A deterministic evaluation of alternative management options for the smallholder dairy cattle production system in South Africa

By

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Declaration

I, Samuel Atanasio Mustafa Abin, declare that this thesis, which I hereby submit for the award of the degree of Philosophiae Doctor in Animal Science at the University of Pretoria, South Africa, is entirely my original work, and has not been submitted for the award of any degree in this or any other tertiary institution. Notably, any parts of the thesis that have been published, and or will be submitted for publication in conferences/journals are done in compliance with the regulations, and requirements of the University of Pretoria.

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Dedication

To my beautiful, and loving wife Mrs. Hania S.A. Elmuhajer, my daughters, Santa, Rozeta Chadu, and Rhoda Riya

Preface

The aim of this thesis was to evaluate alternative management options for the improvement of the smallholder dairy cattle production system in South Africa. Six chapters, addressing a number of topics and objectives, were generated to achieve this aim. Chapter I introduces the current study, by explaining the importance of dairy cattle farming, with particular emphasis on the smallholder system and its limitations. It also presents the aim, and objectives of the thesis. Chapter II presents an overview of the dairy sector in South Africa, and discusses the relevance of the dairy cattle performance traits evaluated in the current study. Additionally, it explains the methodologies used in addressing the objectives used to achieve the aim of this thesis. This includes a detailed discussion of the methodology used in comparative analysis, and the major processes involved in the development, and application of a bio-economic simulation model. Chapter III is a published benchmarking study (*Trop Anim Health Prod*, 2018) that compared the productive and reproductive performance, as well as udder health status, of dairy cows in low-input smallholder, and high-input commercial production systems in South Africa. The objective of such benchmarking was to determine the performance potential of dairy cows under the smallholder system, in order to identify the performance lag as compared to the high-input system, and to develop recommendations for the development of the former. A typical smallholder dairy herd model was developed in Chapter IV, by adaptation, and implementation of a previously developed model for the high-input dairy herd production system in South Africa. This was done by applying a conceptual framework, describing smallholder dairy herd dynamics, breeding, feeding, production costs, and outputs such as production (milk & beef), revenues, and gross margins. The herd model considered, and integrated the biological, and economic factors influencing the smallholder production system, with the goal to determine how best the existing potential in herd profitability can be realized. Chapter V evaluated alternative strategies to improve smallholder dairy herd profitability, by simulating changes to the herd model developed in Chapter IV. Chapter VI gives a summary of the results reported in the previous chapters, discusses their implications on smallholder dairy farming, and presents the concluding remarks, and recommendations on how improvement in smallholder dairy herd profitability may be achieved.

Ethics approval (EC160817-067) for the use of all data in this study was obtained from the Ethics Committee of the Faculty of Natural and Agricultural Sciences at the University of Pretoria.

Thesis outputs

i. Chapter III has been published in a peer-reviewed scientific journal:

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. Tropical Animal Health and Production, 50 (7), 1479-1484.

ii. A poster was presented at the 50th SASAS (South African Society of Animal Science) Congress:

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iii. An oral contribution was presented at the 51st SASAS congress:

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Abstract

The aim of this thesis was to evaluate alternative management options for the smallholder dairy cattle production system in South Africa (SA). Specific objectives included, were to benchmark cow performance in the smallholder (SH) against their counterparts in a high-input system (H), to develop a SH herd model, and to evaluate alternative management options for the improvement of smallholder dairy herd profitability.

Data on production (305-day yields of milk, fat and protein), lactation length, somatic cell count (SCC), and reproductive traits (age at first calving (AFC), and calving interval (CI) obtained from the South African National Dairy Animal Improvement scheme (NDAIS) were used in a benchmarking study. Least squares means per trait were compared between the two systems, and lactation curves for production traits and SCC were plotted. Results revealed that mean yields of milk, fat and protein were significantly ($P<0.05$) lower in the SH (4 097±165, 174±5.1 and 141±4.5 respectively) compared to the H system (6 921±141, 298±4.7, and 245±4.1, respectively). Mean lactation length was significantly ($P<0.05$) shorter for the SH (308±15.1) compared to the H system (346±12.8). Log-transformed SCC was significantly ($P<0.05$) higher in the SH (2.41±0.01) relative to the H system (2.27±0.01). Cows in H herds exhibited typical lactation curves, in contrast to flat and low-peaking curves obtained for the SH system. SH cows had significantly ($P<0.05$) older AFC (30±0.5) than those in the H system (27±0.5). There was no significant difference ($P<0.05$) in CI between the two systems.

A bio-economic SH herd model was developed by adapting a previously developed model for the H system in SA. Parameters used were obtained from NDAIS, survey data, personal communications, and literature. The model integrated herd dynamics, outputs, nutrient energy requirements, management, and their associated economics. Nutrient energy requirements were estimated for maintenance, growth, reproduction, and lactation. The developed SH herd model was used to evaluate alternative herd management options, using the partial budget approach. Milk yield (MY), live weight (LW), AFC, and CI were used as indicators of cow performance. Herd management practices studied were herd size (HS), replacement rate (RR), feeding system (FS), breeding methods (natural service vs artificial insemination), and source of replacement heifers (raising vs. buying in).

Improvements in profitability were attained by increasing MY or increasing herd size, using small to medium sized cows, or reducing AFC, CI or RR. Break-even points were 3 687.4 l/year, 500 kg, 29 months, 420 days and 25% for MY, LW, AFC, CI, and RR, respectively.

Profitability was mostly sensitive to the prices of milk and feed. A drop in the price of milk below R4.50/l or increase in the cost of feed above R5.60/kg DM generally resulted in non-profitability. Relying on pasture only for feed was non-viable, and supplementation of pasture with concentrate was the most profitable feeding system. Feeding systems based on supplementation of pasture with concentrate, and silage were resilient to fluctuations in the price of milk, remaining profitable even when the price dropped to R4.10/l. Using artificial insemination or buying-in replacement heifers are additional management strategies that increase SH dairy farming profitability. These recommended management options should be used in combination for achieving maximum herd profitability.

Keywords: Benchmarking, Bio-economic model, high-input, production, reproduction, simulation, smallholder, somatic cell count

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Abbreviations

ABPSS	Alberta Beef Production Simulation System
AFC	Age at first calving
AFRC	Agricultural and Food Research Council
ARC	Agriculture Research Council
B'	Buying in replacement heifers
BCS	Body condition score
BW	Body weight
cbw	Calf birth weight
CD	Calving date
CE	Calving ease
cmr	Calf mortality rate
cr	Cow culling rate
CI	Calving interval
d	Day
DAFF	Department of Agriculture, Forestry, and Fisheries
DMI	Dry matter intake
ED	Estrus detection
F	Fat
FAO	Food & Agriculture Organization of the United Nations
GL	Gestation length
GLMs	General linear models
H	High-input
ICAR	International Committee for Animal Recording
ID	Identity
INTERGIS	Integrated Registration and Genetic Information System
Kg	Kilogram
LL	Lactation length
LSM	Least squares means
LW	Live weight
M	Milk
ME	Metabolizable energy

MJ	Mega joule
ml	Milliliter
NEB	Negative energy balance
NDAIS	National dairy animal improvement Scheme
NMRIS	National milk recording and improvement scheme
NRC	National Research Council
NRR	Non-return rate
P	Protein
R	Rand
R'	Raising replacement heifers
RR	Replacement rate
SA	South Africa
SCC	Somatic cell count
SCS	Somatic cell score
SE	Standard errors
SH	Smallholder
TAI	Timed artificial insemination
TMR	Total mixed ration
USA	United States of America
ZAR	South African Rand

CHAPTER I

1.1. General introduction

Dairy production has been an important part of the global agricultural system for decades. The livelihoods of more than half a billion people, comprising more than 140 million households, depend on milk production worldwide (Hemme & Otte, 2010; Lacto data, 2019). Dairy farming is increasing in importance globally, driven by the substantial shift in diets, and food consumption patterns towards livestock products (Hoffmann & Baumung, 2013; Herrero *et al.*, 2014; Hanrahan *et al.*, 2018). In addition to its nutritional, and health-promoting attributes, milk production in especially smallholder system, is a reliable resource for income, and poverty alleviation (Ojango *et al.*, 2017). Smallholder milk production also offers employment opportunities within the entire dairy value chain, through the creation of small-scale rural processors, and other intermediaries (Hemme & Otte, 2010).

The smallholder livestock production system is mostly characterized by limited resources, a harsh production environment, and low input-output intensities, compared to the high-input commercial system. Flaten (2002), and Narayanan & Gulati (2002) described smallholder dairy production as a system, which comprises of less than two to five hectares of land, and two to 20 heads of livestock. Ojango *et al.* (2017) defined smallholder dairy production as a system, where less than 10 head of cattle are reared on variable land sizes, typically of less than 4 hectares. The definition of a smallholder dairy (SH) farm however, depends on the extent of the structural, and production environment of a particular region/country. In South Africa, a SH dairy farm may have more than 20 cows per herd, due to the larger herd sizes commonly found in the commercially oriented production system. In spite of these varying definitions, the smallholder production systems in most Sub-Saharan African countries face a similar challenge regarding relatively poor cow performance (Meissner *et al.*, 2013; DAFF, 2014; Ojango *et al.*, 2017). Poor cow performance impacts negatively on the economic efficiency, and the viability of individual herds, which constraints the potential outputs from the dairy industry.

