Holstein cattle maintained under tropical and subtropical conditions. Adv. Env. Biol. 7, 366-372.

Van den Berg, B. & Howarth, C., 2014. All about Afi: technology. The Dairy Mail, 21,102-109.

Van Doormaal, B.J. & Kistemaker, G.J., 2003. Dairy genetic improvement through artificial insemination, performance recording and genetic evaluation. Can. J. Anim. Sci. 83, 385–392.

Van Marle-Köster, E., Visser, C. & Berry, D.P., 2013. A review of genomic selection-Implications for the South African beef and dairy cattle industries. S. Afr. J. Anim. Sci. 43, 1-17.

Van Niekerk, D.J., Neser, F.W.C. & Van Der Westhuizen, J., 2006. An investigation into the possibility of a genotype by environmental interaction for milk production in the South African Jersey population. S. Afr. J. Anim. Sci. 36, 107-110.

Veerkamp, R.F. & Beerda, B., 2007. Genetics and genomics to improve fertility in high producing dairy cows. Theriogenology. 68**,** 266-273.

Vukasinovic, N., Bacciu, N., Przybyla, C.A., Boddhireddy, P. & DeNise, S.K., 2017. Development of genetic and genomic evaluation for wellness traits in US Holstein cows. J. Dairy Sci. 100, 428–438.

Walsh, S.W., Buckley, F., Berry, D.P., Rath, M., Pierce, K., Byrne, N. & Dillon, P., 2007. Effects of breed, feeding system, and parity on udder health and milking characteristics. J. Dairy Sci. 90, 5767-5779.

Walsh, S.W., Williams, E.J. & Evans, A.C.O., 2011. A review of the causes of poor fertility in high milk producing dairy cows. Anim. Reprod. Sci. 123, 127-138.

Wathes, D.C., Brickell, J.S., Bourne, N.E., Swali, A. & Cheng, Z., 2008. Factors influencing heifer survival and fertility on commercial dairy farms. Animal. 2, 1135–1143.

Wathes, D.C., Pollott, G.E., Johnson, K.F., Richardson, H. & Cooke, J.S., 2014. Heifer fertility and carry over consequences for life time production in dairy and beef cattle. Animal. 8, 91–104.

Weigel, K.A. & Lin, S.W., 2000. Use of computerized mate selection programs to control inbreeding of Holstein and Jersey cattle in the next generation. J. Dairy Sci. 83, 822-828.

Weigel, K.A., 2001. Controlling inbreeding in modern breeding programs. J. Dairy Sci. 84, 177-184.

Weigel, K.A., Zwald, N.R. & Rekaya, R., 2001. International dairy sire evaluation based on multiple-trait BLUP analysis of daughter performance records. INTERBULL Bulletin, 19.

Weigel, K.A., 2006. Prospects for improving reproductive performance through genetic selection. Anim. Reprod. Sci. 96, 323–330.

Weller, J.I. & Ezra, E., 2015. Environmental and genetic factors affecting cow survival of Israeli Holsteins. J. Dairy Sci. 98, 676–684.

Williams, R., Scholtz, M.M. & Neser, F.W.C., 2016. Geographical influence of heat stress on milk production of Holstein dairy cattle on pasture in South Africa under current and future climatic conditions. S. Afr. J. Anim. Sci, 46, 441-447.

Wojcik, P. & Rudzinski, J., 2014. Effectiveness of using activity tags in management of high-producing dairy herd. Universitatis Technologiae Stetinensis. Agricultura, Alimentaria, Piscaria et Zootechnica. 293, 13–26.

Yamazaki, T., Hagiya, K., Takeda, H., Yamaguchi, S., Osawa, T. & Nagamine, Y., 2014. Genetic correlations among female fertility, 305-day milk yield and persistency during the first three lactations of Japanese Holstein cows. Livest. Sci. 168, 26–31.

Yusuf, M., Nakao, T., Ranasinghe, R.B.K., Gautam, G., Long, S.T., Yoshida, C., Koike, K. & Hayashi, A., 2010. Reproductive performance of repeat breeders in dairy herds. Theriogenology. 73, 1220-1229.

Zavadilová, L. & Štípková, M., 2013. Effect of age at first calving on longevity and fertility traits for Holstein cattle. Czech J. Anim. Sci. 58, 47–57.

Zwald, N.R., Weigel, K.A., Fikse, W.F. & Rekaya, R., 2003. Identification of factors that cause genotype by environment interaction between herds of Holstein cattle in seventeen countries. J. Dairy Sci. 86, 1009-1018.

Zwald, N.R., Weigel, K.A., Chang, Y.M., Welper R.D. & Clay, J.S., 2004. Genetic selection for health traits using producer-recorded recorded data. I. Incidence rates, heritability estimates and sire breeding values. J. Dairy Sci. 87, 4287–4294.

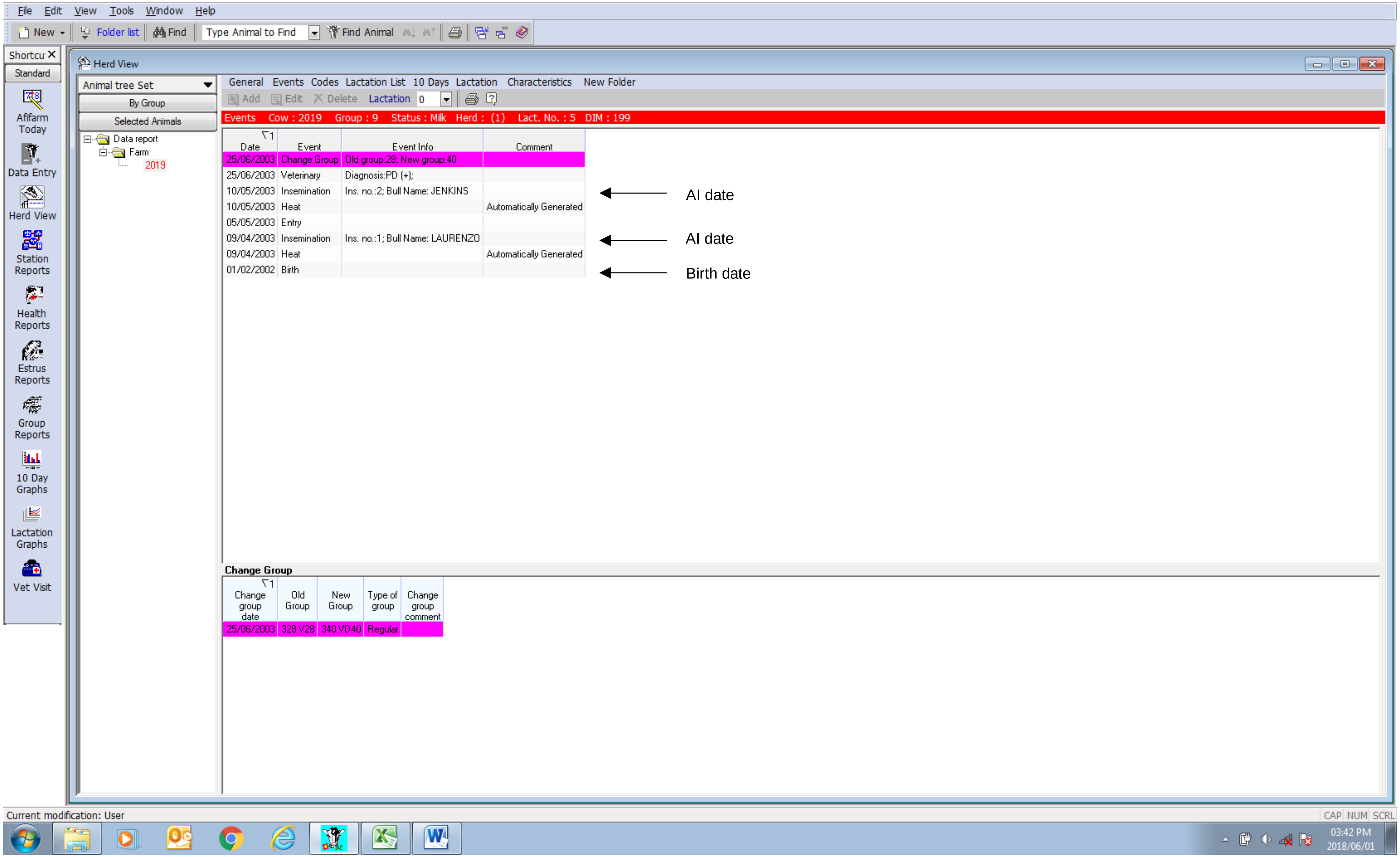
Zwald, N.R., Weigel, K.A., Chang, Y.M., Welper, R.D. & Clay, J.S., 2005. Genetic Evaluation of Dairy Sires for Milking Duration Using Electronically Recorded Milking Times of Their Daughters. J. Dairy Sci. 88, 1192–1198.

Addendum A: Data mining and editing

Table 1A Formulas for parameter extraction from AfiFarm

	Parameter	Formula
All animals	Breed	Breed registered to a respective animal
	Sire registration number	AI sire registration number assigned to the respective animal
	Lactation number	Lactation number upon exit from the herd or on the date of data extraction
	Days on farm	Days between birth date and exit date
	Lifetime milk yield	Total milk produced between first calving date and exit date
	Milk yield/Days on farm	Lifetime milk yield/Days on farm
Heifer	AFS	Months between birth date and first insemination date
	IN	Number of inseminations between birth date and first calving date
	DFLI	Days between first insemination date and last insemination date
	AFConc	Months between birth date and last insemination date
	AFC	Months between birth date and first calving date
Cow	DIMFS	Days between calving date and first insemination date
	IN	Number of inseminations between calving date and dry up date
	DFLI	Days between first insemination date and last insemination date
	DO	Days between calving date and last insemination date
	ICP	Days between subsequent calving dates
	DIM	Days between calving date and dry up date
	AMY	Average daily milk yield between calving date and dry up date
	LMY	Total milk yield between calving date and dry up date
	DD	Days between the dry up date and subsequent calving date

AFS=age at first service; AFConc=age at first conception; IN=insemination number; DFLI=days between first and last insemination; AFC=age at first calving; DIMFS=days in milk at first service; ICP=inter calving period; DO=days open; DD=days dry; DIM=days in milk; LMY=lactation milk yield; AMY=average daily milk yield



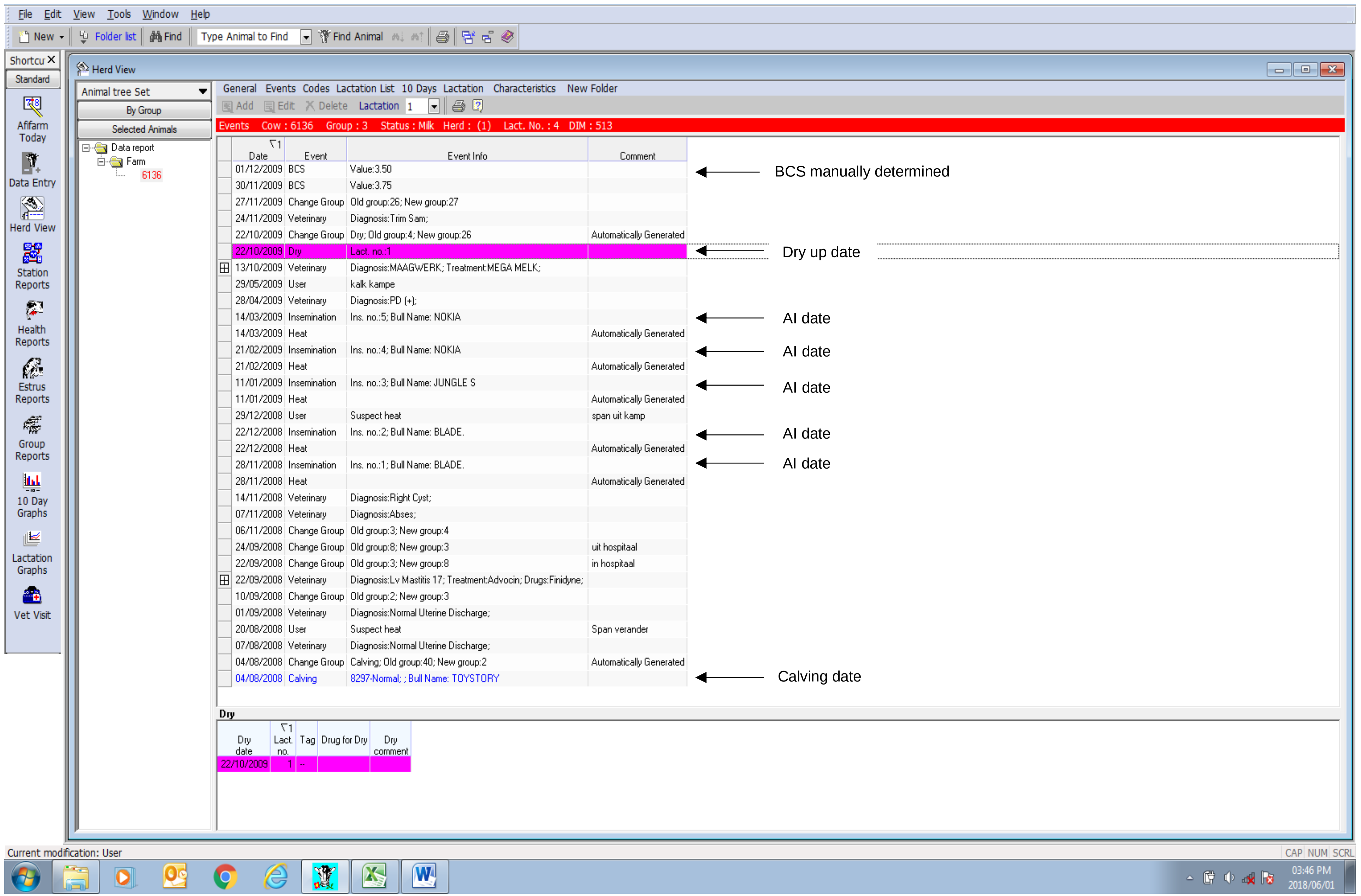
Events Cow : 2019 Group : 9 Status : Milk Herd : (1) Lact. No. : 5 DIM : 199

Date	Event	Event Info	Comment
25/06/2003	Change Group	Old group:28; New group:40	
25/06/2003	Veterinary	Diagnosis:PD (+);	
10/05/2003	Insemination	Ins. no.:2; Bull Name: JENKINS	
10/05/2003	Heat		Automatically Generated
05/05/2003	Entry		
09/04/2003	Insemination	Ins. no.:1; Bull Name: LAURENZO	
09/04/2003	Heat		Automatically Generated
01/02/2002	Birth		

Change Group

Change group date	Old Group	New Group	Type of group	Change group comment
25/06/2003	328 V28	340 VD40	Regular	

Figure 1A Heifer events saved on AfiFarm



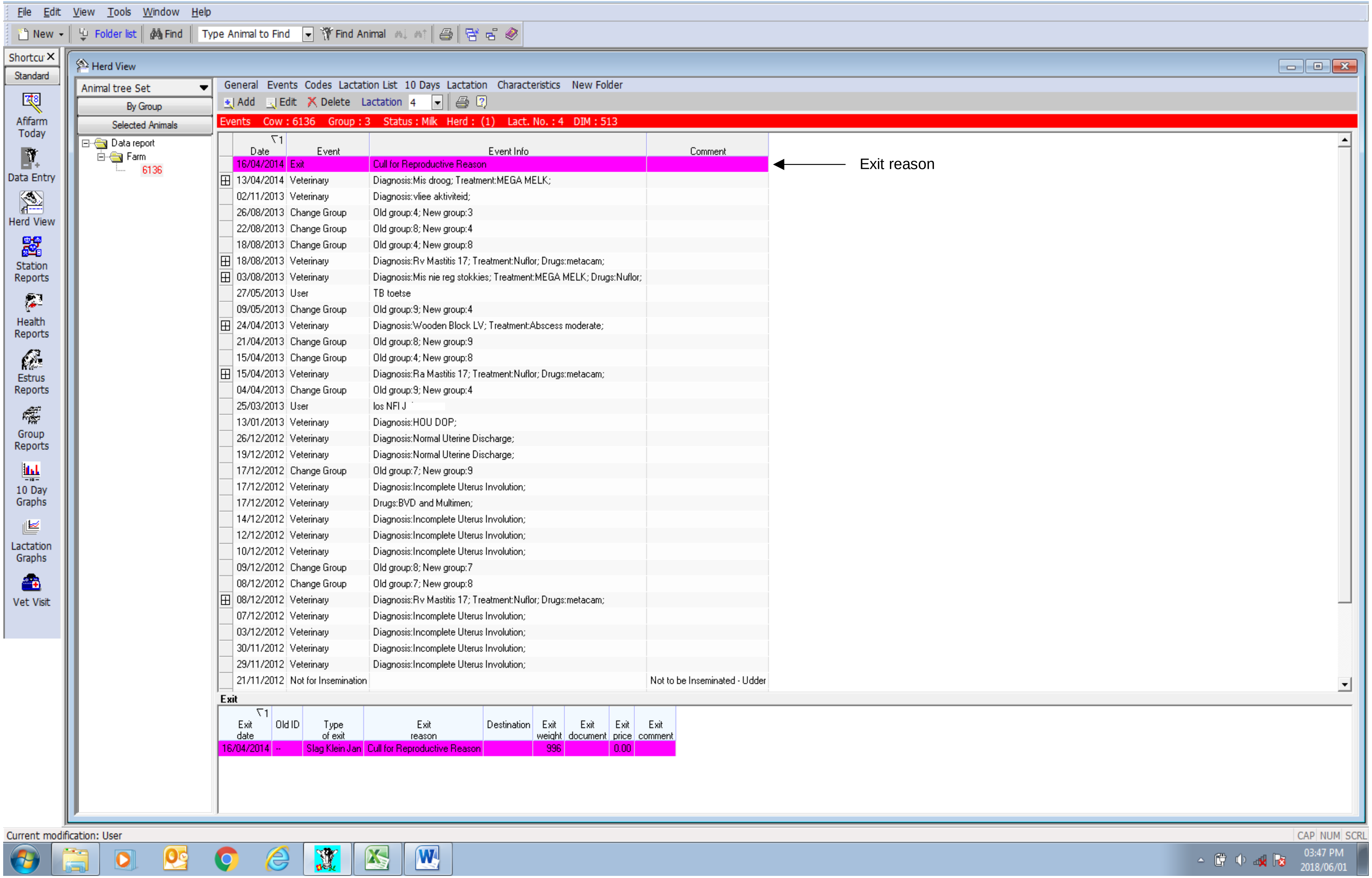
Events Cow : 6136 Group : 3 Status : Milk Herd : (1) Lact. No. : 4 DIM : 513

Date	Event	Event Info	Comment
01/12/2009	BCS	Value:3.50	
30/11/2009	BCS	Value:3.75	
27/11/2009	Change Group	Old group:26; New group:27	
24/11/2009	Veterinary	Diagnosis:Trim Sam;	
22/10/2009	Change Group	Dry; Old group:4; New group:26	Automatically Generated
22/10/2009	Dry	Lact. no.:1	
13/10/2009	Veterinary	Diagnosis:MAAGWERK; Treatment:MEGA MELK;	
29/05/2009	User	kalk kampe	
28/04/2009	Veterinary	Diagnosis:PD (+);	
14/03/2009	Insemination	Ins. no.:5; Bull Name: NOKIA	
14/03/2009	Heat		Automatically Generated
21/02/2009	Insemination	Ins. no.:4; Bull Name: NOKIA	
21/02/2009	Heat		Automatically Generated
11/01/2009	Insemination	Ins. no.:3; Bull Name: JUNGLE S	
11/01/2009	Heat		Automatically Generated
29/12/2008	User	Suspect heat	span uit kamp
22/12/2008	Insemination	Ins. no.:2; Bull Name: BLADE.	
22/12/2008	Heat		Automatically Generated
28/11/2008	Insemination	Ins. no.:1; Bull Name: BLADE.	
28/11/2008	Heat		Automatically Generated
14/11/2008	Veterinary	Diagnosis:Right Cyst;	
07/11/2008	Veterinary	Diagnosis:Abses;	
06/11/2008	Change Group	Old group:3; New group:4	
24/09/2008	Change Group	Old group:8; New group:3	uit hospitaal
22/09/2008	Change Group	Old group:3; New group:8	in hospitaal
22/09/2008	Veterinary	Diagnosis:Lv Mastitis 17; Treatment:Advocin; Drugs:Finidyne;	
10/09/2008	Change Group	Old group:2; New group:3	
01/09/2008	Veterinary	Diagnosis:Normal Uterine Discharge;	
20/08/2008	User	Suspect heat	Span verander
07/08/2008	Veterinary	Diagnosis:Normal Uterine Discharge;	
04/08/2008	Change Group	Calving; Old group:40; New group:2	Automatically Generated
04/08/2008	Calving	8297-Normal; ; Bull Name: TOYSTORY	

Dry

Dry date	Lact. no.	Tag	Drug for Dry	Dry comment
22/10/2009	1	--		

Figure 2A Cow events saved on AfiFarm



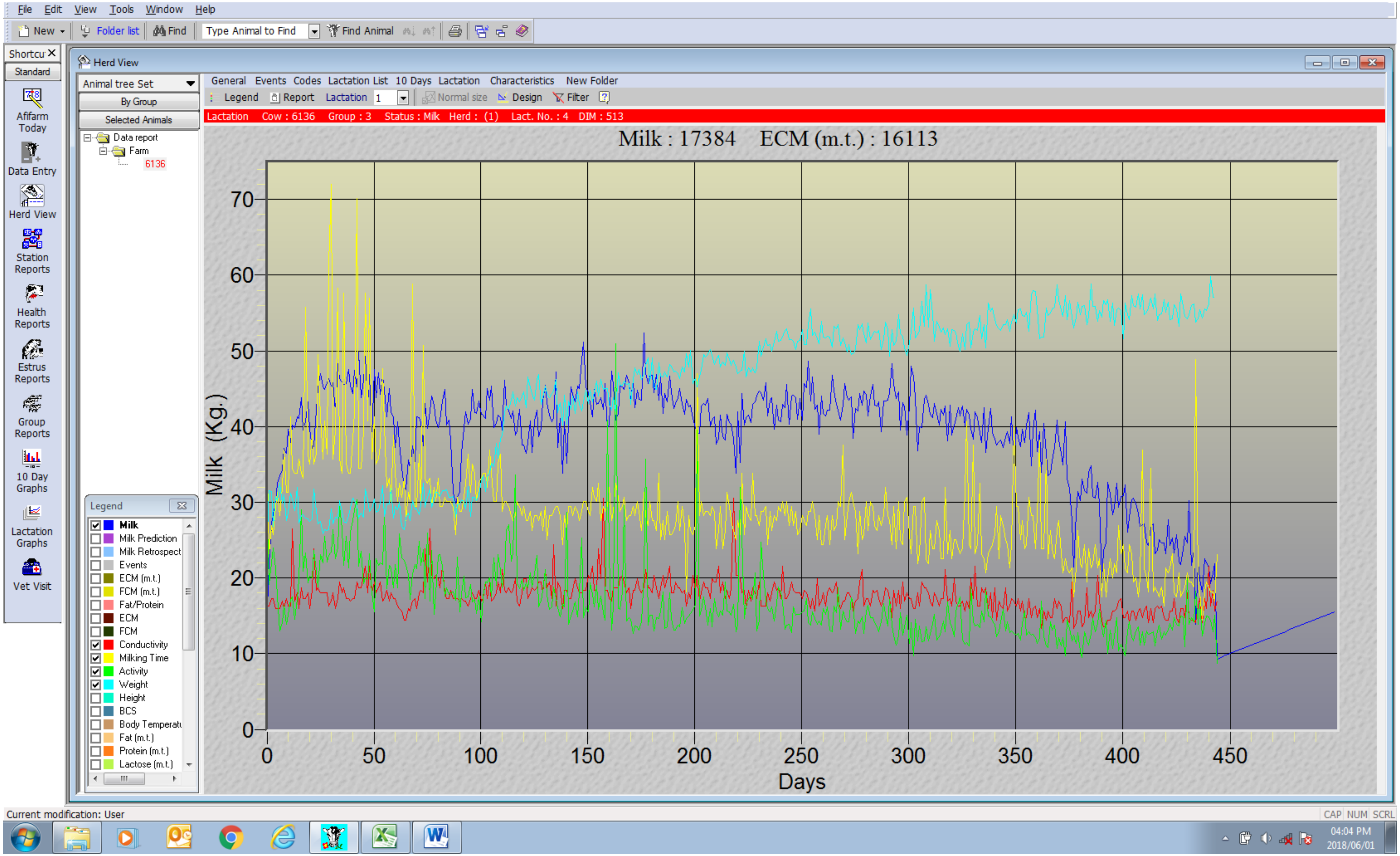
Events Cow : 6136 Group : 3 Status : Milk Herd : (1) Lact. No. : 4 DIM : 513

Date	Event	Event Info	Comment
16/04/2014	Exit	Cull for Reproductive Reason	
13/04/2014	Veterinary	Diagnosis:Mis droog; Treatment:MEGA MELK;	
02/11/2013	Veterinary	Diagnosis:vliee aktiviteid;	
26/08/2013	Change Group	Old group:4; New group:3	
22/08/2013	Change Group	Old group:8; New group:4	
18/08/2013	Change Group	Old group:4; New group:8	
18/08/2013	Veterinary	Diagnosis:Rv Mastitis 17; Treatment:Nuflor; Drugs:metacam;	
03/08/2013	Veterinary	Diagnosis:Mis nie reg stokkies; Treatment:MEGA MELK; Drugs:Nuflor;	
27/05/2013	User	TB toetse	
09/05/2013	Change Group	Old group:9; New group:4	
24/04/2013	Veterinary	Diagnosis:Wooden Block LV; Treatment:Abscess moderate;	
21/04/2013	Change Group	Old group:8; New group:9	
15/04/2013	Change Group	Old group:4; New group:8	
15/04/2013	Veterinary	Diagnosis:Ra Mastitis 17; Treatment:Nuflor; Drugs:metacam;	
04/04/2013	Change Group	Old group:9; New group:4	
25/03/2013	User	los NFI J [redacted]	
13/01/2013	Veterinary	Diagnosis:HOU DOP;	
26/12/2012	Veterinary	Diagnosis:Normal Uterine Discharge;	
19/12/2012	Veterinary	Diagnosis:Normal Uterine Discharge;	
17/12/2012	Change Group	Old group:7; New group:9	
17/12/2012	Veterinary	Diagnosis:Incomplete Uterus Involution;	
17/12/2012	Veterinary	Drugs:BVD and Multimen;	
14/12/2012	Veterinary	Diagnosis:Incomplete Uterus Involution;	
12/12/2012	Veterinary	Diagnosis:Incomplete Uterus Involution;	
10/12/2012	Veterinary	Diagnosis:Incomplete Uterus Involution;	
09/12/2012	Change Group	Old group:8; New group:7	
08/12/2012	Change Group	Old group:7; New group:8	
08/12/2012	Veterinary	Diagnosis:Rv Mastitis 17; Treatment:Nuflor; Drugs:metacam;	
07/12/2012	Veterinary	Diagnosis:Incomplete Uterus Involution;	
03/12/2012	Veterinary	Diagnosis:Incomplete Uterus Involution;	
30/11/2012	Veterinary	Diagnosis:Incomplete Uterus Involution;	
29/11/2012	Veterinary	Diagnosis:Incomplete Uterus Involution;	
21/11/2012	Not for Insemination		Not to be Inseminated - Udder

Exit

Exit date	Old ID	Type of exit	Exit reason	Destination	Exit weight	Exit document	Exit price	Exit comment
16/04/2014	--	Slag Klein Jan	Cull for Reproductive Reason		996		0.00	