Development of the smallholder sector in South Africa is necessary, as it could transform SH dairy farming into a commercially competitive production system, while reducing poverty, boosting food security, and providing the much-needed animal products for feeding the growing population. This is apparent in countries like Kenya, and India, where smallholder dairy development has contributed to increased milk production, and income generation (Staal *et al.*, 2004; Grillenberger *et al.*, 2006; Staal *et al.*, 2006).

Current information with regards to the performance of dairy cows in the SH dairy production system in South Africa is either lacking completely or very limited. This presents a serious constraint to any initiatives aimed towards the development of the SH dairy sector, as benchmarking of current performance is a major prerequisite to any form of improvement. Benchmarking is a diagnostic measure, which involves a comparative analysis of performance indicators between alternative production systems with similar production objectives (Bredrup & Bredrup, 1995; Wilson *et al.*, 2005).

The need for research to determine how to improve the performance efficiency of the smallholder dairy production system is imperative. Genetic improvement of economically important performance traits such as milk yield, and quality, reproduction, and health form the basis for the development of profitable dairy farming (Banga, 2009). However, the benefits from such an improvement would not be realized without appropriate management strategies. Different management options affecting herd performance should be evaluated to achieve efficient improvement of the production system. Simulation modelling could assist in the evaluation of alternative herd management practices affecting animals' performance (at individual and herd levels), by determining, and comparing the impact of such management options (Oltenacu *et al.*, 1980; Macdonald *et al.*, 2007; Horváth *et al.*, 2017). The use of simulation modelling also offers the opportunity for adoption of appropriate herd management strategies among smallholder dairy production systems across the Sub-Saharan Africa region.

1.2. Aim and objectives

The main aim of this study was to evaluate alternative management options for the improvement of the smallholder dairy cattle production system in South Africa. The objectives towards achieving this aim were to:

i. Benchmark the productive and reproductive performance, as well as udder health status, of dairy cows in smallholder dairy herds against their counterparts in the high-input production system,
ii. Develop a bio-economic model of a typical smallholder dairy herd, depicting current management practices and cow performance levels,
iii. Evaluate alternative management strategies for the smallholder dairy herd production system, through simulated changes to the model developed in objective II,

iv. Study the implications of the alternative production models on the development of smallholder dairy farming in Sub-Saharan Africa.

1.3. References

Banga, C.B., 2009. The development of breeding objectives for Holstein and Jersey cattle in South Africa. Ph.D. thesis, University of the Free State, Bloemfontein, South Africa.

Bredrup, H. & Bredrup, R., 1995. Benchmarking as performance reference in a performance management model. In Benchmarking-Theory and Practice. Springer, Boston, MA. pp. 341-349.

DAFF (Department of Agriculture, Forestry, and Fisheries), 2014. A profile of the South African dairy market value chain. Published by the Directorate of marketing of the Department of Agriculture, Forestry and Fisheries. Arcadia, Pretoria South Africa. www.nda.agric.za/.../Dairy%20market%20value%20chain%20profile%202014.pdf.

Flaten, O., 2002. Alternative rates of structural change in Norwegian dairy farming: impacts on costs of production and rural employment. J. Rural Stud. 18, 429-441.

Grillenberger, M., Neumann, C.G., Murphy, S.P., Bwibo, N.O., Weiss, R.E., Jiang, L., Hautvast, J.G.A.J., & West, C.E., 2006. Intake of micronutrients high in animal-source foods is associated with better growth in rural Kenyan school children. Br. J. Nutr. 95, 379-390.

Hanrahan, L., McHugh, N., Hennessy, T., Moran, B., Kearney, R., Wallace, M., & Shalloo, L., 2018. Factors associated with profitability in pasture-based systems of milk production. J. Dairy Sci. 101, 5474-5485.

Hemme, T. & Otte, J., 2010. Status and prospects for smallholder milk production: a global perspective. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Herrero, M., Havlik, P., McIntire, J., Palazzo, A. & Valin, H., 2014. African Livestock Futures: Realizing the potential of livestock for food security, poverty reduction and the environment in Sub-Saharan Africa. Office of the Special Representative of the UN Secretary-General for Food Security and Nutrition and the United Nations System Influenza Coordination (UNSIC), Geneva, Switzerland. pp. 1-118.

Hoffmann, I. & Baumung, R., 2013. The role of livestock and livestock diversity in sustainable diets. In: Diversifying food and diets: using agricultural biodiversity to improve nutrition and health. Eds: Fanzo, Hunter, J. D., Borelli, T. & Mattei, F., Routledge, Abingdon & New York. pp. 68-78.

Horváth, J., Tóth, Z. & Mikó, E., 2017. The Analysis of Production and Culling Rate With Regard to the Profitability in a Dairy Herd. Adv. Res. life Sci. 1, 48-52

Lacto data, 2019 Statistics: A Milk SA publication compiled by the milk producers' organization. 22, 1-32. www.milksa.co.za.

Macdonald, K.A., Verkerk, G.A., Thorrold, B.S., Pryce, J.E., Penno, J.W, McNaughton, L.R., Burton, L.J., Lancaster, J.A.S, Williamson, J.H & Holmes, C.W., 2007. A Comparison of Three Strains of Holstein-Friesian Grazed on Pasture, and Managed Under Different Feed Allowances. J. Dairy Sci. 91, 1693-1707.

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. S. Afr. J. Anim. Sci. 43, 282-297.

Narayanan, S. & A. Gulati. 2002. Globalization and the smallholders: A review of issues, approaches, and implications. Markets and Structural Studies Division Discussion Washington, D.C. International Food Policy Research Institute. Discussion paper no. 50.

Ojango, J.M.K., Mrode, R., Okeyo, A.M., Rege, J.E.O., Chagunda, M.G.G. & Kugonza, D.R. 2017. Improving smallholder dairy farming in Africa. In: Achieving sustainable production of milk Volume 2: Safety, quality and sustainability. Ed: Belzen, N. van. Cambridge, UK: Burleigh Dodds Science Publishing Limited.

Oltenacu, P.A., Milligan, R.A., Rounsaville, T.R. & Foote, R.H., 1980. Modelling reproduction in a herd of dairy cattle. Agric. Syst. 5, 193-205.

Staal, S.J., Waithaka, M.M., Owuor, G.A., & Herrero, M. 2004. Demand and supply changes in the livestock sector and their impact on smallholders: the case of dairy in Kenya. In: Responding to the livestock revolution: the role of globalization and implications for poverty alleviation. Eds: Owen E., Smith T., Steele M.A., Anderson S., Duncan, A.J., Herrero M., Leaver J.D., Reynolds C.K., Richards J.I. & Ku-Vera, J.C., British Society of Animal Science Publication, Nottingham University Press, Nottingham, UK. pp. 33.

Staal, S.J., Baltenweck, I., Njoroge, L., Patil, B.R., Ibrahim, M.N.M. & Kariuki, E. 2006. Smallholder dairy farmer access to alternative milk market channels in Gujarat. In IAAE Conference, Brisbane, Australia.

Wilson, R.H., Charry, A.A. & Kemp, D.R., 2005. Performance indicators and benchmarking in Australian agriculture: synthesis and perspectives. Ext. Farming Syst. 1, 45-5.

CHAPTER II

2. Literature review

2.1. The agro-ecological areas for livestock production in South Africa

The Republic of South Africa (SA) lies between ± 22^0, and 34^0S at the extreme end of the Southern part of Africa, having diverse climatic conditions ranging from semi-arid to subtropical and Mediterranean climates (Benhin, 2006). These diverse climatic conditions have a great impact on the agro-ecological areas in SA. The agro-ecological areas of South Africa include a large biome of grasslands, mainly in the central and coastal highland regions, separated by scattered biomes of forest, savannah, and Nama-karoo (Palmer & Ainslie, 2005). Approximately 80% of these agro-ecological areas is suitable for animal grazing, making natural pasture the cheapest feed source in the country (DAFF, 2015). The availability, and quality of this pasture depend on the extent of the climatic conditions (e.g. summer, and winter season) in a particular production area (Mucina & Rutherford, 2006). The annual rainfall generally varies, from as low as <50 mm in the Richtersveldt on the border with Namibia, to as high as >3,000 mm in the mountainous areas of the South Western Cape, with an average of about 450 mm per annum (Palmer &Ainslie, 2005).