Figure 3A Exit reason saved on AfiFarm

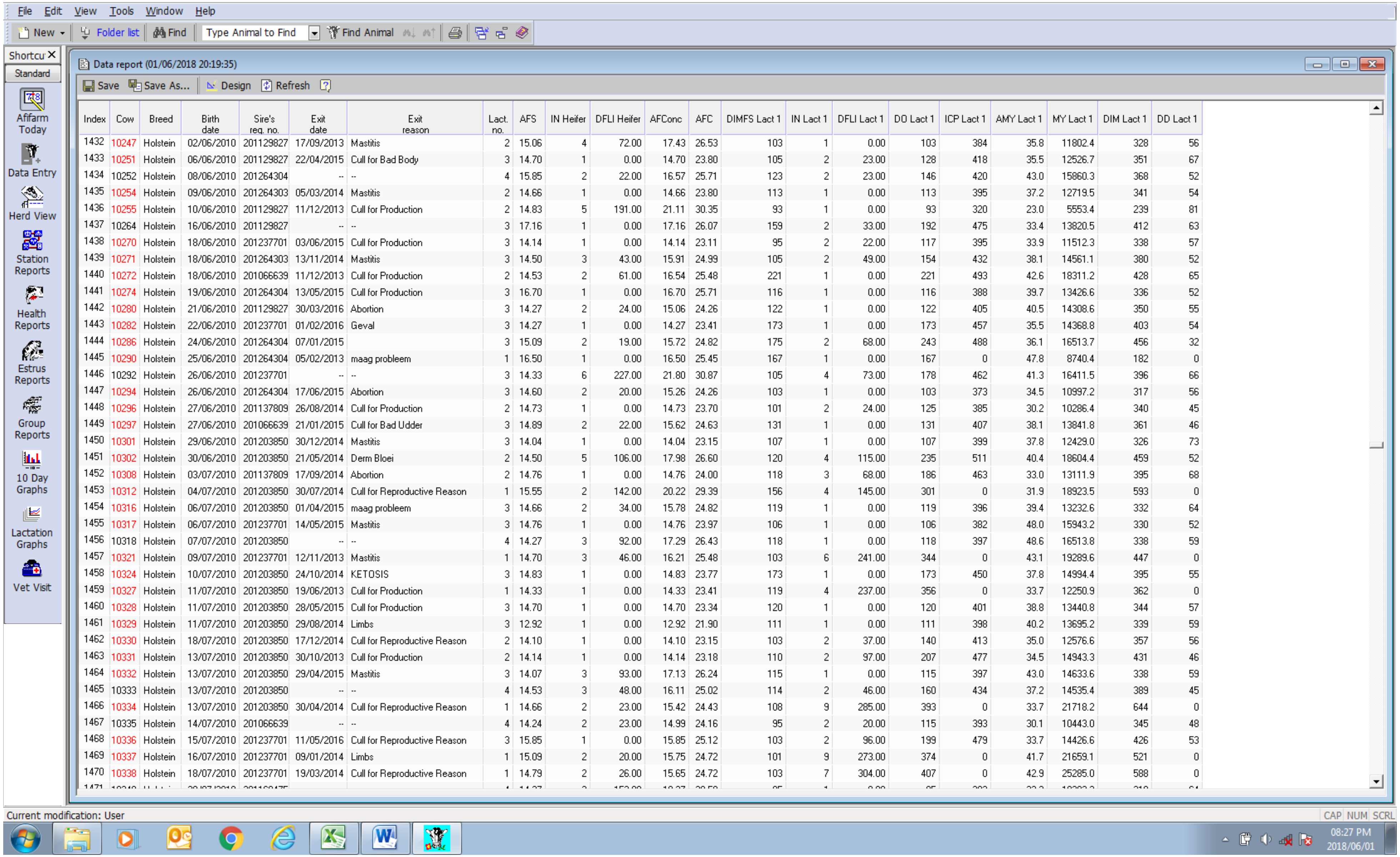


Lactation Cow : 6136 Group : 3 Status : Milk Herd : (1) Lact. No. : 4 DIM : 513

Milk : 17384 ECM (m.t.) : 16113

Legend
- ☑ 🟦 **Milk**
- ☐ Milk Prediction
- ☐ Milk Retrospect
- ☐ Events
- ☐ ECM (m.t.)
- ☐ FCM (m.t.)
- ☐ Fat/Protein
- ☐ ECM
- ☐ FCM
- ☑ 🟥 Conductivity
- ☑ 🟨 Milking Time
- ☑ 🟩 Activity
- ☑ Weight
- ☐ Height
- ☐ BCS
- ☐ Body Temperatu
- ☐ Fat (m.t.)
- ☐ Protein (m.t.)
- ☐ Lactose (m.t.)

Figure 4A Variables recorded during the lactation period

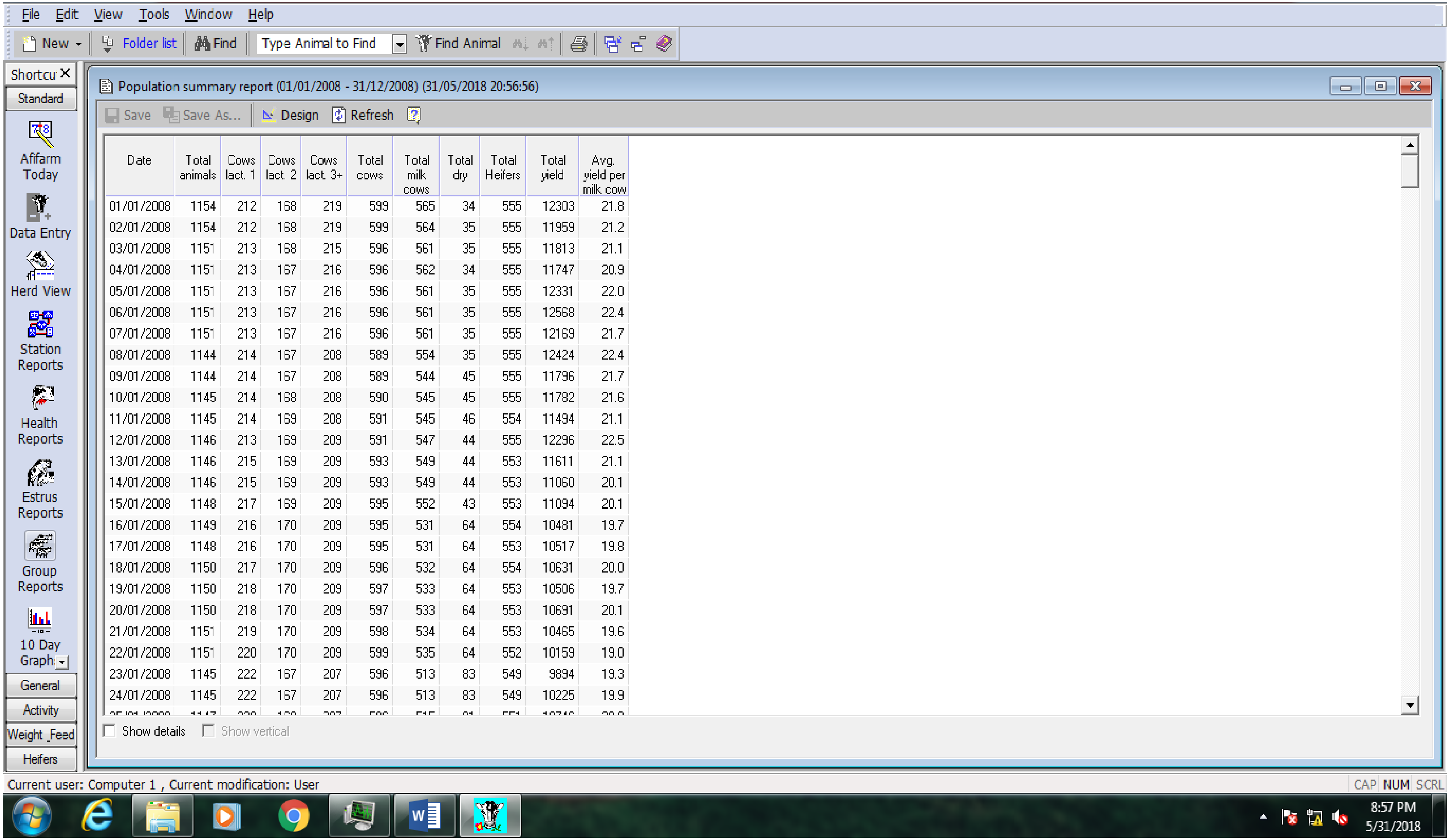


Data report (01/06/2018 20:19:35)

Index	Cow	Breed	Birth date	Sire's reg. no.	Exit date	Exit reason	Lact. no.	AFS	IN Heifer	DFLI Heifer	AFConc	AFC	DIMFS Lact 1	IN Lact 1	DFLI Lact 1	DO Lact 1	ICP Lact 1	AMY Lact 1	MY Lact 1	DIM Lact 1	DD Lact 1
1432	10247	Holstein	02/06/2010	201129827	17/09/2013	Mastitis	2	15.06	4	72.00	17.43	26.53	103	1	0.00	103	384	35.8	11802.4	328	56
1433	10251	Holstein	06/06/2010	201129827	22/04/2015	Cull for Bad Body	3	14.70	1	0.00	14.70	23.80	105	2	23.00	128	418	35.5	12526.7	351	67
1434	10252	Holstein	08/06/2010	201264304	--	--	4	15.85	2	22.00	16.57	25.71	123	2	23.00	146	420	43.0	15860.3	368	52
1435	10254	Holstein	09/06/2010	201264303	05/03/2014	Mastitis	2	14.66	1	0.00	14.66	23.80	113	1	0.00	113	395	37.2	12719.5	341	54
1436	10255	Holstein	10/06/2010	201129827	11/12/2013	Cull for Production	2	14.83	5	191.00	21.11	30.35	93	1	0.00	93	320	23.0	5553.4	239	81
1437	10264	Holstein	16/06/2010	201129827	--	--	3	17.16	1	0.00	17.16	26.07	159	2	33.00	192	475	33.4	13820.5	412	63
1438	10270	Holstein	18/06/2010	201237701	03/06/2015	Cull for Production	3	14.14	1	0.00	14.14	23.11	95	2	22.00	117	395	33.9	11512.3	338	57
1439	10271	Holstein	18/06/2010	201264303	13/11/2014	Mastitis	3	14.50	3	43.00	15.91	24.99	105	2	49.00	154	432	38.1	14561.1	380	52
1440	10272	Holstein	18/06/2010	201066639	11/12/2013	Cull for Production	2	14.53	2	61.00	16.54	25.48	221	1	0.00	221	493	42.6	18311.2	428	65
1441	10274	Holstein	19/06/2010	201264304	13/05/2015	Cull for Production	3	16.70	1	0.00	16.70	25.71	116	1	0.00	116	388	39.7	13426.6	336	52
1442	10280	Holstein	21/06/2010	201129827	30/03/2016	Abortion	3	14.27	2	24.00	15.06	24.26	122	1	0.00	122	405	40.5	14308.6	350	55
1443	10282	Holstein	22/06/2010	201237701	01/02/2016	Geval	3	14.27	1	0.00	14.27	23.41	173	1	0.00	173	457	35.5	14368.8	403	54
1444	10286	Holstein	24/06/2010	201264304	07/01/2015		3	15.09	2	19.00	15.72	24.82	175	2	68.00	243	488	36.1	16513.7	456	32
1445	10290	Holstein	25/06/2010	201264304	05/02/2013	maag probleem	1	16.50	1	0.00	16.50	25.45	167	1	0.00	167	0	47.8	8740.4	182	0
1446	10292	Holstein	26/06/2010	201237701	--	--	3	14.33	6	227.00	21.80	30.87	105	4	73.00	178	462	41.3	16411.5	396	66
1447	10294	Holstein	26/06/2010	201264304	17/06/2015	Abortion	3	14.60	2	20.00	15.26	24.26	103	1	0.00	103	373	34.5	10997.2	317	56
1448	10296	Holstein	27/06/2010	201137809	26/08/2014	Cull for Production	2	14.73	1	0.00	14.73	23.70	101	2	24.00	125	385	30.2	10286.4	340	45
1449	10297	Holstein	27/06/2010	201066639	21/01/2015	Cull for Bad Udder	3	14.89	2	22.00	15.62	24.63	131	1	0.00	131	407	38.1	13841.8	361	46
1450	10301	Holstein	29/06/2010	201203850	30/12/2014	Mastitis	3	14.04	1	0.00	14.04	23.15	107	1	0.00	107	399	37.8	12429.0	326	73
1451	10302	Holstein	30/06/2010	201203850	21/05/2014	Derm Bloei	2	14.50	5	106.00	17.98	26.60	120	4	115.00	235	511	40.4	18604.4	459	52
1452	10308	Holstein	03/07/2010	201137809	17/09/2014	Abortion	2	14.76	1	0.00	14.76	24.00	118	3	68.00	186	463	33.0	13111.9	395	68
1453	10312	Holstein	04/07/2010	201203850	30/07/2014	Cull for Reproductive Reason	1	15.55	2	142.00	20.22	29.39	156	4	145.00	301	0	31.9	18923.5	593	0
1454	10316	Holstein	06/07/2010	201203850	01/04/2015	maag probleem	3	14.66	2	34.00	15.78	24.82	119	1	0.00	119	396	39.4	13232.6	332	64
1455	10317	Holstein	06/07/2010	201237701	14/05/2015	Mastitis	3	14.76	1	0.00	14.76	23.97	106	1	0.00	106	382	48.0	15943.2	330	52
1456	10318	Holstein	07/07/2010	201203850	--	--	4	14.27	3	92.00	17.29	26.43	118	1	0.00	118	397	48.6	16513.8	338	59
1457	10321	Holstein	09/07/2010	201237701	12/11/2013	Mastitis	1	14.70	3	46.00	16.21	25.48	103	6	241.00	344	0	43.1	19289.6	447	0
1458	10324	Holstein	10/07/2010	201203850	24/10/2014	KETOSIS	3	14.83	1	0.00	14.83	23.77	173	1	0.00	173	450	37.8	14994.4	395	55
1459	10327	Holstein	11/07/2010	201203850	19/06/2013	Cull for Production	1	14.33	1	0.00	14.33	23.41	119	4	237.00	356	0	33.7	12250.9	362	0
1460	10328	Holstein	11/07/2010	201203850	28/05/2015	Cull for Production	3	14.70	1	0.00	14.70	23.34	120	1	0.00	120	401	38.8	13440.8	344	57
1461	10329	Holstein	11/07/2010	201203850	29/08/2014	Limbs	3	12.92	1	0.00	12.92	21.90	111	1	0.00	111	398	40.2	13695.2	339	59
1462	10330	Holstein	18/07/2010	201203850	17/12/2014	Cull for Reproductive Reason	2	14.10	1	0.00	14.10	23.15	103	2	37.00	140	413	35.0	12576.6	357	56
1463	10331	Holstein	13/07/2010	201203850	30/10/2013	Cull for Production	2	14.14	1	0.00	14.14	23.18	110	2	97.00	207	477	34.5	14943.3	431	46
1464	10332	Holstein	13/07/2010	201203850	29/04/2015	Mastitis	3	14.07	3	93.00	17.13	26.24	115	1	0.00	115	397	43.0	14633.6	338	59
1465	10333	Holstein	13/07/2010	201203850	--	--	4	14.53	3	48.00	16.11	25.02	114	2	46.00	160	434	37.2	14535.4	389	45
1466	10334	Holstein	13/07/2010	201203850	30/04/2014	Cull for Reproductive Reason	1	14.66	2	23.00	15.42	24.43	108	9	285.00	393	0	33.7	21718.2	644	0
1467	10335	Holstein	14/07/2010	201066639	--	--	4	14.24	2	23.00	14.99	24.16	95	2	20.00	115	393	30.1	10443.0	345	48
1468	10336	Holstein	15/07/2010	201237701	11/05/2016	Cull for Reproductive Reason	3	15.85	1	0.00	15.85	25.12	103	2	96.00	199	479	33.7	14426.6	426	53
1469	10337	Holstein	16/07/2010	201237701	09/01/2014	Limbs	1	15.09	2	20.00	15.75	24.72	101	9	273.00	374	0	41.7	21659.1	521	0
1470	10338	Holstein	18/07/2010	201237701	19/03/2014	Cull for Reproductive Reason	1	14.79	2	26.00	15.65	24.72	103	7	304.00	407	0	42.9	25285.0	588	0