2.2. Overview of the dairy sector in South Africa

The dairy industry, which comprises approximately 1.3 million cows, is one of the most important agricultural sectors in the country (Meissner *et al.*, 2013). It comprises over 1,200 milk producers (Lacto data, 2019), employing almost 100,000 people across the value chain (DAFF, 2017). The SA dairy industry is characterized by low-input low-output smallholder, and high-input, highly productive production systems. These two production systems could be further differentiated by diverse herd sizes, which range from less than 50 in smallholder systems to more than 500 cows (Lassen, 2012; DAFF, 2015), with an average herd size of more than 350 milking cows in the high-input production system (Lacto data, 2019). The veld/pasture-based system constitutes the major feed source for the majority of low-input smallholder herds, with limited supplementation, and managerial inputs. On the other hand, the high-input production system is characterized by high genetic potential dairy cows, good quality management, and an intensive feeding system (Lacto data, 2019). The main feeding systems for high-input commercial dairy cattle in SA are total mixed ration (TMR), pasture, and/or a combination of the two feeding systems (Banga, 2009; Theron & Mostert, 2009). Farmers in the high-input system sell milk to dairy processors, whilst their contemporaries in the low, and medium input-output system sell most of their milk directly to consumers, and only limited amounts to processors (DAFF, 2017).

Dairy cattle are reared throughout the country, but most farms are concentrated in the coastal, and central provinces (DAF, 2017). This is probably driven by the favorable production environment in the coastal regions, and the proximity of markets, and processing facilities in the central areas like Gauteng province. South African dairy cattle include pure, crossed, and dual-purpose breeds. The major dairy breeds are Holstein-Friesian, Jersey, Ayrshire and Guernsey breeds (Maiwashe *et al.*, 2006). Minor dairy cattle breeds include the Dairy Shorthorn, Brown-Swiss, and crossbred animals (Milk SA, 2013; de Ponte Bouwer *et al.*, 2013).

2.3. Dairy cattle milk recording in South Africa

The conventional dairy cattle milk recording scheme in South Africa started with the commencement of the national milk recording, and improvement scheme (NMRIS) in 1917 (Banga, 2002). This scheme still strives to promote a productive, and economically vibrant milk production sector (ARC, 2016). Its objectives are achieved through regular monitoring, and evaluation of cows' performance traits, research, and training, to promote effective management, feeding, and estimation of animals' producing ability. Milk recording, and improvement services are provided by the Agricultural Research Council (ARC), and SA Studbook, and farmers participate on a voluntary basis. To participate in the scheme, a farmer needs to keep basic records such as animal identification (ID), parents IDs, animal birth, and calving dates, and use weighing tools approved by the International Committee for Animal Recording (ARC, 2016).

Official milk testing, and recording are conducted on all the lactating cows within the herd, on a regular basis of 35-day intervals, generating 10 milk recording test-day events per herd per year (ARC, 2016). Milk yield from 2 or 3 milkings is recorded for each lactating cow in the herd on test day. Milk samples are collected from cow's milk on each test day, and analyzed for fat content (%), protein content (%), somatic cell count (cells/ml), lactose content (%), and milk urea nitrogen (mg/dl). Test day yields of milk, fat, protein, and lactose are used to calculate yields for standard 305-d lactations, using ICAR guidelines. All milk recording data are stored on the National Livestock Database known as the INTERGIS (Integrated Registration and Genetic Information System). The data is used to generate herd reports that can be used by farmers as a management tool or by milk recording technicians, and relevant service providers for advisory work. It is also used as a resource for research, and to estimate breeding values for making breeding decisions. Milk recording systems in South are accredited by ICAR, and the structure is presented in Figure 2.1.

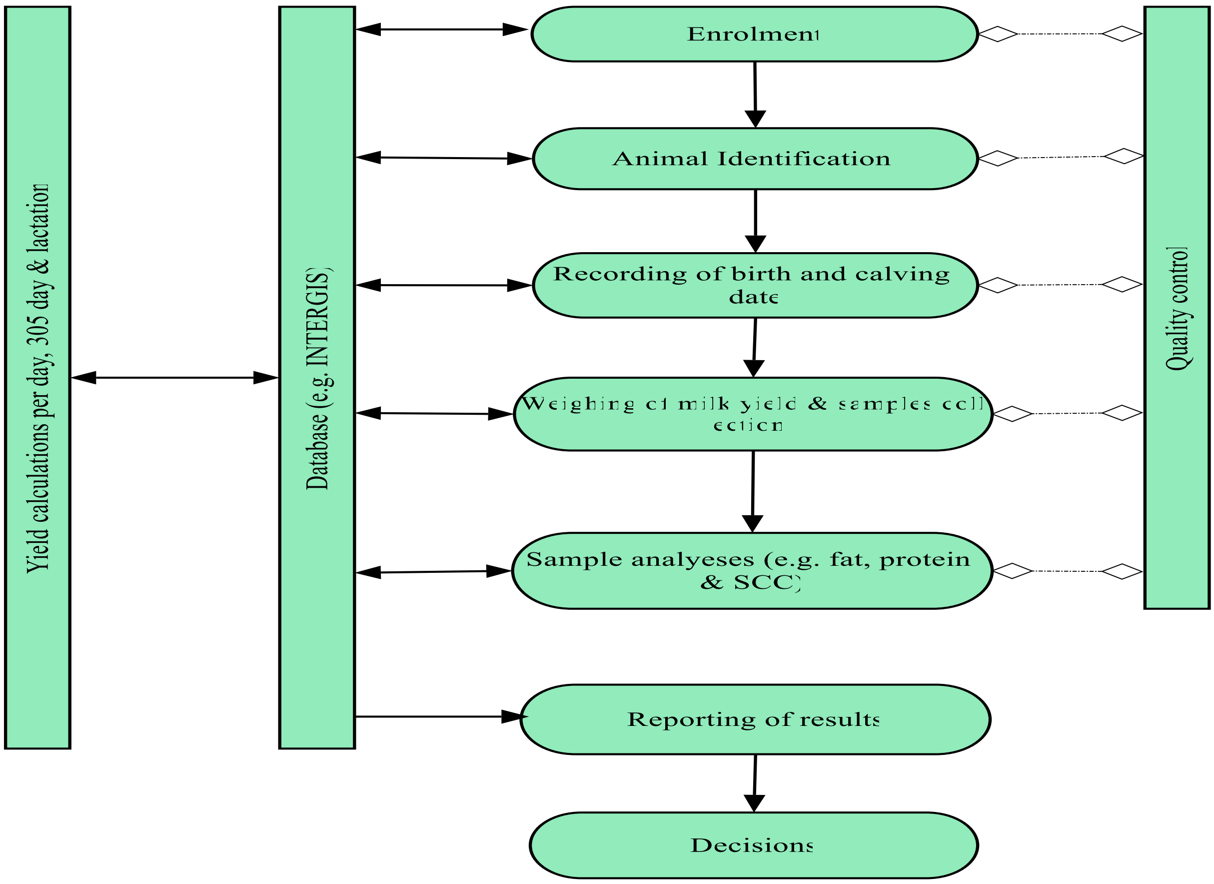

Figure 2.1: Schematic diagram of a milk recording system (adapted from ICAR, 2017)

2.4. Dairy cattle performance traits

The sustainability of dairy farming depends on the improvement of both the productive, and functional performance traits of dairy cows (Groen *et al.*, 1997; Zwald *et al.*, 2004; Miglior *et al.*, 2005). The primary objective for improvement of these traits is to ensure efficient utilization of the input factors, in order to improve productivity, and optimize farm profitability. Major economically relevant traits of dairy cattle are discussed in the following sections.

2.4.1. Production traits

The profitability of dairy farming is significantly influenced by a number of production performance traits. These traits include measurable, consumable, and saleable outputs produced from a dairy cow. In a dairy production system, the overall production performance efficiency can best be measured by the components of milk. The rationale for measuring, and quantifying these production performance measures in dairy cows are herein discussed.

2.4.1.1. Yield traits

The production performance of dairy cows is mainly determined by milk yield, and its components. Milk components mainly comprise fat, protein, milk urea nitrogen, lactose, minerals, vitamins, and water (Muehlhoff *et al.*, 2013; Park & Haenlein, 2013). Milk, fat, and protein yields are the primary production traits recorded for management, and genetic selection of dairy cattle (Miglior *et al.*, 2005; ICAR, 2014). These traits are of major economic importance in most dairy industries, as they directly affect revenue from the sale of milk. Milk production is polygenetic in nature, and is partially controlled by genes that control secretory cells, and regulate milk yield in relation to nutritional intake (Davis, 1997). Feeding management practices, therefore, dictate the levels of milk, fat, and protein produced by a cow (Ganie *et al.*, 2011).

The basic measures of milk production are yield of milk in terms of weight (kg) or volume (litres), and percentages of milk components produced during a specific production period. Lactation length is standardised to 305-days, and yields of milk per lactation are calculated from test-day production records, with the test-days having intervals of 1 week, 1 month or 35 days (Mostert, 2007; ICAR, 2014; Bucek *et al.*, 2015). Incomplete lactations are usually extended to 305-days, while those longer than 305 days are standardized to 305 days (Interbull, 2001; Mostert, 2007; ICAR, 2014).