Current modification: User

Figure 5A Data report constructed on AfiFarm

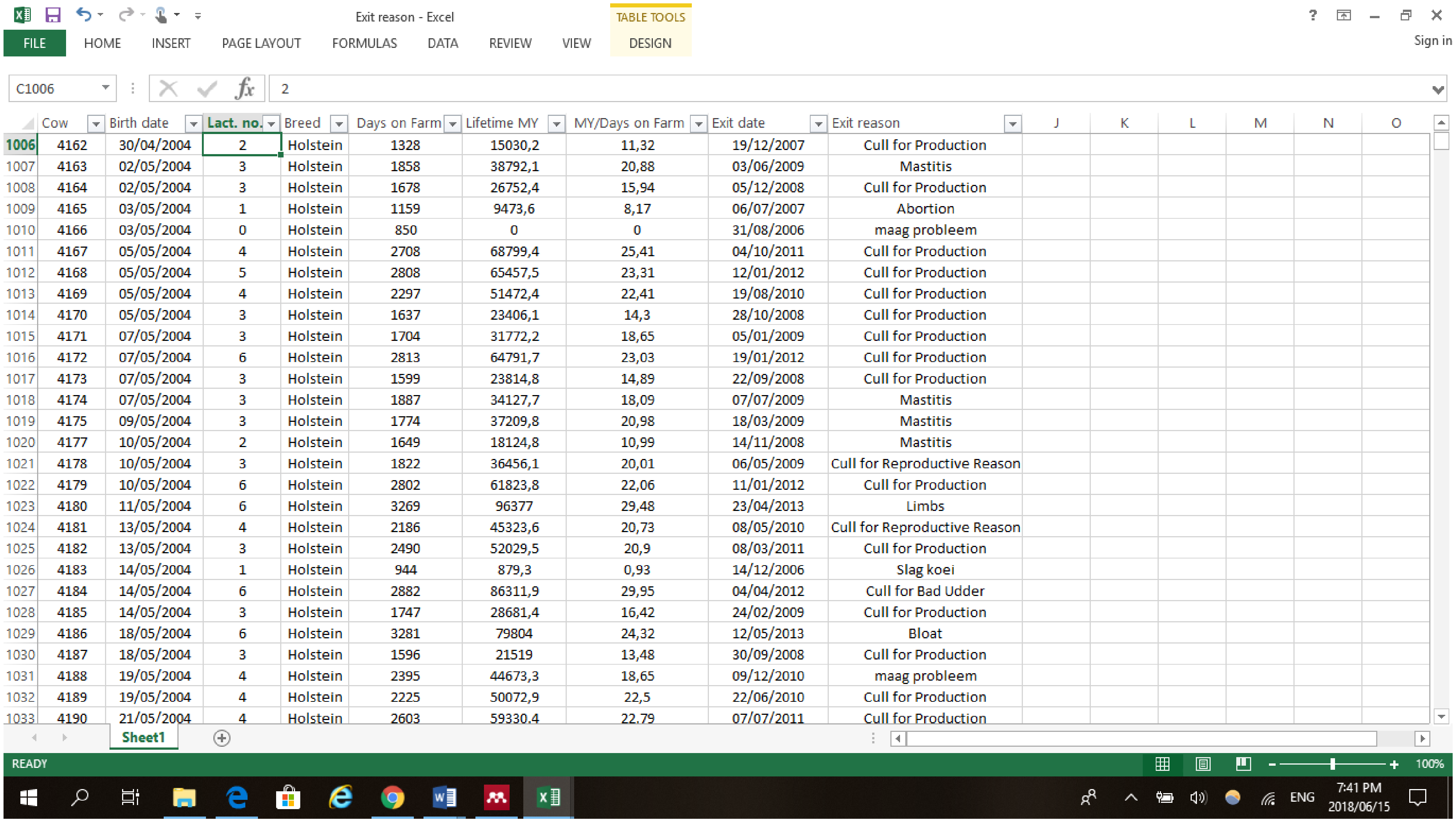


Population summary report (01/01/2008 - 31/12/2008) (31/05/2018 20:56:56)

Date	Total animals	Cows lact. 1	Cows lact. 2	Cows lact. 3+	Total cows	Total milk cows	Total dry	Total Heifers	Total yield	Avg. yield per milk cow
01/01/2008	1154	212	168	219	599	565	34	555	12303	21.8
02/01/2008	1154	212	168	219	599	564	35	555	11959	21.2
03/01/2008	1151	213	168	215	596	561	35	555	11813	21.1
04/01/2008	1151	213	167	216	596	562	34	555	11747	20.9
05/01/2008	1151	213	167	216	596	561	35	555	12331	22.0
06/01/2008	1151	213	167	216	596	561	35	555	12568	22.4
07/01/2008	1151	213	167	216	596	561	35	555	12169	21.7
08/01/2008	1144	214	167	208	589	554	35	555	12424	22.4
09/01/2008	1144	214	167	208	589	544	45	555	11796	21.7
10/01/2008	1145	214	168	208	590	545	45	555	11782	21.6
11/01/2008	1145	214	169	208	591	545	46	554	11494	21.1
12/01/2008	1146	213	169	209	591	547	44	555	12296	22.5
13/01/2008	1146	215	169	209	593	549	44	553	11611	21.1
14/01/2008	1146	215	169	209	593	549	44	553	11060	20.1
15/01/2008	1148	217	169	209	595	552	43	553	11094	20.1
16/01/2008	1149	216	170	209	595	531	64	554	10481	19.7
17/01/2008	1148	216	170	209	595	531	64	553	10517	19.8
18/01/2008	1150	217	170	209	596	532	64	554	10631	20.0
19/01/2008	1150	218	170	209	597	533	64	553	10506	19.7
20/01/2008	1150	218	170	209	597	533	64	553	10691	20.1
21/01/2008	1151	219	170	209	598	534	64	553	10465	19.6
22/01/2008	1151	220	170	209	599	535	64	552	10159	19.0
23/01/2008	1145	222	167	207	596	513	83	549	9894	19.3
24/01/2008	1145	222	167	207	596	513	83	549	10225	19.9

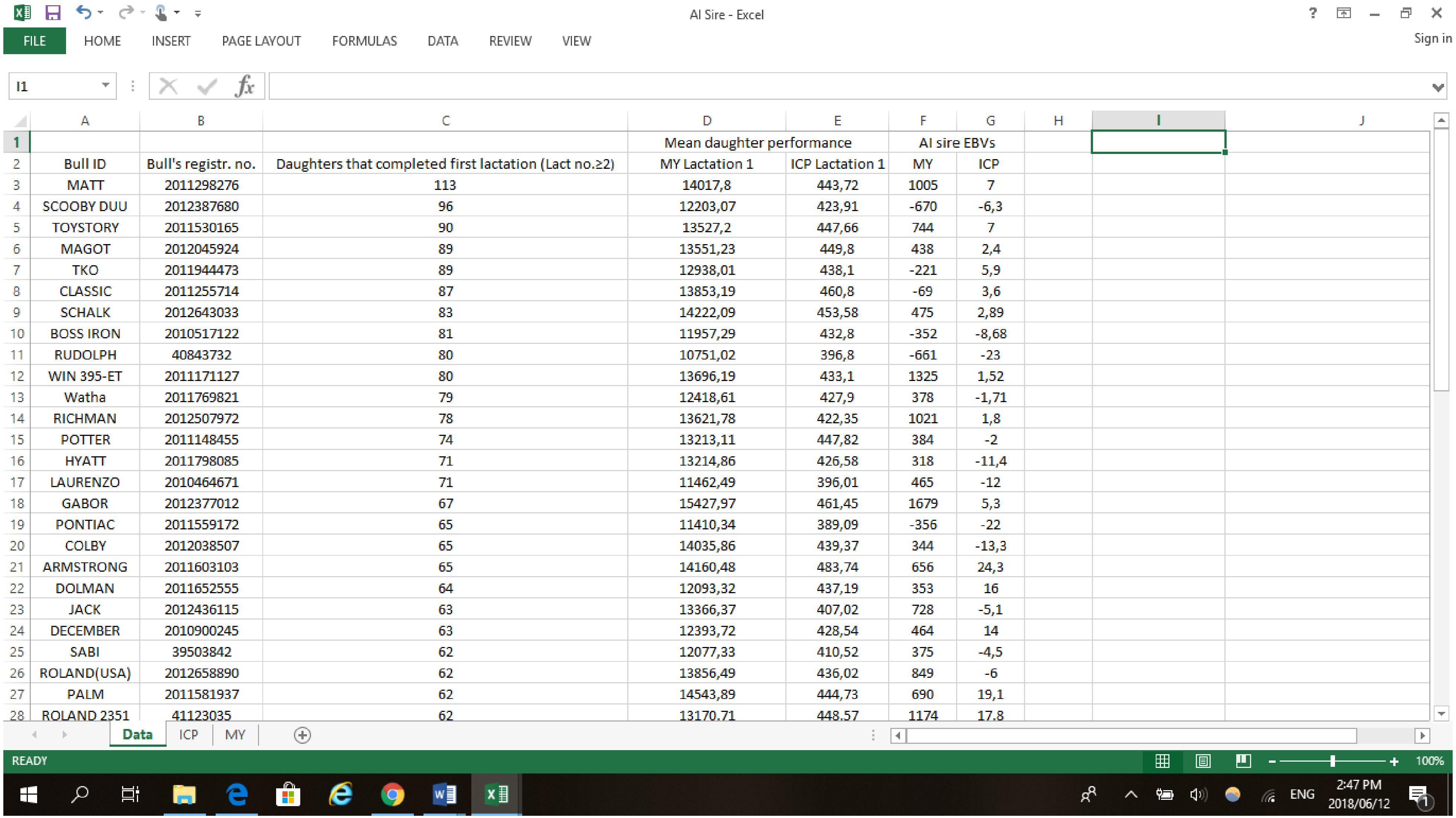
Current user: Computer 1 , Current modification: User

Figure 6A Population summary report constructed on AfiFarm



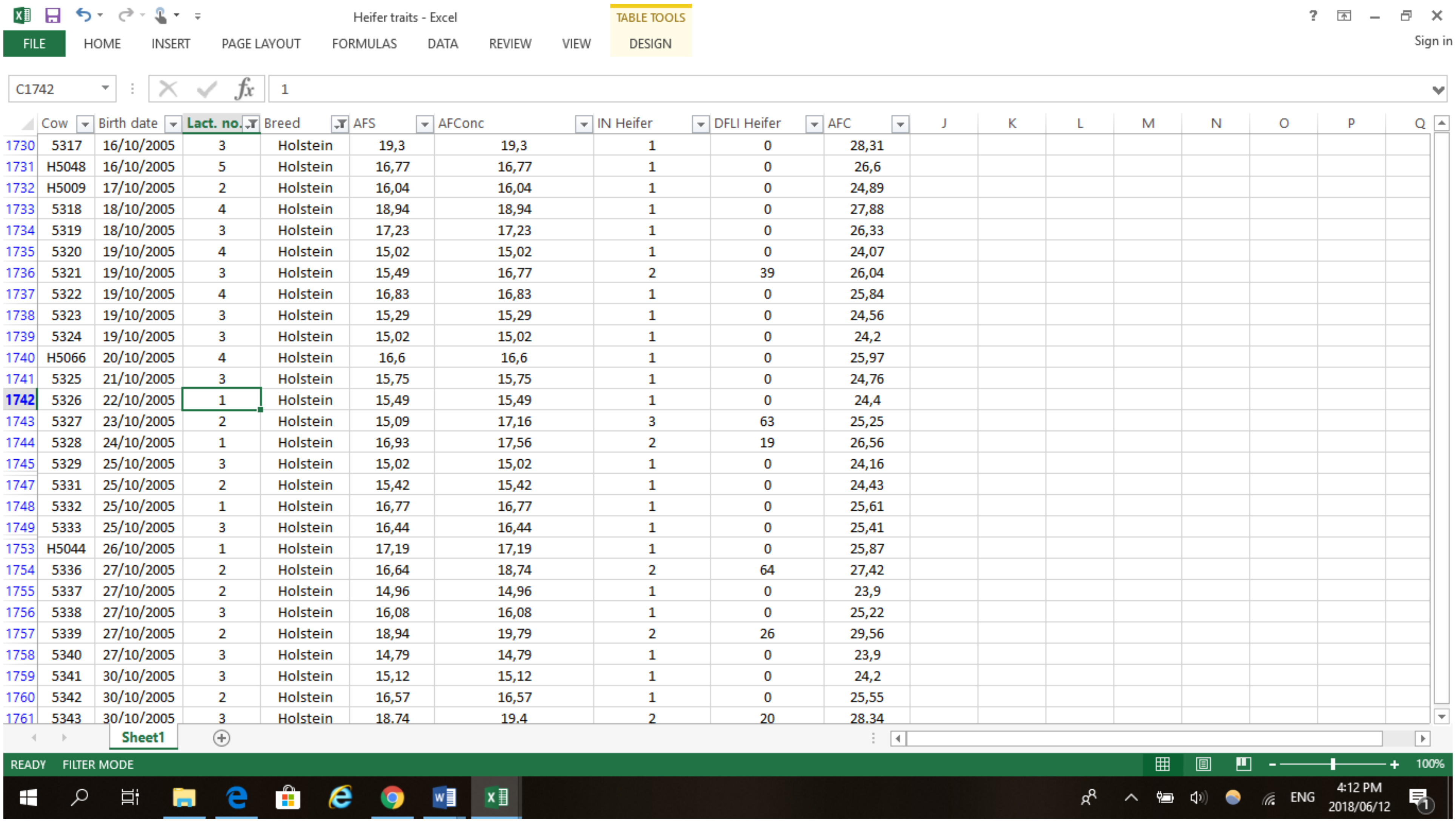
	Cow	Birth date	Lact. no.	Breed	Days on Farm	Lifetime MY	MY/Days on Farm	Exit date	Exit reason
1006	4162	30/04/2004	2	Holstein	1328	15030,2	11,32	19/12/2007	Cull for Production
1007	4163	02/05/2004	3	Holstein	1858	38792,1	20,88	03/06/2009	Mastitis
1008	4164	02/05/2004	3	Holstein	1678	26752,4	15,94	05/12/2008	Cull for Production
1009	4165	03/05/2004	1	Holstein	1159	9473,6	8,17	06/07/2007	Abortion
1010	4166	03/05/2004	0	Holstein	850	0	0	31/08/2006	maag probleem
1011	4167	05/05/2004	4	Holstein	2708	68799,4	25,41	04/10/2011	Cull for Production
1012	4168	05/05/2004	5	Holstein	2808	65457,5	23,31	12/01/2012	Cull for Production
1013	4169	05/05/2004	4	Holstein	2297	51472,4	22,41	19/08/2010	Cull for Production
1014	4170	05/05/2004	3	Holstein	1637	23406,1	14,3	28/10/2008	Cull for Production
1015	4171	07/05/2004	3	Holstein	1704	31772,2	18,65	05/01/2009	Cull for Production
1016	4172	07/05/2004	6	Holstein	2813	64791,7	23,03	19/01/2012	Cull for Production
1017	4173	07/05/2004	3	Holstein	1599	23814,8	14,89	22/09/2008	Cull for Production
1018	4174	07/05/2004	3	Holstein	1887	34127,7	18,09	07/07/2009	Mastitis
1019	4175	09/05/2004	3	Holstein	1774	37209,8	20,98	18/03/2009	Mastitis
1020	4177	10/05/2004	2	Holstein	1649	18124,8	10,99	14/11/2008	Mastitis
1021	4178	10/05/2004	3	Holstein	1822	36456,1	20,01	06/05/2009	Cull for Reproductive Reason
1022	4179	10/05/2004	6	Holstein	2802	61823,8	22,06	11/01/2012	Cull for Production
1023	4180	11/05/2004	6	Holstein	3269	96377	29,48	23/04/2013	Limbs
1024	4181	13/05/2004	4	Holstein	2186	45323,6	20,73	08/05/2010	Cull for Reproductive Reason
1025	4182	13/05/2004	3	Holstein	2490	52029,5	20,9	08/03/2011	Cull for Production
1026	4183	14/05/2004	1	Holstein	944	879,3	0,93	14/12/2006	Slag koei
1027	4184	14/05/2004	6	Holstein	2882	86311,9	29,95	04/04/2012	Cull for Bad Udder
1028	4185	14/05/2004	3	Holstein	1747	28681,4	16,42	24/02/2009	Cull for Production
1029	4186	18/05/2004	6	Holstein	3281	79804	24,32	12/05/2013	Bloat
1030	4187	18/05/2004	3	Holstein	1596	21519	13,48	30/09/2008	Cull for Production
1031	4188	19/05/2004	4	Holstein	2395	44673,3	18,65	09/12/2010	maag probleem
1032	4189	19/05/2004	4	Holstein	2225	50072,9	22,5	22/06/2010	Cull for Production
1033	4190	21/05/2004	4	Holstein	2603	59330,4	22,79	07/07/2011	Cull for Production

Figure 7A Data table for analysing exit reasons



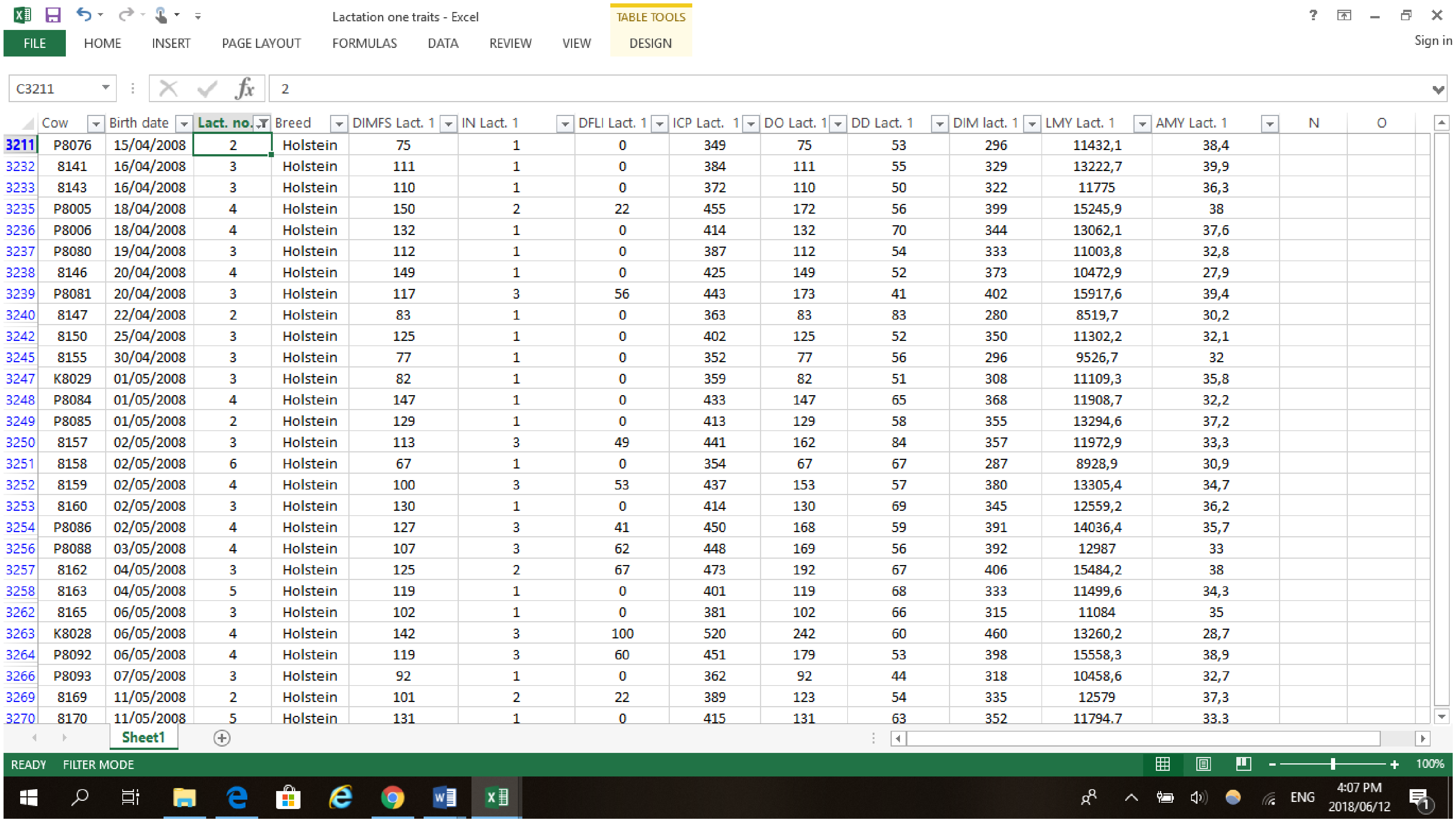
	A	B	C	D	E	F	G
1				Mean daughter performance		AI sire EBVs	
2	Bull ID	Bull's registr. no.	Daughters that completed first lactation (Lact no.≥2)	MY Lactation 1	ICP Lactation 1	MY	ICP
3	MATT	2011298276	113	14017,8	443,72	1005	7
4	SCOOBY DUU	2012387680	96	12203,07	423,91	-670	-6,3
5	TOYSTORY	2011530165	90	13527,2	447,66	744	7
6	MAGOT	2012045924	89	13551,23	449,8	438	2,4
7	TKO	2011944473	89	12938,01	438,1	-221	5,9
8	CLASSIC	2011255714	87	13853,19	460,8	-69	3,6
9	SCHALK	2012643033	83	14222,09	453,58	475	2,89
10	BOSS IRON	2010517122	81	11957,29	432,8	-352	-8,68
11	RUDOLPH	40843732	80	10751,02	396,8	-661	-23
12	WIN 395-ET	2011171127	80	13696,19	433,1	1325	1,52
13	Watha	2011769821	79	12418,61	427,9	378	-1,71
14	RICHMAN	2012507972	78	13621,78	422,35	1021	1,8
15	POTTER	2011148455	74	13213,11	447,82	384	-2
16	HYATT	2011798085	71	13214,86	426,58	318	-11,4
17	LAURENZO	2010464671	71	11462,49	396,01	465	-12
18	GABOR	2012377012	67	15427,97	461,45	1679	5,3
19	PONTIAC	2011559172	65	11410,34	389,09	-356	-22
20	COLBY	2012038507	65	14035,86	439,37	344	-13,3
21	ARMSTRONG	2011603103	65	14160,48	483,74	656	24,3
22	DOLMAN	2011652555	64	12093,32	437,19	353	16
23	JACK	2012436115	63	13366,37	407,02	728	-5,1
24	DECEMBER	2010900245	63	12393,72	428,54	464	14
25	SABI	39503842	62	12077,33	410,52	375	-4,5
26	ROLAND(USA)	2012658890	62	13856,49	436,02	849	-6
27	PALM	2011581937	62	14543,89	444,73	690	19,1
28	ROLAND 2351	41123035	62	13170,71	448,57	1174	17,8

Figure 8A Data table built to analyse the relationship between AI sire EBVs and progeny performance



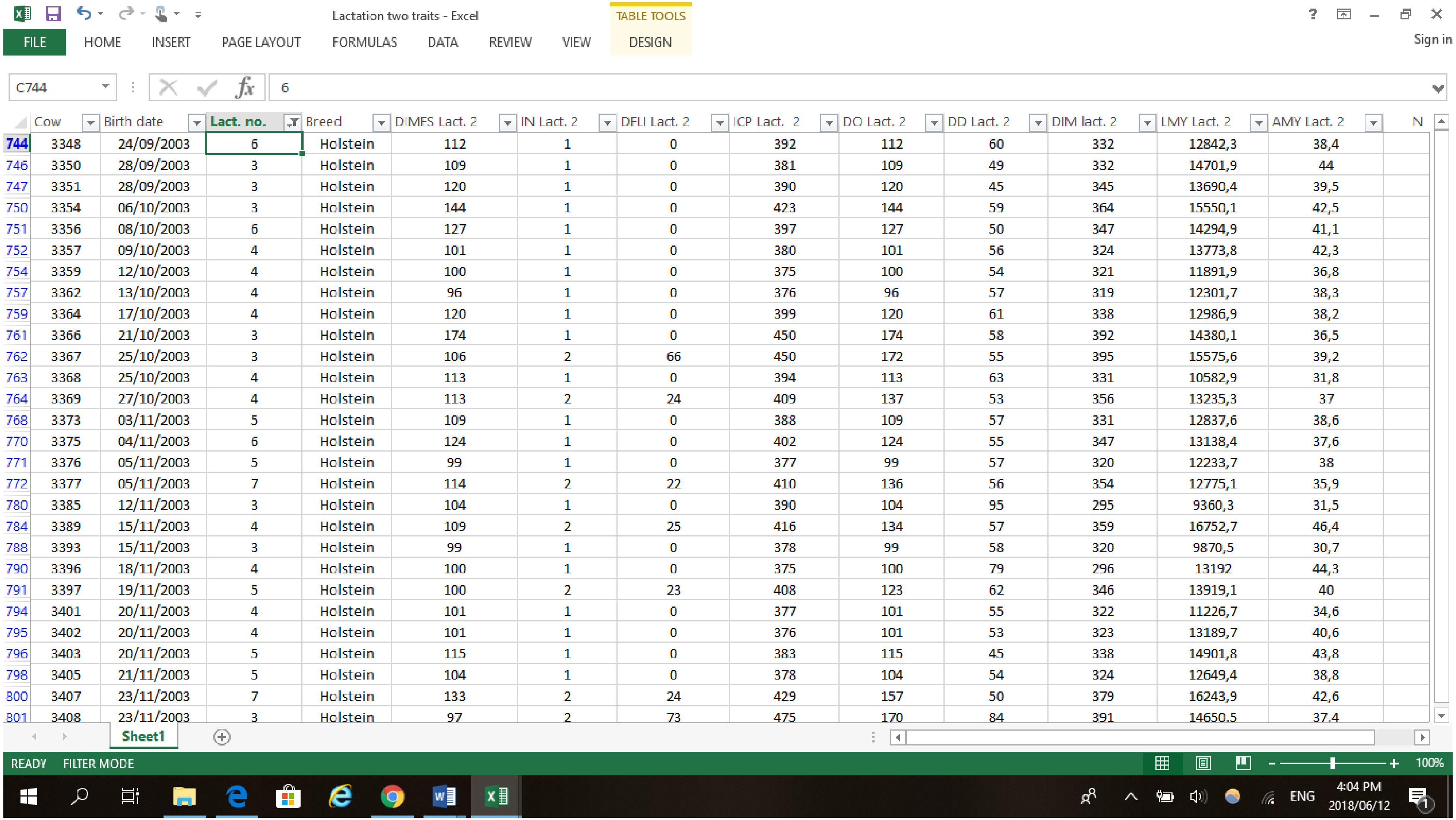
	Cow	Birth date	Lact. no.	Breed	AFS	AFConc	IN Heifer	DFLI Heifer	AFC
1730	5317	16/10/2005	3	Holstein	19,3	19,3	1	0	28,31
1731	H5048	16/10/2005	5	Holstein	16,77	16,77	1	0	26,6
1732	H5009	17/10/2005	2	Holstein	16,04	16,04	1	0	24,89
1733	5318	18/10/2005	4	Holstein	18,94	18,94	1	0	27,88
1734	5319	18/10/2005	3	Holstein	17,23	17,23	1	0	26,33
1735	5320	19/10/2005	4	Holstein	15,02	15,02	1	0	24,07
1736	5321	19/10/2005	3	Holstein	15,49	16,77	2	39	26,04
1737	5322	19/10/2005	4	Holstein	16,83	16,83	1	0	25,84
1738	5323	19/10/2005	3	Holstein	15,29	15,29	1	0	24,56
1739	5324	19/10/2005	3	Holstein	15,02	15,02	1	0	24,2
1740	H5066	20/10/2005	4	Holstein	16,6	16,6	1	0	25,97
1741	5325	21/10/2005	3	Holstein	15,75	15,75	1	0	24,76
1742	5326	22/10/2005	1	Holstein	15,49	15,49	1	0	24,4
1743	5327	23/10/2005	2	Holstein	15,09	17,16	3	63	25,25
1744	5328	24/10/2005	1	Holstein	16,93	17,56	2	19	26,56
1745	5329	25/10/2005	3	Holstein	15,02	15,02	1	0	24,16
1747	5331	25/10/2005	2	Holstein	15,42	15,42	1	0	24,43
1748	5332	25/10/2005	1	Holstein	16,77	16,77	1	0	25,61
1749	5333	25/10/2005	3	Holstein	16,44	16,44	1	0	25,41
1753	H5044	26/10/2005	1	Holstein	17,19	17,19	1	0	25,87
1754	5336	27/10/2005	2	Holstein	16,64	18,74	2	64	27,42
1755	5337	27/10/2005	2	Holstein	14,96	14,96	1	0	23,9
1756	5338	27/10/2005	3	Holstein	16,08	16,08	1	0	25,22
1757	5339	27/10/2005	2	Holstein	18,94	19,79	2	26	29,56
1758	5340	27/10/2005	3	Holstein	14,79	14,79	1	0	23,9
1759	5341	30/10/2005	3	Holstein	15,12	15,12	1	0	24,2
1760	5342	30/10/2005	2	Holstein	16,57	16,57	1	0	25,55
1761	5343	30/10/2005	3	Holstein	18,74	19,4	2	20	28,34