The length of a lactation is an indicator of the persistency of milk production (Syrstad, 1993), which influences the amount of milk, and components produced by a cow per lactation (Alphonsus & Essien, 2012; Hossein-Zadeh, 2013). Shorter lactation length is thus associated with decreased production (Madalena *et al.*, 1992; Kumar *et al.,* 2014a; Rahman *et al.,* 2017). Estimates of least squares means for 305-days milk, and component yields as well as lactation length (LL), reported in some previous studies are summarized in Table 2.

Table 2.1. Summary of the least squares means for 305-days milk and component yields and lactation length

Country	Milk yield (kg)	F yield (kg)	P yield (kg)	LL (d)	Breed	Source
Bangladesh	-	-	-	198±2.4 to 266±1.2	Crossbred	Rahman *et al.,* 2017
Egypt	7 638±0 to 9 145±0	-	-	-	Holstein, Brown Swiss & their crosses	El-Tarabany *et al.,* 2017
Egypt	8 417±55.5	-	-	-	Holstein	Hammoud & Salem, 2013
Ethiopia	3 604±38.4	-	-	-	Holstein	Ayalew *et al.,* 2015
Ethiopia	-	-	-	275±65.2	Crossbred	Kumar *et al.,* 2014a
India	1 707±13.25	-	-	296±2.3	Crossbred	Wondifraw *et al.,* 2013
Ireland	4 230±43.5 to 5 217±31.2	193±3.8 to 226±1.8	168±3.1 to 186±1.1	-	Holstein & Jersey and their crosses	Coffey *et al.,* 2016
México	-	-	-	348±6.0 to 358±5.8	Holstein & Brown Swiss	Rios-Utrera *et al.,* 2013
Mexico	5 417±96 to 4 807±131	-	-	-	Holstein & Holstein x Gyr	Mellado *et al.,* 2011
Morocco	6 144±1 462.3	222±53.6	-	325±42.4	Holstein	Talbi & Madidi, 2016
Nepal	-	-	422±7.7	-	Crossbred	Paneru *et al.,* 2016
Pakistan	1 613±49.03	-	-	240±5.5	Crossbred	Hassan & Khan, 2013
Pakistan	-	-	-	314±0.9	Holstein	Sandhu *et al.,* 2011

SA	6 330±117 to 6 108±97	252±4.7 to 251±3.9	202±3.5 to 200±2.9	-	Holstein & Fleckvieh x Holstein	Metaxas, 2016
SA	5 398±95 to 6 141±10	246±3.0 to 272±4.0	194±2 to 246±3	-	Jersey & Fleckvieh x Jersey	Goni, 2014
SA	5 347±1 156 to 8 147±2 260	251±54 to 310±83	200±43 to 262±70	-	Holstein & Jersey	Theron & Mostert, 2009
Sudan	-	-	-	294±3.6	Friesian	Abdel Gader *et al.,* 2007
Thailand	-	-	-	376±0.3	Crossbred	Endris *et al.,* 2012
Turkey	5 725±149	-	-	322±4.6		Ural, 2012
USA	8 530 ± 89 to 9 757±101.6	319±3.2 to 346±3.6	277±2.7 to 305±3.0	-	Holsteins, Holstein x Normande, Montbeliarde & Scandinavian Red	Heins *et al.,* 2006
USA	6 408±76.7 to 8 444±122.6	321±4.3 to 230±2.7	205±2.3 to 256±3.7	-	Jersey x Holstein & Holsteins	Heins *et al.,* 2008
USA	11 417±86.4	409±3.3	352± 2.6	-	Normande x Holstein, Montbéliarde x Holstein, Scandinavian Red x Holstein & Holsteins	Heins & Hansen, 2012

F: fat; P: protein; kg: kilogram; LL: lactation length

2.4.1.2. Lactation curve

Pregnancy stimulates milk synthesis in the mammary glands, which reach potential capacity for milk secretion towards the end of the gestation period (Neville *et al.*, 2002; Macciotta *et al.*, 2011). Milk production typically shows a curvilinear pattern, which is termed a lactation curve. The lactation curve of an individual cow could be quantified by regressing test-day yields over the lactation period (Madouasse, 2009; Hering *et al.*, 2016) or extrapolation from test-day yields using different algebraic models (Macciotta *et al.*, 2011).

The lactation curve consists of three distinct phases: initial milk let-down followed by an inclining phase to peak yield, a plateau, and then a declining phase until the cow is dried off. Concentrations of milk components often follow an inverse curve, decreasing from calving until the peak in yield, and then rising thereafter (Madouasse, 2009; Silvestre *et al.*, 2009). Cows differ in their potential to attain each phase of the lactation curve, due to genetic, feeding or environmental influences (Wood 1967; Strandberg, & Lundberg, 1991; Boujenane & Hilal, 2012). Persistency is important as it indicates an animal's ability to produce, and maintain peak yield, under the prevailing production environment (Dekkers *et al.*, 1998; Macciotta *et al.*, 2005). The shape of the lactation curve provides an excellent tool for efficient herd management, and improvement of dairy production.

2.4.2. Functional traits of economic importance to the dairy industry

The lifetime productive performance of a dairy cow is influenced by functional traits (Philipsson & Lindhé, 2003; Miglior *et al.*, 2005; Oltenacu & Broom, 2010). Functional traits are mostly related to production costs rather than income, and they include udder health, fitness (reproduction, longevity), and efficiency of feed utilization (Miglior *et al.*, 2005; Berry & Crowley, 2013; Cabrera, 2014). Economic efficiency of herd performance implies optimization of input factors to maximize the profit margin. Maximization of the profit margin could be attained not only by increasing outputs, but also through minimization of costs, which is of particular importance in the smallholder dairy production system. Most functional traits are difficult to record, especially in SH dairy farms. This overview of functional traits will focus on somatic cell count as an indicator of udder health, some easily recordable reproductive traits under the smallholder dairy production system, and longevity.

2.4.2.1. Somatic cell count

Udder health of dairy cows should be monitored to enhance animal welfare, and to ensure milk production is sound, and hygienic. The most common way for monitoring the status of udder health within a dairy herd is by recording somatic cell count (SCC) per cow or bulk tank (Hamann, 2005). Milk SCC (cells/ml) comprises of leukocytes, and epithelial cells, which increase in the presence of mastitis-causing bacteria as a result of an immune defensive response (Hamann, 2005; Brandt *et al.*, 2010). An increase in the level of SCC in milk indicates possible infections of a cow/herd with subclinical or clinical mastitis (Bortolami *et al.*, 2015; Gonçalves *et al.*, 2016). The normal concentration of SCC in the milk of an uninfected cow is around 100,000 cells/ml, with an internationally accepted standard threshold of 200,000 cells/ml (Schukken *et al.*, 2003). A concentration above this threshold indicates potential infection with mastitis pathogens (Dodd & Booth, 2000; Brandt *et al.*, 2010).

Major causes of clinical, and subclinical mastitis include poor management of cow housing or the milking system (Abera *et al.*, 2012; Katsande *et al.*, 2013; Iraguha *et al.*, 2015). Subclinical mastitis reduces milk yield, and content of fat, and casein in milk, and increases whey content, which negatively influence milk pH, cheese quality, and other milk processing properties (Seegers *et al.*, 2003; Waldner *et al.*, 2005; Barbano *et al.*, 2006; Ogola *et al.*, 2007; Le Maréchal *et al.*, 2011).

Clinical mastitis is caused by pathogenic bacteria species (spp), such as *Staphylococcus aureus*, *Streptococcus uberis*, *Mycoplasma*, and *Escherichia coli* (Carrillo-Casas *et al.*, 2012). It is clinically characterized by udder inflammation, and a persistent fever, which may affect the reproductive system, if it is not effectively treated (Lavon *et al.*, 2010; Hudson *et al.*, 2012; Wolfenson *et al.*, 2015). The occurrence of clinical mastitis often results in huge economic losses from reduced milk yield, discarded milk or withdrawal of an animal from the milking cohort, treatment costs of sick cows, and increased culling rate.

No clear clinical disorder or changes in milk are apparent during subclinical mastitis. Cows with subclinical mastitis are often identified through high level of SCC in milk (Schukken *et al.*, 2003). Recording of SCC, therefore, serves multiple objectives, including the prevention of extra costs that may result from reduced milk yield, milk rejection, treatment, culling (Seegers *et al.*, 2003; Halasa *et al.*, 2009), identification of genetically superior mastitis resistant cows (Detilleux *et al.*, 1997; Dube *et al.*, 2008), and provision of a platform for monitoring, and evaluating udder health.

2.4.2.2. Reproductive traits

A viable dairy production system depends on the reproductive performance of the cows (Andersen-Ranberg *et al.*, 2003; Dobson *et al.*, 2007; Inchaisri *et al.*, 2010; Egger-Danner *et al.*, 2015). Reproduction initiates, and determines an animal's productive life (longevity). Earlier selection, and management of dairy cattle mainly focused on yield traits at the expense of reproductive, and other dairy relevant functional traits (Cammack *et al.*, 2009; Cassandro, 2014; Berry *et al.*, 2016). In the past 2 decades, some dairy production industries have recognized this, and started to include reproductive traits in their selection, and management programmes (Cassandro, 2014; Berry *et al.*, 2016). Inclusion of these reproductive traits has reversed the earlier deteriorating trend observed in dairy cows' fertility (Berry *et al.*, 2016; Crowe *et al.*, 2018).

Various measures may be used to evaluate the reproductive performance of dairy cows. These include, age at first calving (AFC), calving interval between successive parturitions (CI), inseminations per conception, conception rate, and non-return rate (NRR). Due to the ease of recording dates of birth and calving, AFC and CI are commonly available, and can be determined with a relative degree of accuracy under different dairy production systems, especially those participating in the routine milk recording, and improvement scheme (Olori *et al.*, 2002; Gonza´lez-Recio *et al.*, 2004; Mostert *et al.*, 2010). Recording of insemination dates, and events related to pregnancy are often not compulsory for herds participating in the national milk recording, and improvement scheme as in the case of South Africa.

Age at first calving: Age at first calving (AFC) is a measure of reproductive performance, which marks the beginning of the productive life of a dairy cow. It dependents on the genetic potential of a heifer calf to grow, sexually mature, and reproduce in the prevailing production environment. It determines the costs of rearing the heifer, before it becomes productive. Higher AFC is associated with an increase in the non-productive life of the heifer, from birth to first lactation (Heinrichs & Vazquez-Anon, 1993; Pirlo *et al.*, 2000; Nilforooshan & Edriss, 2004). This results in an increase in the cost of rearing replacement heifers, reduces cow productive life, increases the generation interval, and thus slows genetic improvement (Lin *et al.*, 1988; Tozer & Heinrichs, 2001; Do *et al.*, 2013; Penev *et al.*, 2014).

Although AFC between 21 and 25 months was reported to be optimum for productive efficiency of dairy cows (Mourits *et al.*, 1999; Pirlo *et al.*, 2000; Cooke *et al.*, 2013; Zavadilová & Štípková, 2013; Wathes *et al.*, 2014), a range of ages have been reported (Table 2.2). The economic impact of varying AFC needs to be evaluated for each production system, in order to provide guidance on herd management and improvement programmes (Meyer *et al.*, 2004).

Table 2.2. Summary of the estimated least squares means for age at first calving and calving interval reported for dairy cows in the literature

Country	AFC (months)	CI (days)	Source
Bangladesh	41±0.1 to 45±0.2	437±1 to 481±0.3	Rahman *et al.*, 2017
Egypt	-	397±0 to 432±0	El-Tarabany *et al.*, 2017
Egypt	30±0.1	403±1.9	Hammoud *et al.*, 2010
Ethiopia	47±1.1	-	Zereu *et al.*, 2016
Ethiopia	39±0.5	465±7.2	Worku *et al.*, 2016
Ethiopia	-	439±66.3	Kumar *et al.*, 2014b
Kenya	-	468 ± 5.3	Ilatsia *et al.*, 2007
México	-	389±3.8 to 402±4.2	Calderón-Robles *et al.*, 2011
Pakistan	-	543±17.9	Hassan & Khan, 2013
Pakistan	-	408±2.1	Sandhu *et al.*, 2011
South Africa	29.4±5.2	-	Muller *et al.*, 2014
South Africa	26.2±3	-	Goni, 2014
Sudan	29±0.40	433±6.70	Abdel Gader *et al.*, 2007
Sudan	41±2.2 to 49±1.3	367±21.4 to 394±16.3	Ahmed *et al.*, 2007
Sudan	45±3.5	382± 8.3	Musa *et al.*, 2005
Turkey	27±0.6	403±7.8	Ural, 2012

CI: calving interval; AFC: age at first calving

Calving interval: Calving interval (CI) is the period between two successive parturitions, and is a good indicator of reproductive performance (Wall *et al.*, 2003; Mostert *et al.*, 2010). It is easy to record, and reflects the ability of a cow to re-calve successfully. It summarizes the postpartum interval to oestrous, conception, and gestation length (Berry *et al.*, 2014).

Shorter calving intervals are desirable for increased milk production, provision of female replacements, and or bull calves. A longer CI decreases the animal's productive life, and increases the rate of involuntary culling within a herd (Olori *et al.*, 2002; Do *et al.*, 2013). Higher culling rate increases replacement costs, and the proportion of younger animals, which reduces herd productivity (Boichard, 1990; Do *et al.*, 2013). A wide range of CI has been reported in different dairy cow populations, as shown in Table 2.2. The economic impact of these intervals should be evaluated under specific production system due to their variation with production circumstances (Gonza´lez-Recio *et al.*, 2004; Němečková *et al.*, 2015).

2.4.2.3. Longevity

Longevity is a lifetime or stayability trait, which is usually managed, and selected for indirectly. It is a measure of fitness, which determines the ability of a cow to survive both voluntary, and involuntary culling at different stages of a production cycle within the herd (van Doormal *et al.*, 1985; Vollema & Groen, 1996). The cause of voluntary culling among dairy cows is mainly poor production performance, while involuntary culling is due to various reasons, which include poor udder health, diseases and infertility (Ahlman *et al.*, 2011; Wu *et al.*, 2012). The rates of culling (voluntary and involuntary), and survival are important parameters for modelling herd age structure, and evaluation of alternative herd management strategies in the bio-economic model (Hearnshaw *et al.*, 2002).

Decreasing the rate of involuntary culling by alleviating its causes (e.g. udder infection) allows for a more flexible voluntary culling strategy, and improves cow longevity (Vollema & Groen, 1996). Extended longevity may improve herd productivity, and economic returns of dairy farming by reducing replacement costs, and increasing milk production (Hearnshaw *et al.*, 2002; Banga *et al.*, 2014; De Vries, 2017).

2.4.2.4. Live weight

Most of the dairy producing countries including South Africa are currently experiencing a steady increase in production cost that is mainly caused by escalating feed costs (Lacto data, 2019). An excessive increase in feed cost, which is not adequately compensated for by the farm gate price poses a threat to the viability of the dairy farmer. For example, the number of milk producers in South Africa declined from 3 551 in 2009 to 1 228 in 2019, mainly due to high production cost (Lacto data, 2019).

This situation underscores the need for including traits relating to feed costs, particularly in the smallholder system, where the production margin is most fragile. Live weight (LW) is one of the economically relevant traits that could be used to mitigate the burden of feed cost. It is directly associated with dietary energy requirements for maintenance of body tissue functions in heifers, and cows (AFRC, 1993; NRC, 2001). A marginal increase in LW results in an increase in dietary energy requirements for maintenance, which particularly increase feeding cost over revenue in the dairy herds (Berry *et al.*, 2005; Banga *et al.*, 2014; Wahinya *et al.*, 2015). Insufficient supply of energy requirements for maintenance adversely affects productivity, reproduction, and health in dairy cattle (Domecq *et al.*, 1997; Roche *et al.*, 2009; Tazangi *et al.*, 2015; Singh *et al.*, 2015; Stádník *et al.*, 2017), which may lead to economic loss or increase in production cost. This entail the importance of matching dairy cattle LW with a production environment for efficient production, and increase profitability.

2.5. Nutritional effects on productive and reproductive performance of dairy cows

Expression of genetic potential for productive, and reproductive performance of a dairy cow is influenced by nutrient dry matter intake (Tas *et al.*, 2005; Morrison & Patterson, 2007; Esposito *et al.*, 2014; VandeHaar *et al.*, 2016). Dry matter intake (DMI) represents the amount of nutrients (excluding moisture) that are available in feed for an animal's consumption (Tas *et al.*, 2005; Friggens *et al.*, 2013). The essential nutrients for dairy cattle are: energy (fat and carbohydrates), protein (amino acids), vitamins, minerals, and water. Energy is the nutrient with the largest effect on dairy cows' performance (Kunz *et al.*, 1985; Butler, 2000; NRC, 2001; Kitilit *et al.*, 2016). The effect of energy level on dairy cows' performance is more profound in pasture-based feeding systems, where dry matter, and metabolizable energy (ME) are often low (Clark *et al.*, 1997). Energy deficiency often results in decreased production, poor reproduction, and a deterioration in health (Remppis *et al.*, 2011; Chebel *et al.*, 2018). Each stage of a dairy cow's production cycle is physiologically distinct, and therefore has different energy requirements (NRC, 2001). Figure 2.2 illustrates the partitioning of feed energy in an animal's body. The efficiency of converting ME into net energy (NE) varies according to the animal's requirements for maintenance, growth, pregnancy and production (AFRC, 1993).