Figure 9A Data table for analysing heifer traits



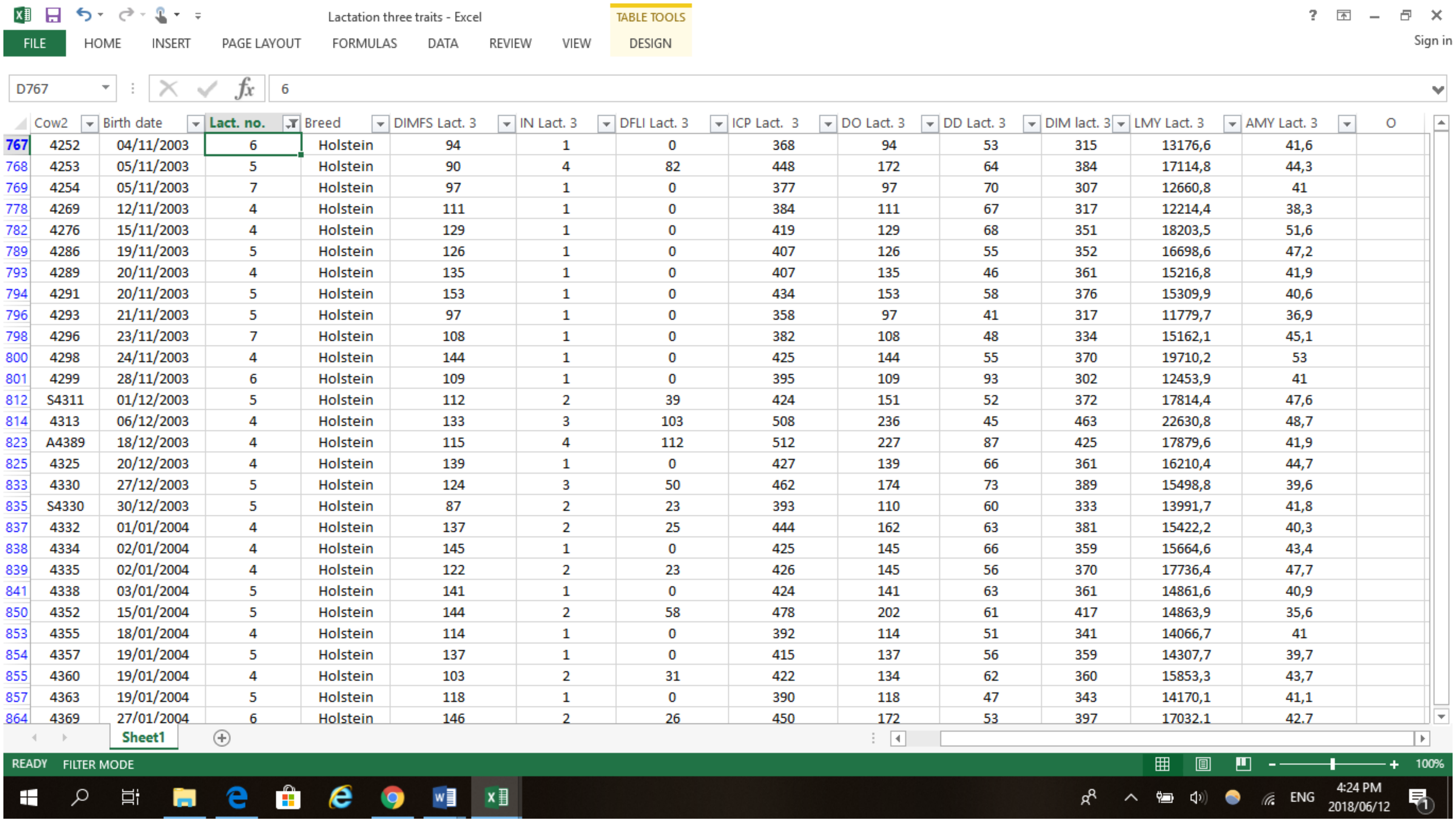
	Cow	Birth date	Lact. no.	Breed	DIMFS Lact. 1	IN Lact. 1	DFLI Lact. 1	ICP Lact. 1	DO Lact. 1	DD Lact. 1	DIM lact. 1	LMY Lact. 1	AMY Lact. 1	N	O
3211	P8076	15/04/2008	2	Holstein	75	1	0	349	75	53	296	11432,1	38,4		
3232	8141	16/04/2008	3	Holstein	111	1	0	384	111	55	329	13222,7	39,9		
3233	8143	16/04/2008	3	Holstein	110	1	0	372	110	50	322	11775	36,3		
3235	P8005	18/04/2008	4	Holstein	150	2	22	455	172	56	399	15245,9	38		
3236	P8006	18/04/2008	4	Holstein	132	1	0	414	132	70	344	13062,1	37,6		
3237	P8080	19/04/2008	3	Holstein	112	1	0	387	112	54	333	11003,8	32,8		
3238	8146	20/04/2008	4	Holstein	149	1	0	425	149	52	373	10472,9	27,9		
3239	P8081	20/04/2008	3	Holstein	117	3	56	443	173	41	402	15917,6	39,4		
3240	8147	22/04/2008	2	Holstein	83	1	0	363	83	83	280	8519,7	30,2		
3242	8150	25/04/2008	3	Holstein	125	1	0	402	125	52	350	11302,2	32,1		
3245	8155	30/04/2008	3	Holstein	77	1	0	352	77	56	296	9526,7	32		
3247	K8029	01/05/2008	3	Holstein	82	1	0	359	82	51	308	11109,3	35,8		
3248	P8084	01/05/2008	4	Holstein	147	1	0	433	147	65	368	11908,7	32,2		
3249	P8085	01/05/2008	2	Holstein	129	1	0	413	129	58	355	13294,6	37,2		
3250	8157	02/05/2008	3	Holstein	113	3	49	441	162	84	357	11972,9	33,3		
3251	8158	02/05/2008	6	Holstein	67	1	0	354	67	67	287	8928,9	30,9		
3252	8159	02/05/2008	4	Holstein	100	3	53	437	153	57	380	13305,4	34,7		
3253	8160	02/05/2008	3	Holstein	130	1	0	414	130	69	345	12559,2	36,2		
3254	P8086	02/05/2008	4	Holstein	127	3	41	450	168	59	391	14036,4	35,7		
3256	P8088	03/05/2008	4	Holstein	107	3	62	448	169	56	392	12987	33		
3257	8162	04/05/2008	3	Holstein	125	2	67	473	192	67	406	15484,2	38		
3258	8163	04/05/2008	5	Holstein	119	1	0	401	119	68	333	11499,6	34,3		
3262	8165	06/05/2008	3	Holstein	102	1	0	381	102	66	315	11084	35		
3263	K8028	06/05/2008	4	Holstein	142	3	100	520	242	60	460	13260,2	28,7		
3264	P8092	06/05/2008	4	Holstein	119	3	60	451	179	53	398	15558,3	38,9		
3266	P8093	07/05/2008	3	Holstein	92	1	0	362	92	44	318	10458,6	32,7		
3269	8169	11/05/2008	2	Holstein	101	2	22	389	123	54	335	12579	37,3		
3270	8170	11/05/2008	5	Holstein	131	1	0	415	131	63	352	11794,7	33,3		

Figure 10A Data table for analysing lactation one traits



	Cow	Birth date	Lact. no.	Breed	DIMFS Lact. 2	IN Lact. 2	DFLI Lact. 2	ICP Lact. 2	DO Lact. 2	DD Lact. 2	DIM lact. 2	LMY Lact. 2	AMY Lact. 2	N
744	3348	24/09/2003	6	Holstein	112	1	0	392	112	60	332	12842,3	38,4	
746	3350	28/09/2003	3	Holstein	109	1	0	381	109	49	332	14701,9	44	
747	3351	28/09/2003	3	Holstein	120	1	0	390	120	45	345	13690,4	39,5	
750	3354	06/10/2003	3	Holstein	144	1	0	423	144	59	364	15550,1	42,5	
751	3356	08/10/2003	6	Holstein	127	1	0	397	127	50	347	14294,9	41,1	
752	3357	09/10/2003	4	Holstein	101	1	0	380	101	56	324	13773,8	42,3	
754	3359	12/10/2003	4	Holstein	100	1	0	375	100	54	321	11891,9	36,8	
757	3362	13/10/2003	4	Holstein	96	1	0	376	96	57	319	12301,7	38,3	
759	3364	17/10/2003	4	Holstein	120	1	0	399	120	61	338	12986,9	38,2	
761	3366	21/10/2003	3	Holstein	174	1	0	450	174	58	392	14380,1	36,5	
762	3367	25/10/2003	3	Holstein	106	2	66	450	172	55	395	15575,6	39,2	
763	3368	25/10/2003	4	Holstein	113	1	0	394	113	63	331	10582,9	31,8	
764	3369	27/10/2003	4	Holstein	113	2	24	409	137	53	356	13235,3	37	
768	3373	03/11/2003	5	Holstein	109	1	0	388	109	57	331	12837,6	38,6	
770	3375	04/11/2003	6	Holstein	124	1	0	402	124	55	347	13138,4	37,6	
771	3376	05/11/2003	5	Holstein	99	1	0	377	99	57	320	12233,7	38	
772	3377	05/11/2003	7	Holstein	114	2	22	410	136	56	354	12775,1	35,9	
780	3385	12/11/2003	3	Holstein	104	1	0	390	104	95	295	9360,3	31,5	
784	3389	15/11/2003	4	Holstein	109	2	25	416	134	57	359	16752,7	46,4	
788	3393	15/11/2003	3	Holstein	99	1	0	378	99	58	320	9870,5	30,7	
790	3396	18/11/2003	4	Holstein	100	1	0	375	100	79	296	13192	44,3	
791	3397	19/11/2003	5	Holstein	100	2	23	408	123	62	346	13919,1	40	
794	3401	20/11/2003	4	Holstein	101	1	0	377	101	55	322	11226,7	34,6	
795	3402	20/11/2003	4	Holstein	101	1	0	376	101	53	323	13189,7	40,6	
796	3403	20/11/2003	5	Holstein	115	1	0	383	115	45	338	14901,8	43,8	
798	3405	21/11/2003	5	Holstein	104	1	0	378	104	54	324	12649,4	38,8	
800	3407	23/11/2003	7	Holstein	133	2	24	429	157	50	379	16243,9	42,6	
801	3408	23/11/2003	3	Holstein	97	2	73	475	170	84	391	14650,5	37,4	

Figure 11A Data table for analysing lactation two traits



	Cow2	Birth date	Lact. no.	Breed	DIMFS Lact. 3	IN Lact. 3	DFLI Lact. 3	ICP Lact. 3	DO Lact. 3	DD Lact. 3	DIM lact. 3	LMY Lact. 3	AMY Lact. 3	O
767	4252	04/11/2003	6	Holstein	94	1	0	368	94	53	315	13176,6	41,6	
768	4253	05/11/2003	5	Holstein	90	4	82	448	172	64	384	17114,8	44,3	
769	4254	05/11/2003	7	Holstein	97	1	0	377	97	70	307	12660,8	41	
778	4269	12/11/2003	4	Holstein	111	1	0	384	111	67	317	12214,4	38,3	
782	4276	15/11/2003	4	Holstein	129	1	0	419	129	68	351	18203,5	51,6	
789	4286	19/11/2003	5	Holstein	126	1	0	407	126	55	352	16698,6	47,2	
793	4289	20/11/2003	4	Holstein	135	1	0	407	135	46	361	15216,8	41,9	
794	4291	20/11/2003	5	Holstein	153	1	0	434	153	58	376	15309,9	40,6	
796	4293	21/11/2003	5	Holstein	97	1	0	358	97	41	317	11779,7	36,9	
798	4296	23/11/2003	7	Holstein	108	1	0	382	108	48	334	15162,1	45,1	
800	4298	24/11/2003	4	Holstein	144	1	0	425	144	55	370	19710,2	53	
801	4299	28/11/2003	6	Holstein	109	1	0	395	109	93	302	12453,9	41	
812	S4311	01/12/2003	5	Holstein	112	2	39	424	151	52	372	17814,4	47,6	
814	4313	06/12/2003	4	Holstein	133	3	103	508	236	45	463	22630,8	48,7	
823	A4389	18/12/2003	4	Holstein	115	4	112	512	227	87	425	17879,6	41,9	
825	4325	20/12/2003	4	Holstein	139	1	0	427	139	66	361	16210,4	44,7	
833	4330	27/12/2003	5	Holstein	124	3	50	462	174	73	389	15498,8	39,6	
835	S4330	30/12/2003	5	Holstein	87	2	23	393	110	60	333	13991,7	41,8	
837	4332	01/01/2004	4	Holstein	137	2	25	444	162	63	381	15422,2	40,3	
838	4334	02/01/2004	4	Holstein	145	1	0	425	145	66	359	15664,6	43,4	
839	4335	02/01/2004	4	Holstein	122	2	23	426	145	56	370	17736,4	47,7	
841	4338	03/01/2004	5	Holstein	141	1	0	424	141	63	361	14861,6	40,9	
850	4352	15/01/2004	5	Holstein	144	2	58	478	202	61	417	14863,9	35,6	
853	4355	18/01/2004	4	Holstein	114	1	0	392	114	51	341	14066,7	41	
854	4357	19/01/2004	5	Holstein	137	1	0	415	137	56	359	14307,7	39,7	
855	4360	19/01/2004	4	Holstein	103	2	31	422	134	62	360	15853,3	43,7	
857	4363	19/01/2004	5	Holstein	118	1	0	390	118	47	343	14170,1	41,1	
864	4369	27/01/2004	6	Holstein	146	2	26	450	172	53	397	17032,1	42,7	

Figure 12A Data table for analysing lactation three traits

Table 2A Categories assigned to exit reasons in herd A

Category	Exit reason
Production	Cull for production
Reproduction	Cull for reproductive reason, Abortion, Dystocia, Calf dead in uterus, Prolapse uterus, Dirty uterus, Metritis, Reproduction disease, Torn uterus, Sterility, Early calf, Freemartin, Caesarean
Mastitis	Mastitis, E-coli mastitis, Blue udder
Heath related	Pneumonia (BRD), Stifle muscle, Other illness, Anaplasmosis, Leptospirosis, Cull for pneumonia, Rapture/Hernia, Bovine Leukaemia Virus, Infectious disease, Lumpy skin disease, Blind, Jaundice, Cyst, Cull for poisoning
Conformation	Limbs, Cull for bad udder, Cull for bad body, Feet/Hoof problems, Growth retardation
Accident	Accident, Injury, Fracture, Wire in stomach, Wire in heart
Metabolic	Bloat, Twisted gut, Stomach problem, Intestine bleed, Ketosis, Diarrhoea, Milk fever, Metabolic disease, Peritonitis, Stomach sore/bleed, Displaced abomasum, Cull for enteritis
Missing or Sold	Transfer to another herd, Missing, Sold
Cull for other reason	Abnormal, Slaughter, Died, Unknown Slaughter

Table 3A Categories assigned to exit reasons in herd B

Category	Exit reason
Production	Cull for production, Cull for low profitability
Reproduction	Cull for fertility, Cull for abortion, Heifer cull for fertility, Cull for reproductive reason, Cull for no conception, Heifer cull for abortion, Abortion, Dystocia, Prolapse uterus, Heifer cull for no conception, Freemartin
Mastitis	Cull high SCC, Cull for mastitis, Mastitis
Heath related	Sickly, Other illness, Anaplasmosis, Pneumonia (B.R.D.), Septicaemia, Liver infection/abscess, Cull facial eczema, Redwater, Infectious diseases, Pneumonia, Cull for pneumonia, Calf dipthera, Clostridial disease, Cull for cancer, EBL, Cull for blindness, Poisoning
Conformation	Cull for bad udder, Limbs, Heifer cull for size/index, Cull for limbs/structure, Growth retardation, Genetic deformity, Pelvis, Heifer cull for Limbs
Accident	Accident, Fracture, Hip dislocation, Snake bite, Rectal tear
Metabolic	Metabolic disease, Pasteurella viral diarrhoea, Diarrhoea, Milk fever, Twisted gut, Cull for enteritis, Ruptured stomach ulcer
Sold	Sold
Cull for other reason	Heifer cull for other reason, Abnormal, Premature, Various, Died, Euthanasia