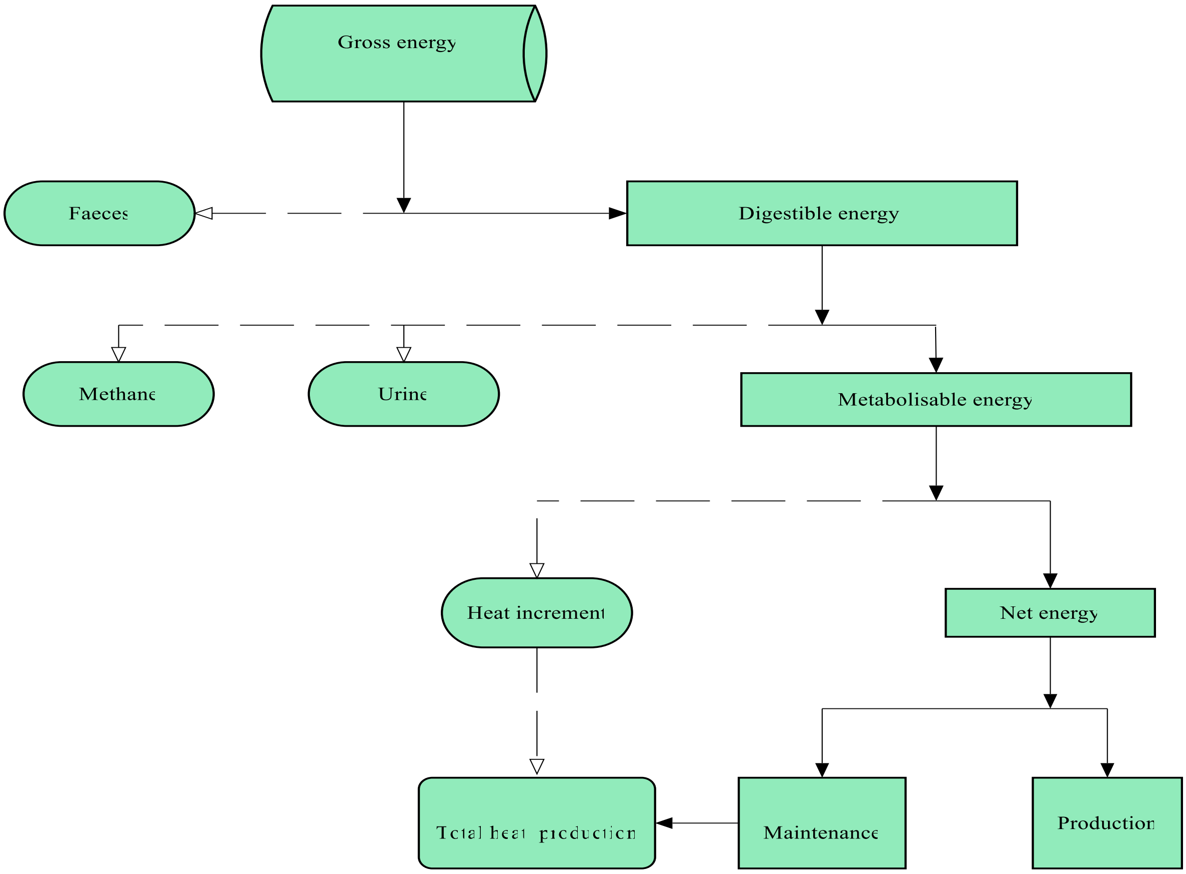

Figure 2.2: Partitioning of feed energy in an animal (Konandreas & Anderson, 1982)

Adequate energy intake is important, especially during the transitional period (period around calving) in dairy cows, to replenish the deficit in ME. Late gestation, and early lactation periods in a dairy cow are often accompanied by two transient stages. Late gestation is characterized by a reduction in dry matter intake prepartum, approximately three weeks before calving, which results in a subsequent negative energy balance (NEB) 3 to 4 weeks postpartum, following the metabolic transition to peak milk yield (NRC, 2001; Opsomer, 2015). The level of NEB is reflected by the loss in body weight or BCS due to the mobilization of body reserves (Jílek *et al.*, 2008). The extent of mobilization of adipose tissue to compensate the deficit in ME inputs varies, and depends on the relationships between the quantity, rate of increase, persistency of peak yield, and the ME intake (Opsomer, 2015). If the metabolic conditions or management practices impaired nutrient energy intake, this will drastically affect both body condition score, and lactation yield (Opsomer, 2015; Chebel *et al.*, 2018).

A balanced energy intake is also important for efficient reproduction. It has been well established that the partitioning of energy consumed by lactating dairy cows inherently favours maintenance, and milk yield, rather than reproduction (Bauman *et al.*, 1980; Lucy, 2000). Consequently, NEB, and failure to replenish body energy reserves negatively affect reproductive performance of the dairy cow (Lopez *et al.*, 2004; Wathes *et al.*, 2007). Negative energy balance, and poor body condition score delay normal ovarian cyclicity, inhibit follicular growth, and reduce fertility (Beam & Butler, 1999; Butler, 2001; Llewellyn *et al.*, 2007). NEB is also associated with reduced concentrations of progesterone during the breeding period (Butler, 2003), which minimizes the probability of conception in dairy cows (Royal *et al.*, 2000; Butler, 2003).

Excessive nutrient energy intake also negatively affects the productive lifetime of a dairy cow. Excessive energy intake by a dairy cow, prepartum, and during the dry period, can cause obesity, lower reproductive efficiency, and increase calving difficulties (Bindari *et al.*, 2013). In heifers, excess energy intake may lead to over-conditioning (excess deposition of adipose tissue), which also increases metabolic disorders, dystocia, and subsequently reduces milk production (Akins, 2016). Adequate energy intake is essential for a dairy cow to maintain optimum body condition score, avoid metabolic stress, and achieve potential peak milk yield, and reproductive performance. Figure 2.3 summarizes the effects of energy imbalance on the reproductive performance of dairy cows.

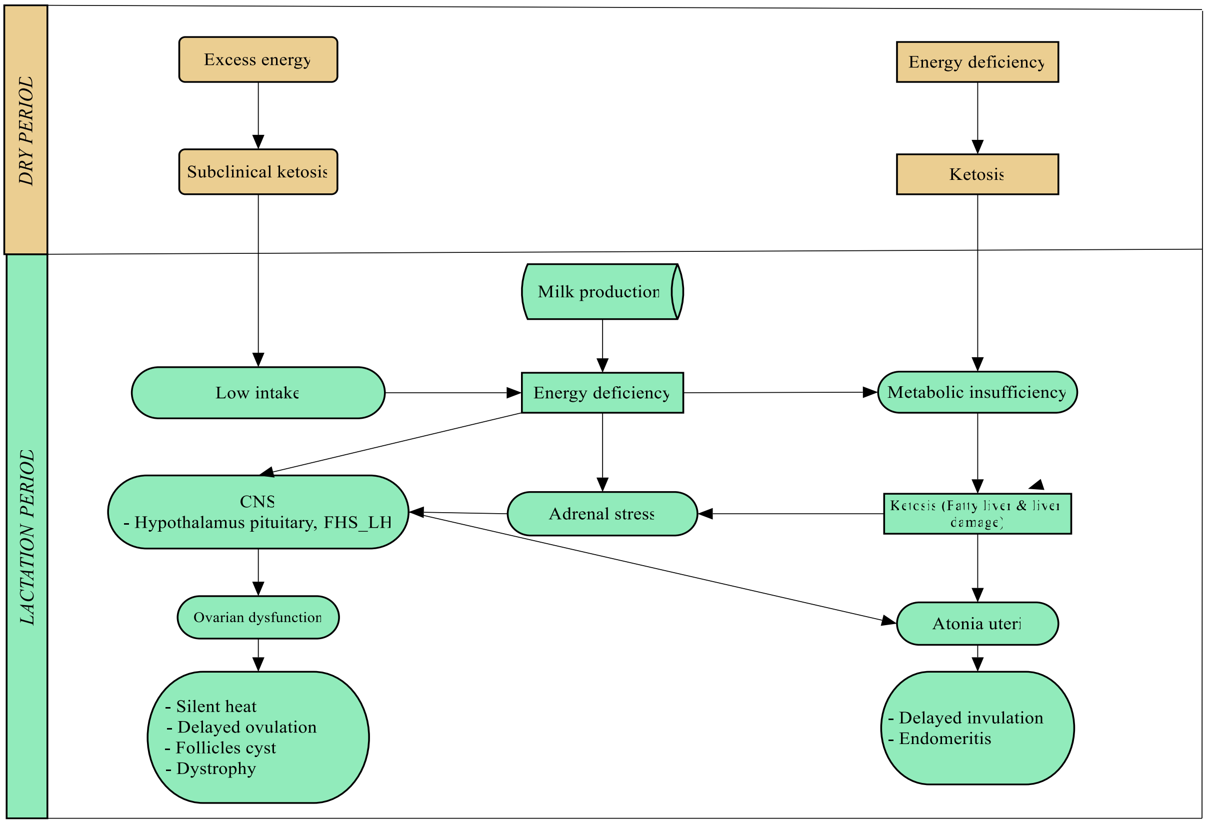

Figure 2.3: Summary of the effects of energy imbalance on the reproductive performance of dairy cows (Adapted from Lotthammer, 1991)

2.6. Benchmarking of dairy cow performance traits

Livestock performance determines the economic returns from a farming operation, and is a measure of both animal productivity, and herd management quality. Dairy cow productivity is influenced by both production, and functional traits (Miglior *et al.*, 2005; ICAR, 2014; Egger-Danner *et al.*, 2015).

Recording of cow performance traits plays an important role in terms of monitoring, and evaluating dairy cows' productivity (van der Westhuizen *et al.*, 2006). Effective monitoring, and evaluation of livestock performance traits could be conducted through benchmarking. Benchmarking is a process of comparing an industry sub-sector to the industry best practices, with the aim of identifying weaknesses, and providing guidance for improvement (Lau *et al.*, 2005). The benchmarking process involves systematic measurement of performance indicators, as well as statistical analysis, and interpretation of the results in relation to the management practices (Manning *et al.*, 2008).

The performance of dairy cows, or livestock in general, may vary remarkably. This variation is mostly attributed to differences in genetic potential as well as non-genetic factors such as lactation stage, parity, year, and season of both birth, and calving, and herd management (feeding, health and milking system). These factors should be accounted for, when comparing the performance of different animals (Cai, 2014). In livestock, performance data are often unbalanced, making estimates of simple averages biased.

The least squares means (lsmeans) procedure is ideal for predicting, and comparing group means of a particular response variable in different samples against each other (Cai, 2014). It adjusts the means for unbalanced, and biased sources of variance by implicitly or explicitly using least squares weights to optimize explained variance, minimize model error variance, exploit the resultant latent synthetic variables to score measured variables, and yield variance-accounted-for size effects (Thompson, 1998; Graham, 2008).

General linear models (GLMs) are widely used in statistical analysis of livestock performance data (Thompson, 1990; Taylor, 2007; Kollalpitiya *et al.*, 2012; Worku *et al.*, 2016). The analytic GLM statistics are readily available in many software packages, such as SAS® (SAS, 2015), SPSS® (IBM Corp, 2016), Stata® (StataCorp, 2013), and R® (R Core Team, 2016) for prediction of lsmeans from linear models. The GLMs are suitable for modelling longitudinal, and discrete data as a function of linear explanatory (predictor) variables. The explanatory variables in GLM models could either be assumed as fixed effects, random effects, and/or both as mixed effects, plus the error terms (SAS, 2015).

2.7. Simulation models for the improvement of dairy cattle production systems

The efficiency of a dairy production system is a result of complex interactions among interdependent bio-economic sub-systems that are partially or totally controlled by management practices (Groen, 1989). Poor cow performance is a major constraint to the smallholder dairy production system to contribute meaningfully to food security, and socio-economic development in Sub-Saharan Africa (Ojango *et al.*, 2017). Thus, there is a need to develop strategies to adopt management practices that will make the system more productive, competitive, and economically viable for sustainable production.

In agriculture, management involves a decision-making process, where the available resources are allocated to a number of production alternatives to determine the best potential production efficiency (Lai *et al.*, 2018). A critical aspect of good management is making the right decisions in order to achieve the desired production goals that earn profits (Jalvingh *et al.*, 1991). A pre-requisite for making the right decisions in livestock management rests upon prior knowledge of the system behavior, and the potential impact of various decisions on the biological, and economic efficiency of the production system (Jalvingh *et al.*, 1991; Herrero *et al.*, 1999).

A systems approach, through bio-economic simulation modelling, offers great opportunities to study complex bio-economic production systems (Wilson & Morren, 1990; Sørensen, 1997; Herrero *et al.*, 1999; Ashfield *et al.*, 2013; Ash *et al.*, 2015). A number of livestock simulation models have been developed, and are used in evaluating, and improving livestock production systems. Models previously developed include, among others, models for poultry (Groen *et al.,* 1998; Leinonen *et al.,* 2015), pigs (Tess *et al.* 1983; Ali *et al.,* 2018), sheep (Finlayson *et al.* 1995; Bohan *et al.,* 2016), beef cattle (Sanders & Cartwright 1979; Mulindwa *et al.*, 2011) and dairy cattle (Banga, 2009; Kikuhara *et al.,* 2009; Getaneh *et al.,* 2017). Table 2.3 presents a summary of studies conducted on dairy cattle production systems using simulation models.

Table 2.3. Studies conducted on dairy cattle production systems using simulation models

Reference	**Aim**
Brockington *et al.*, 1983	To identify priority areas for applied research, to explore various combinations of herd potential and level of feeding, the behavior of different herd sizes and the potential returns from specific technical innovations
Visscher *et al.*, 1994	Derivation of economic weights for milk production traits, survival and mature body size for a pasture-based production system
Herrero *et al.*, 1999	Evaluation of dairy farm management scenarios using integrated simulation and multiple-criteria models, with reference to Costa Rica dairy farming
Kahi & Nitter, 2004	Derivation of profit functions for pasture based dairy producers and estimate economic values for breeding objective traits.
Pärna *et al.*, 2005	Estimation of economic values for milk production, fat production, protein production, length of production life, calving interval and age at first service
Kikuhara *et al.*, 2009	Development of a mixed farming system model for dairy cattle in Japan
Banga, 2009	Derivation of economic values for South African Holstein and Jersey cattle breeds
Cunha *et al.*, 2010	Comparison of the profitability of herds of Holstein and Jersey breeds, under varying milk price payment system
Inchaisri *et al.*, 2011	Calculating the economic effects of different voluntary waiting periods
Giordano *et al.*, 2011	Estimating potential differences in profitability when applying different reproductive management strategies and comparing the economic outcomes of 3 reproductive management strategies for a specific dairy farm
Galvão *et al.*, 2013	Comparing the economic outcome of reproductive programs using estrus detection (ED), timed artificial insemination (TAI), or a combination of both (TAI-ED)
Brun-Lafleur *et al.*, 2013	Building an animal reproduction model sensitive to both milk yield and body condition score
Ashfield *et al.*, 2014	Simulating beef production from male and female calves born to Holstein-Friesian dairy cows

2.7.1. Simulation models

A simulation model is a diagnostic approach for system analysis that provides detail on processes underlying the system under study (Spedding, 1988; Leon-Velarde & Quiroz, 2001, Butler *et al.*, 2002; Jones *et al.*, 2016). It could be referred to as a software experimentation process, set in an attempt to capture the underlying interaction, and behaviour of the system, and predict the impact of management options on the determinants of performance efficiency of the system (Dent & Anderson, 1971; Wilson & Morren, 1990; Leon-Velarde & Quiroz, 2001, Reinmuth & Dabbert, 2017). A major benefit of a simulation study is its ability to mimic a production system, and thereby minimize time, and financial costs required for the diagnosis of a complex range of management practices, production levels, and marketing policies (Spedding, 1988; Leon-Velarde & Quiroz, 2001). A model can be used by researchers alone or in co-operation with other stakeholders such as farmers or farm consultants to study the consequences of decision making or change in production environment (Reinmuth & Dabbert, 2017).

The major challenge in using simulation models in livestock production systems is their complexity, and the time required for construction, verification, and validation /experimentation. However, once developed, simulation models can be adapted to study problems for which it was not originally designed for (Anderson & Dent, 1971; Thornton & Herrero, 2001). The analysis of livestock production systems can conveniently be approached at the farm/herd level, where management decisions directly influence individual animals, and their productivity (Groen, 1989; Louhichi *et al.*, 2010; Martin *et al.*, 2013).

2.7.2. Methodologies involved in the simulation model

Simulation is the process through which man develops an idea in order to understand a system, and define the best available solution for the problems facing the system (Dent & Anderson, 1971). The basic procedure of simulating the actual system involves model construction, verification, validation, and sensitivity analysis (Dent & Anderson, 1971; Anderson, 1972; de Vries, 1977; Kleijnen, 2009; Mateus & Franz, 2015; Iooss & Lemaître, 2015). These major procedures will be discussed in more detail:

Construction: The conceptual description of a farming system forms an important initial step towards modelling the real system (Dent & Anderson, 1971, Reinmuth & Dabbert, 2017). It provides a platform for identifying the sort, and form of the data required for analysis. This serves to define the boundary of a system, and identify the relevance of the model with respect to the problem, and objective of the analysis (Dent & Anderson, 1971; de Vries, 1977;

Reinmuth & Dabbert, 2017). The model must be simple, and consistent with the objectives of the farming system, and mimic the actual setups of the system. The framework for constructing or modelling a system can be described by identifying (Dent & Anderson, 1971):

- Major sub-systems
- Important components and relationships within each sub-system
- Associations between sub-systems
- Important environmental variables, and
- Control points (e.g. management)

Verification and validation: The simulation model needs to be verified, and validated before adoption for evaluation of a production system. The purpose of verification is to check the reliability of the model setup or equations to ensure the accuracy of prediction (Dent & Anderson, 1971; de Vries, 1977). Validation is used for authenticating the dynamics of the biological components of the real system with the corresponding components in the model. The validation of a model using empirical data sets the basis for experimentation, and evaluation of alternative options (Dent & Anderson, 1971; de Vries, 1977; van der Lee *et al.*, 1993; Reeves *et al.*, 2011; Kebreab *et al.*, 2019).