Addendum B: Additional results for producer A

Table 1B Mean and standard deviation for heifer reproduction traits grouped within year of birth for herd A

		AFS		AFConc		IN		DFLI		AFC	
Years	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2002	340	16.33^{c}	3.63	17.18^{de}	3.89	1.53^{ef}	0.81	25.86^{de}	54.20	26.24^{de}	4.12
2003	371	15.86^{d}	2.94	16.86^{e}	3.19	1.57^{def}	0.78	30.51^{cd}	54.29	25.93^{e}	3.14
2004	391	16.73^{b}	1.92	17.61^{bc}	2.58	1.68^{bcd}	0.93	26.67^{de}	49.93	26.62^{bcd}	2.55
2005	462	16.73^{b}	2.51	17.74^{b}	3.32	1.64^{cde}	0.91	30.65^{cd}	60.30	26.72^{bc}	3.30
2006	492	17.60^{a}	2.77	18.83^{a}	4.22	1.63^{cdef}	0.96	37.60^{ab}	95.58	27.83^{a}	4.23
2007	500	16.72^{b}	2.55	17.79^{b}	3.32	1.71^{abc}	1.11	32.34^{bcd}	76.76	26.83^{b}	3.36
2008	588	16.24^{c}	1.84	17.4^{cd}	3.04	1.69^{bcd}	1.15	35.39^{abc}	76.88	26.43^{cd}	3.06
2009	489	15.05^{ef}	1.18	16.02^{f}	2.19	1.76^{ab}	1.13	29.44^{d}	56.51	25.09^{f}	2.19
2010	606	14.94^{f}	1.35	16.06^{f}	2.49	1.82^{a}	1.23	33.97^{bc}	64.96	25.07^{f}	2.45
2011	889	15.66^{d}	1.47	16.97^{e}	2.82	1.80^{a}	1.07	39.87^{a}	75.06	26.03^{e}	2.84
2012	676	15.09^{ef}	0.97	15.82^{f}	1.72	1.64^{cde}	0.98	22.04^{e}	43.07	24.90^{f}	1.72
2013	664	15.17^{e}	1.26	15.90^{f}	1.79	1.70^{bc}	0.99	22.31^{e}	36.97	24.94^{f}	1.83
2014	318	14.33^{g}	0.92	14.78^{g}	1.27	1.51^{f}	0.90	13.84^{f}	27.74	23.84^{g}	1.30

Means within column classification followed by different subscripts differ ($P<0.05$); AFS=age at first service (months); AFConc=age at first conception (months); IN=insemination number; DFLI=days between first and last insemination; AFC=age at first calving (months); SD=standard deviation

Table 2B Mean and standard deviation for reproduction traits grouped within year of birth for herd A

			DIMFS		IN		DFLI		ICP		DO		DD	
	Year	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lact 1	2002	267	119.30^{b}	43.81	2.05^{cd}	1.68	51.69^{abc}	87.94	452.20^{ab}	98.47	171.00^{ab}	99.24	72.31^{a}	28.67
	2003	299	92.70^{f}	35.04	1.99^{cd}	1.42	36.22^{d}	59.45	406.50^{gh}	69.69	128.90^{e}	69.55	62.96^{cde}	18.89
	2004	332	106.00^{de}	34.00	1.95^{d}	1.51	36.34^{d}	65.50	417.30^{fg}	71.67	142.40^{d}	72.36	61.54^{ef}	20.01
	2005	384	112.20^{c}	30.78	1.94^{d}	1.47	38.31^{d}	69.98	427.50^{ef}	77.71	150.60^{cd}	77.27	65.08^{bcd}	27.88
	2006	395	122.20^{b}	33.84	2.36^{ab}	2.03	53.64^{ab}	86.16	451.30^{ab}	94.65	175.90^{a}	92.96	65.33^{bcd}	33.74
	2007	417	127.90^{a}	24.98	2.35^{ab}	1.96	48.55^{bc}	74.52	453.30^{a}	77.38	176.40^{a}	78.15	66.28^{bc}	30.23
	2008	498	109.80^{cd}	27.92	2.17^{bc}	1.69	42.64^{cd}	64.82	429.70^{de}	71.89	152.40^{c}	72.16	67.09^{b}	26.45
	2009	395	103.20^{e}	28.32	2.33^{ab}	1.99	48.95^{abc}	76.81	430.60^{de}	83.16	152.10^{cd}	84.28	66.37^{bc}	22.46
	2010	478	112.40^{c}	30.29	2.28^{ab}	1.71	50.28^{abc}	73.29	439.00^{cd}	80.54	162.70^{b}	81.81	62.94^{de}	22.78
	2011	656	107.00^{de}	35.86	2.37^{a}	1.63	57.20^{a}	79.47	441.30^{bc}	88.53	164.30^{b}	87.99	62.95^{de}	25.86
	2012	493	103.20^{e}	28.51	2.29^{ab}	1.74	47.16^{c}	67.50	428.40^{e}	74.54	150.40^{cd}	73.18	58.50^{fg}	21.33
	2013	142	102.60^{f}	23.20	1.61^{e}	0.94	17.86^{e}	29.40	398.30^{h}	37.09	120.40^{e}	36.92	54.89^{g}	14.38
Lact 2	2002	211	85.80^{e}	24.87	2.20^{d}	1.49	49.82^{bc}	70.30	412.60^{e}	75.13	135.60^{f}	76.18	72.83^{de}	29.51
	2003	232	103.70^{d}	21.85	2.24^{cd}	1.75	50.88^{bc}	72.92	431.30^{d}	76.34	154.50^{e}	76.92	67.05^{ef}	26.53
	2004	232	115.10^{b}	30.76	2.15^{d}	1.39	45.06^{c}	61.05	437.00^{cd}	67.74	160.20^{de}	67.08	75.65^{cd}	36.82
	2005	241	131.40^{a}	40.46	2.15^{d}	1.62	50.06^{bc}	79.22	458.60^{b}	89.66	182.80^{b}	90.34	82.44^{ab}	42.65
	2006	286	133.60^{a}	29.15	2.51^{abc}	1.90	63.45^{a}	89.78	473.50^{a}	93.29	197.00^{a}	94.66	80.96^{abc}	38.96
	2007	285	109.30^{c}	30.46	2.64^{a}	1.96	63.33^{a}	78.79	449.80^{bc}	84.87	172.90^{bc}	86.33	79.54^{bc}	38.42
	2008	323	109.40^{c}	28.20	2.49^{abc}	1.90	56.54^{ab}	78.13	442.70^{cd}	82.71	166.00^{cde}	81.94	79.50^{bc}	37.99
	2009	256	115.00^{b}	28.50	2.56^{ab}	1.83	57.34^{ab}	70.45	450.10^{bc}	75.61	172.30^{bcd}	75.05	85.75^{a}	39.70
	2010	306	109.00^{c}	29.48	2.28^{cd}	1.59	48.08^{bc}	66.41	433.50^{d}	72.13	157.00^{e}	72.34	77.75^{bcd}	40.13
	2011	374	110.10^{c}	29.61	2.32^{bcd}	1.68	45.98^{c}	62.24	433.80^{d}	68.67	156.10^{e}	68.03	66.30^{f}	28.30
	2012	77	107.20^{cd}	24.19	1.53^{e}	0.85	15.40^{d}	24.52	398.60^{e}	32.89	122.60^{f}	34.03	55.32^{g}	17.41
Lact 3	2002	128	112.20^{bc}	34.63	2.21^{bcd}	1.68	44.02^{bc}	63.85	433.90^{c}	73.16	156.20^{c}	72.53	73.27^{c}	30.85
	2003	122	117.30^{bc}	30.80	2.00^{cd}	1.59	44.29^{bc}	80.18	439.10^{c}	86.48	161.60^{c}	88.43	74.04^{bc}	32.74
	2004	128	135.60^{a}	40.36	2.23^{bc}	1.99	52.20^{bc}	83.12	463.40^{ab}	95.07	187.80^{ab}	93.32	78.94^{abc}	45.35
	2005	138	138.20^{a}	42.29	2.37^{bc}	1.63	53.66^{bc}	66.69	467.40^{a}	72.29	191.90^{a}	73.97	82.75^{a}	42.66
	2006	156	118.50^{b}	27.52	2.91^{a}	2.02	75.39^{a}	82.99	468.20^{a}	86.56	193.80^{a}	88.14	81.53^{ab}	41.20
	2007	170	113.30^{bc}	24.10	2.47^{b}	1.78	58.74^{b}	73.11	449.40^{bc}	74.70	172.10^{bc}	76.95	80.78^{abc}	37.36
	2008	168	115.30^{bc}	35.24	2.23^{bc}	1.48	46.73^{bc}	57.24	439.10^{c}	64.49	162.10^{c}	64.66	76.54^{abc}	35.23
	2009	117	117.80^{bc}	34.44	2.25^{bc}	1.78	49.46^{bc}	75.51	444.40^{bc}	86.43	167.30^{c}	85.45	78.70^{abc}	36.49
	2010	119	118.80^{b}	33.42	2.20^{bcd}	1.51	41.00^{c}	54.61	438.00^{c}	64.18	159.80^{c}	63.78	75.50^{abc}	36.30
	2011	25	105.10^{c}	21.79	1.52^{d}	1.48	12.60^{d}	34.41	396.50^{d}	36.90	117.70^{d}	35.75	68.36^{c}	34.38

Means within column classification followed by different subscripts differ ($P<0.05$); DIMFS=days in milk at first service; IN=insemination number; DFLI=days between first and last insemination; ICP=inter calving period (days); DO=days open; DD=days dry; SD=standard deviation

Table 3B Mean and standard deviation for production traits grouped within year of birth for herd A

			DIM		LMY		AMY	
	Year	n	Mean	SD	Mean	SD	Mean	SD
Lact 1	2002	267	379.90^{ab}	84.01	12422^{ef}	3099	32.69^{ef}	3.48
	2003	299	343.50^{e}	62.23	11210^{h}	2604	32.68^{f}	3.84
	2004	332	355.80^{de}	68.02	11758^{g}	2752	32.84^{ef}	3.58
	2005	384	362.40^{cd}	68.98	12004^{fg}	2761	32.94^{ef}	4.03
	2006	395	385.90^{a}	82.59	13421^{ab}	3428	34.55^{c}	4.25
	2007	417	387.00^{a}	71.87	13144^{bc}	2964	33.77^{d}	3.94
	2008	498	362.60^{cd}	65.94	12587^{de}	2949	34.39^{c}	4.11
	2009	395	364.30^{cd}	76.78	12970^{cd}	3277	35.30^{b}	4.52
	2010	478	376.00^{b}	73.95	13834^{a}	3345	36.48^{a}	4.73
	2011	656	378.30^{ab}	82.83	13461^{ab}	3629	35.29^{b}	4.90
	2012	493	369.90^{bc}	71.52	13386^{b}	3297	35.96^{a}	5.42
	2013	142	343.40^{e}	35.97	11635^{gh}	2247	33.54^{de}	4.52
Lact 2	2002	211	339.80^{f}	64.36	12597^{e}	2671	37.07^{f}	4.65
	2003	232	364.30^{bcd}	69.05	14085^{d}	3074	38.60^{e}	4.24
	2004	232	361.30^{cd}	60.02	14323^{cd}	2733	39.63^{d}	4.22
	2005	241	376.10^{b}	86.89	14760^{bc}	3725	39.20^{de}	4.55
	2006	286	392.50^{a}	79.14	15631^{a}	3418	39.85^{cd}	4.81
	2007	285	370.20^{bc}	74.43	15128^{ab}	3716	40.55^{bc}	5.31
	2008	323	363.20^{cd}	73.04	14990^{b}	3609	41.09^{ab}	5.42
	2009	256	364.30^{bcd}	61.92	14910^{b}	3003	40.70^{bc}	4.84
	2010	306	355.80^{de}	66.44	14664^{bc}	3214	41.06^{ab}	5.35
	2011	374	367.50^{bc}	62.88	15092^{b}	3192	40.90^{b}	5.67
	2012	77	343.30^{ef}	32.99	14601^{bcd}	2346	42.20^{a}	5.25
Lact 3	2002	128	360.60^{b}	61.11	14413^{de}	2690	39.93^{c}	4.61
	2003	122	365.00^{b}	78.71	15169^{cd}	3297	41.54^{b}	4.25
	2004	128	384.50^{a}	80.83	16020^{ab}	3510	41.94^{ab}	4.46
	2005	138	384.90^{a}	64.48	15739^{bc}	3342	40.89^{bc}	5.16
	2006	156	386.70^{a}	83.23	16744^{a}	4166	43.00^{a}	5.60
	2007	170	368.80^{b}	66.87	16156^{ab}	3661	43.51^{a}	5.63
	2008	168	362.60^{b}	56.09	15650^{bc}	3188	42.89^{a}	5.33
	2009	117	365.70^{b}	71.28	15715^{bc}	3605	42.92^{a}	5.91
	2010	119	362.80^{b}	60.20	15738^{bc}	3372	43.28^{a}	6.88
	2011	25	327.50^{c}	46.63	13769^{e}	3293	41.35^{abc}	6.23

Means within lactation and column classification followed by different subscripts differ (*P*<0.05); DIM=days in milk; LMY=lactation milk yield (kg); AMY=average daily milk yield (kg/day); SD=standard deviation

Table 4B Number distribution of exit reasons for animals born between 2002 and 2015 in herd A

Exit reason	Heifer	Lact 1	Lact 2	Lact 3	Lact 4+	Total
Production	73[a]	392	518	422	306	1711
Mastitis	10[a]	204	280	280	328	1102
Reproduction	266	235	246	171	159	1077
Metabolic	80	83	102	84	62	411
Health related	247	57	43	28	26	401
Missing or Sold	362	4	8	1	1	376
Conformation	51	80	56	69	119	375
Accident	46	70	76	56	50	298
Cull for other reason	305	123	100	94	93	715
Total	1440	1248	1429	1205	1144	6466

(a)Heifers culled due to mastitis and production reasons can be attributed to incorrect allocation of culling reasons

Table 5B Percentage distribution of exit reasons for animals born between 2002 and 2015 in herd A

Exit reason	Heifer	Lact 1	Lact 2	Lact 3	Lact 4+	Total
Production	1.13	6.06	8.01	6.53	4.73	26.46
Mastitis	0.15	3.15	4.33	4.33	5.07	17.04
Reproduction	4.11	3.63	3.80	2.64	2.46	16.66
Metabolic	1.24	1.28	1.58	1.30	0.96	6.36
Health related	3.82	0.88	0.67	0.43	0.40	6.20
Missing or Sold	5.60	0.06	0.12	0.02	0.02	5.82
Conformation	0.79	1.24	0.87	1.07	1.84	5.80
Accident	0.71	1.08	1.18	0.87	0.77	4.61
Cull for other reason	4.72	1.9	1.55	1.45	1.44	11.06
Total %	22.27	19.3	22.1	18.64	17.69	100

Percentages were calculated as a proportion of the total number of animals that left the herd (6466 animals)

Addendum C: Additional results for producer B

Table 1C Mean and standard deviation for heifer reproduction traits grouped within year of birth for herd B

		AFS		AFConc		IN		DFLI		AFC	
Years	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2002	94	14.19^{bc}	0.48	14.85^{cde}	1.35	1.40^{d}	0.59	20.03^{cde}	42.75	24.05^{bcd}	1.31
2003	93	14.06^{cde}	1.48	14.69^{cde}	2.02	1.65^{cd}	1.20	19.06^{de}	36.66	24.00^{bcde}	1.93
2004	197	15.73^{a}	1.60	16.72^{a}	2.38	1.78^{bc}	1.13	30.18^{ab}	53.69	25.69^{a}	2.50
2005	184	15.51^{a}	1.19	16.69^{a}	2.41	1.91^{ab}	1.23	35.72^{a}	62.55	25.73^{a}	2.43
2006	240	14.31^{b}	0.84	15.08^{b}	1.67	1.78^{bc}	1.05	23.52^{bcd}	45.32	24.14^{b}	1.67
2007	217	14.24^{bc}	0.79	15.00^{bc}	1.41	1.78^{bc}	0.99	23.14^{cd}	36.35	24.05^{bcd}	1.45
2008	244	13.68^{g}	0.52	14.58^{e}	1.48	1.93^{ab}	1.24	27.50^{bc}	42.97	23.66^{ef}	1.51
2009	304	14.11^{cd}	0.71	14.99^{bc}	1.40	1.98^{a}	1.36	26.90^{bcd}	39.06	24.07^{bc}	1.43
2010	263	13.92^{ef}	0.68	14.59^{e}	1.04	1.89^{ab}	1.06	20.22^{cde}	25.14	23.61^{f}	1.08
2011	344	13.85^{f}	0.69	14.68^{de}	1.29	1.98^{a}	1.04	25.37^{bcd}	34.60	23.72^{def}	1.35
2012	307	14.08^{cd}	0.80	14.88^{bcd}	1.43	1.79^{bc}	0.99	24.12^{bcd}	38.91	23.95^{bcde}	1.47
2013	353	14.02^{de}	0.78	14.78^{cde}	1.38	1.89^{ab}	1.15	23.11^{cd}	34.64	23.82^{cdef}	1.45
2014	332	14.22^{bc}	0.87	14.78^{cde}	1.34	1.65^{cd}	0.99	17.21^{e}	29.67	23.77^{def}	1.45
2015	62	13.45^{g}	1.43	13.53^{f}	1.49	1.13^{e}	0.34	2.53^{f}	6.66	22.49^{g}	1.61

Means within column classification followed by different subscripts differ ($P<0.05$); AFS=age at first service (months); AFConc=age at first conception (months); IN=insemination number; DFLI=days between first and last insemination; AFC=age at first calving (months); SD=standard deviation

Table 2C Mean and standard deviation for reproduction traits grouped within year of birth for herd B

			DIMFS		IN		DFLI		ICP		DO		DD	
	Year	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lact 1	2002	86	86.28^{ab}	21.68	2.01^{abc}	1.47	33.17^{abcd}	56.89	401.30^{ab}	61.52	119.50^{ab}	61.11	67.30^{ab}	16.82
	2003	72	90.18^{a}	35.67	2.29^{a}	1.42	42.78^{a}	55.52	412.40^{a}	61.97	133.00^{a}	61.29	70.21^{a}	33.47
	2004	164	64.92^{h}	13.87	2.09^{ab}	1.23	38.08^{ab}	53.50	380.30^{efg}	53.75	103.00^{cde}	53.14	59.65^{de}	19.85
	2005	150	71.27^{g}	17.12	1.85^{bcd}	1.11	27.45^{cde}	41.25	378.30^{fg}	45.12	98.70^{e}	44.61	65.43^{b}	20.38
	2006	181	76.48^{de}	18.50	1.71^{d}	0.97	19.76^{e}	30.70	373.60^{g}	35.56	96.20^{e}	34.79	60.34^{de}	10.80
	2007	174	70.82^{g}	16.30	2.28^{a}	1.49	35.21^{abc}	42.03	385.40^{cdef}	45.42	106.00^{cde}	44.21	63.82^{bc}	13.85
	2008	174	79.75^{cd}	19.08	2.02^{abc}	1.35	24.54^{de}	33.95	384.10^{def}	37.67	104.30^{cde}	36.99	66.85^{ab}	15.56
	2009	190	73.75^{fg}	14.91	1.98^{abc}	1.26	26.80^{cde}	35.28	379.70^{fg}	37.13	100.50^{de}	37.27	65.56^{b}	14.81
	2010	194	81.06^{bc}	15.15	1.81^{cd}	1.10	27.22^{cde}	41.71	389.60^{bcde}	43.72	108.30^{bcd}	43.46	66.98^{ab}	16.79
	2011	241	74.98^{ef}	15.11	1.92^{bcd}	1.13	34.87^{abc}	52.77	389.50^{cde}	54.42	109.90^{bc}	55.05	64.95^{bc}	13.95
	2012	220	85.00^{b}	19.69	1.90^{bcd}	1.36	31.04^{bcd}	51.27	394.40^{bc}	54.38	116.00^{b}	54.44	62.27^{cd}	11.03
	2013	242	86.27^{ab}	18.38	1.90^{bcd}	1.25	27.07^{cde}	42.46	392.90^{bcd}	45.64	113.30^{b}	44.59	63.89^{bc}	11.62
	2014	24	88.67^{ab}	18.08	1.04^{e}	0.20	0.12^{f}	0.61	363.40^{g}	21.10	88.80^{e}	18.13	55.13^{e}	10.76
Lact 2	2002	67	69.07^{de}	14.79	1.82^{cd}	1.10	22.94^{cd}	34.86	372.50^{de}	36.28	92.00^{d}	35.06	67.16^{b}	18.90
	2003	49	66.80^{e}	12.39	1.76^{cd}	0.86	23.33^{bcd}	32.05	367.20^{e}	33.78	90.10^{d}	31.77	60.82^{bcd}	20.58
	2004	127	71.28^{de}	16.11	2.01^{bc}	1.12	37.31^{ab}	47.77	389.10^{bc}	48.36	108.60^{b}	48.41	74.76^{a}	30.87
	2005	105	71.34^{cde}	20.19	2.10^{abc}	1.43	32.97^{abc}	46.71	384.60^{bcd}	49.65	104.30^{bcd}	49.01	65.59^{b}	20.34
	2006	145	73.15^{bcd}	20.22	2.37^{a}	1.55	38.99^{a}	44.49	391.60^{bc}	47.30	112.10^{b}	46.89	61.72^{bcd}	16.20
	2007	133	75.57^{bc}	19.48	1.95^{bcd}	1.16	25.90^{bcd}	33.73	380.80^{cde}	37.50	101.50^{cd}	36.88	63.50^{bc}	16.33
	2008	109	69.45^{de}	11.43	2.36^{a}	1.46	37.96^{ab}	43.97	386.60^{bc}	46.13	107.40^{bc}	44.84	64.65^{b}	26.01
	2009	133	76.49^{b}	15.68	1.85^{cd}	1.01	28.19^{bcd}	40.63	386.10^{bc}	42.85	104.70^{bc}	42.37	64.56^{b}	19.06
	2010	121	75.63^{bc}	17.14	1.97^{bcd}	1.20	37.76^{ab}	57.23	393.20^{ab}	59.46	113.40^{b}	59.15	63.77^{bc}	19.99
	2011	171	82.57^{a}	18.90	2.16^{ab}	1.53	41.78^{a}	57.90	403.50^{a}	59.40	124.30^{a}	59.69	59.97^{cd}	15.73
	2012	138	84.83^{a}	18.53	1.70^{d}	0.97	22.59^{d}	35.41	386.30^{bc}	40.57	107.40^{bc}	39.73	58.94^{d}	15.26
Lact 3[a]	2002	51	66.45^{e}	15.45	2.08^{abc}	1.13	31.51	41.00	375.70	44.11	98.00	43.46	64.53^{cd}	23.21
	2003	34	69.79^{cde}	17.20	2.32^{a}	1.25	48.68	53.85	400.50	53.34	118.50	52.47	80.71^{a}	33.66
	2004	84	74.20^{bcd}	18.49	1.76^{cd}	1.06	26.33	39.96	379.10	44.04	100.50	42.94	71.26^{bc}	26.58
	2005	68	70.06^{cde}	16.01	2.15^{ab}	1.55	34.41	47.23	384.70	49.66	104.50	49.02	66.01^{cd}	22.95
	2006	105	74.99^{bc}	17.57	2.20^{a}	1.35	32.61	36.16	386.50	36.04	107.60	36.65	75.68^{ab}	26.00
	2007	84	69.79^{de}	16.08	2.24^{a}	1.36	40.82	51.58	389.70	53.11	110.60	52.54	65.64^{cd}	26.54
	2008	75	76.84^{b}	21.15	1.65^{d}	0.92	28.03	45.23	385.50	48.51	104.90	48.56	63.11^{d}	17.29
	2009	89	72.11^{bcd}	14.56	2.00^{abc}	1.29	37.51	55.51	389.50	57.43	109.60	57.65	62.11^{d}	13.91
	2010	67	83.28^{a}	23.16	2.15^{ab}	1.49	35.66	52.43	399.40	55.29	118.90	55.57	64.57^{cd}	18.82
	2011	92	83.48^{a}	14.68	1.85^{bcd}	1.18	26.29	42.16	388.60	45.86	109.80	44.76	61.78^{d}	16.04

(a)Variation prohibited statistical differences between years for DFLI, DO and ICP; Means within column classification followed by different subscripts differ ($P<0.05$); DIMFS=days in milk at first service; IN=insemination number; DFLI=days between first and last insemination; ICP=inter calving period (days); DO=days open; DD=days dry; SD=standard deviation

Table 3C Mean and standard deviation for production traits grouped within year of birth for herd B

			DIM		LMY		AMY	
	Year	n	Mean	SD	Mean	SD	Mean	SD
Lact 1	2002	86	334.00^{ab}	63.30	6545^{b}	1850	19.42^{de}	3.31
	2003	72	342.20^{a}	53.42	6465^{bc}	1394	18.81^{e}	2.97
	2004	164	320.60^{cde}	53.89	6090^{c}	1291	18.89^{e}	2.54
	2005	150	312.90^{e}	44.45	6246^{bc}	1189	19.90^{cd}	2.96
	2006	181	313.20^{e}	33.66	6360^{bc}	1029	20.18^{c}	2.50
	2007	174	321.60^{cde}	42.75	6978^{a}	1450	21.56^{ab}	3.39
	2008	174	317.30^{cde}	38.70	6518^{bc}	1247	20.41^{c}	2.68
	2009	190	314.10^{de}	36.11	6908^{a}	1281	21.96^{a}	3.29
	2010	194	322.70^{bcd}	45.74	7054^{a}	1678	21.66^{ab}	3.31
	2011	241	324.60^{bcd}	55.21	7063^{a}	1671	21.70^{a}	3.29
	2012	220	332.10^{ab}	54.20	7032^{a}	1620	21.07^{bc}	3.18
	2013	242	329.00^{bc}	43.70	6903^{a}	1244	20.95^{c}	2.73
	2014	24	308.30^{e}	16.70	6530^{bc}	872	21.13^{abc}	2.62
Lact 2	2002	67	305.30^{e}	37.00	7888de	1431	25.69^{c}	3.53
	2003	49	306.30^{e}	38.68	6601^{f}	1266	21.36^{e}	2.91
	2004	127	314.40^{de}	46.35	6771^{f}	1419	21.41^{e}	3.28
	2005	105	319.00^{bcde}	51.15	7008^{f}	1518	21.84^{e}	3.39
	2006	145	329.90^{b}	43.26	7996de	1350	24.18^{d}	3.27
	2007	133	317.30^{cde}	39.56	7747^{e}	1647	24.22^{d}	3.54
	2008	109	322.00^{bcd}	45.60	8277^{d}	1666	25.58^{c}	3.29
	2009	133	321.60^{bcd}	43.72	8738^{c}	1864	27.03^{b}	3.83
	2010	121	329.40^{b}	57.82	9457^{b}	1825	28.85^{a}	4.00
	2011	171	343.50^{a}	55.56	10007^{a}	2077	29.14^{a}	4.50
	2012	138	327.30^{bc}	36.76	9234^{b}	1663	28.15^{a}	4.21
Lact 3	2002	51	311.20^{cde}	44.01	7493^{e}	1384	23.92^{e}	2.90
	2003	34	319.80^{abcde}	50.51	7245^{ef}	1582	22.45^{fg}	3.02
	2004	84	307.90^{e}	39.74	6963^{f}	1304	22.44^{g}	2.76
	2005	68	318.70^{bcde}	44.78	7734^{e}	1458	24.21^{e}	3.44
	2006	105	310.80^{de}	39.60	7355^{ef}	1184	23.64^{ef}	2.97
	2007	84	324.10^{abc}	48.57	9080^{d}	1703	28.04^{d}	4.02
	2008	75	322.40^{abcd}	50.32	9365^{cd}	2147	28.88^{cd}	4.28
	2009	89	327.40^{ab}	57.19	10058^{b}	2732	30.50^{b}	5.09
	2010	67	334.90^{a}	53.79	10684^{a}	2271	31.91^{a}	4.88
	2011	92	326.80^{abc}	44.60	9804^{bc}	1815	29.89^{bc}	3.68

Means within lactation and column classification followed by different subscripts differ ($P<0.05$); DIM=days in milk; LMY=lactation milk yield (kg); AMY=average daily milk yield (kg/day); SD=standard deviation

Table 4C Number distribution of exit reasons for animals born between 2002 and 2015 in herd B

Exit reason	Heifer	Lact 1	Lact 2	Lact 3	Lact 4+	Total
Reproduction	309	336	216	134	147	1142
Mastitis	0	81	132	132	241	586
Production	0	208	127	87	97	519
Conformation	89	55	48	31	89	312
Cull for other reason	98	21	11	13	21	164
Health related	108	18	9	9	8	152
Metabolic	41	8	6	4	15	74
Accident	31	22	7	1	9	70
Sold	30	19	4	6	3	62
Total	706	768	560	417	630	3081

Table 5C Percentage distribution of exit reasons for animals born between 2002 and 2015 in herd B

Exit reasons	Heifer	Lact 1	Lact 2	Lact 3	Lact 4+	Total
Reproduction	10.03	10.91	7.01	4.35	4.77	37.07
Mastitis	0.00	2.63	4.28	4.28	7.82	19.02
Production	0.00	6.75	4.12	2.82	3.15	16.85
Conformation	2.89	1.79	1.56	1.01	2.89	10.13
Cull for other reason	3.18	0.68	0.36	0.42	0.68	5.32
Health related	3.51	0.58	0.29	0.29	0.26	4.93
Metabolic	1.33	0.26	0.19	0.13	0.49	2.40
Accident	1.01	0.71	0.23	0.03	0.29	2.27
Sold	0.97	0.62	0.13	0.19	0.10	2.01
Total %	22.91	24.93	18.18	13.53	20.45	100

Percentages were calculated as a proportion of the total number of animals that left the herd (3081 animals)