The validation process requires operationalization of field testing or using historical biological data. Such data are often expensive to collect, unavailable, and/or limited, rendering a very limited success of running a validation process (Dent & Anderson, 1971; van der Lee *et al.*, 1993; Jones *et al.*, 2017). As a result, the decision to accept a model must essentially incorporate some elements of subjective judgment, which should be rational, and suitable for the required purpose (de Vries, 1977; Sørensen, 1990; Kebreab *et al.*, 2019). This can be done by "calibration of a model", i.e. adjusting some of the parameters, such that model behavior matches the set of the real system (Dent & Anderson, 1971; de Vries, 1977; Kebreab *et al.*, 2019). This implies that a modeler would have three options in dealing with the sources of the parameters required for building the model.

- To use historical biological performance, and/ or experimental results of the real system under study,
- To use the biological experimental results from the scientific literature, and
- If certain functions are not directly obtainable from the real system and literature, a compatible reasonable biological assumption could be made.

Sensitivity analysis: Sensitivity analysis is an essential stage in simulation modelling. Sensitivity analysis is an analysis of response surface, which assesses the relationship between the inputs, and outputs of a model. This analysis is carried out by altering one or a combination of input and output variables, one-at-a-time, to observe the response of the model (Kleijnen, 2009; Mateus & Franz, 2015; Iooss & Lemaître, 2015). A number of objectives can be achieved through sensitivity analysis and may include the following (Kleijnen, 2009; Mateus & Franz, 2015; Iooss & Lemaître, 2015):

- Mapping the behavior of outputs as a function of the inputs by focusing on a specific domain of inputs,
- Identification, and prioritization of the most influential input variables,
- Calibrating of model inputs, if the direction, and magnitude of sensitivity of model outputs are not practically, and biologically plausible, and
- Gaining a better understanding of the simulated system, and its response to various production circumstances.

2.7.3. Components of the bio-economic herd model

The bio-economic herd model is composed of various input, and output components, as a consequence of management decisions. Inputs include both animal, and economic factors required to produce a unit output. Outputs are the indicators of the efficiency of input utilizationand that determine the economic return on inputs (Groen, 1989; Bourdon, 1998). The bio-economic model is built using diverse mathematical equations that simulate the relationships within, and between the biological, management, and economic inputs to determine their biological, and economic outputs (Agabriel *et al.*, 2004; Bytyqi *et al.*, 2015; Mcknight *et al.*, 2019). This process includes three integrated computational phases: The first is focused on simulating the components of biological systems combined with interactions among these components. The second phase simultaneously links the impact of management on biological entities in relation to their performance response. The third phase deals with the economic components, where gross margin analysis is conducted to determine the return on inputs invested.

Management component: The management component represents part of the exogenous factors that influence livestock performance or farm operation (Groen, 1989; Agabriel *et al.*, 2004; Bytyqi *et al.*, 2015). This is mostly controllable by the farmer or farm manager, and may include the setting of production goals, feeding to achieve the production goals, decisions on mating age, herd size, breeding methods, and seasons, raising replacements on the farm, replacement, and culling rates etc. The alternative production management decisions could be derived from different combinations of these mangement factors or different marketing strategies for the farming operation.

Biological component: The main elements of the biological component are the cows in different stages of production cycles (growth, maintenance, lactation and pregnancy), and their respective outflow products. The main products in the simulation of a dairy production system are milk, calves, and cull cows (Groen, 1989; Kahi & Nitter, 2004; Banga, 2009). In the simulation model, feed intake is primarily driven by the energy required to fulfill activities such as maintenance, growth, pregnancy, and lactation. Several mathematical functions are available for modelling the processes underlying an animal's different physiological states, and the nutrients required to fulfill those physiological activities (NRC, 2001; AFRC., 1993; ARC, 1980).

Economic component: The economic component involves the processes for calculating costs and revenues associated with a specific management strategy, and production levels over a specific period of time (Groen, 1989; Bourdon, 1998; Dekkers *et al.*, 2004). These processes require techniques to calculate the economic benefits of each management decision. Profit functions, and partial budgeting are techniques for calculating returns, costs, and resource utilization per unit of product, over a specified production period.

Profit function: It is critical for any market-oriented livestock farming system to achieve a certain level of profit that would ensure its socio-economic obligation, and remain sustainable. Therefore, the profit function approach, including revenue, and related costs is of interest in livestock farming businesses. Accounting for production costs is necessary for input management, and determination of the competitiveness of a dairy farming system (Langrell *et al.*, 2012; Viira *et al.*, 2015). Production costs are classified as fixed or variable costs (Harris & Freeman, 1993; Cesaro *et al.*, 2008). Variable costs are those costs that vary with scale of production, such as feed costs, and reproduction costs. Fixed costs are constant within a specified period of time, irrespective of different production levels (growth, milk yield and quality), and may include buildings, depreciation, interest, rent, taxes, and insurance costs.

Partial budget: Proper herd management does not only include estimates of costs, and returns, but also assessment, and development of better alternative production options. The profit function serves as a basis for the economic evaluation of alternative management strategies. Partial budgeting is a deterministic approach for decision making, which evaluates different management options by inducing marginal changes to the existing farm management plan (Harsh *et al.*, 1981; Huirne & Dijkhuizen, 1997). This is accomplished by changing the value of a single or combination of the production factors at a time, while all other production factors are held constant (Boehlje & Eidman, 1984; Brascamp *et al.*, 1985; Kusumastuti *et al.*, 2018). Such an approach allows the identification of the positive or negative impacts associated with a shift from the prevailing (base) situation to the alternative production options. A positive effect indicates a potential increase in net returns, while negative effect implies a reduction in net returns if the change is adopted (Dalsted & Gutierrez, 1990).

As stated by Huirne & Dijkhuizen (1997), partial budgeting can provide the necessary details on enterprises, while bypassing the difficulties of allocating all the fixed, and overhead costs, using gross margin analysis. For example, variable costs tend to vary directly with small changes in the production levels, and are relatively easy to allocate to a specific enterprise (Huirne & Dijkhuizen, 1997). Partial budgeting offers the opportunity to explore a course of management action that matches a wide range of goals, which are ideal for smallholder dairy farmers, who widely differ in production ability. The process of partial budgeting can be summarized into three sections of economic analysis (Dalsted & Gutierrez, 1990):

- Added returns as a function of extra returns, and reduced costs,
- Added costs associated with reduced returns, and extra costs, and
- Net change in the return, e.g., gross margin or breakeven budgets.

2.7.4. Classes of models for evaluation of livestock production systems

Models can be classified based on the underlying processes (biological, and technical coefficients) influencing the production system (Veerkamp *et al.*, 1995; Fisher, 2001; Jones *et al.*, 2017). Different terms for the same type of models have been used in the literature, and Jalvingh (1993) attempted to group them into three structural categories as follows:

i. *Dynamic versus static:* A dynamic model is explicitly time-dependent, as opposed to a static model, which does not contain time as a variable, and therefore, would not be able to simulate system behavior over time
ii. *Deterministic versus stochastic:* A deterministic model is used to simulate specific outcomes given a set of specified input variables. In a deterministic model, the mean values of the input parameters are considered during evaluation (Brascamp, 1978). The stochastic model incorporates probabilistic or random elements to deal with uncertainty in the behavior of a system, and thereby, it is able to quantify, and compare the risks associated with different scenarios, and decisions. Unlike the deterministic model, the performance parameters in a stochastic model are described by their means, and variances (Wolfová *et al.*, 2007; Jones *et al.*, 2017).

iii. *Optimization versus simulation:* An optimization model determines the optimum solution given the objective function, and restrictions, whilst a simulation model calculates the outcome of a predefined set of variables.

A livestock production system is an aggregate of complex, and interlinked bio-economic sub-models. Its' simulation requires multi-level modelling processes that include animal, herd, and intrinsic interactions of animal or herd with the environment through land use such as feeding system, and feed quality (Jones *et al.*, 2017). From a practical point of view, this situation depicts a wide range of interrelationships among different sub-models. The combination of different classes of models is necessary to complement the limitation in each model, in order to establish a complete, and functional production system (Anderson, 1972; Reinmuth & Dabbert, 2017). In bio-economic simulation, the combination of linear dynamic programming along with deterministic, and/or stochastic procedures can be used to model a livestock production system (Brascamp, 1978; Wolfová *et al.*, 2007; Fuerst-Waltl & Baumung, 2009; Wolf *et al.*, 2013).

Both dynamic, and deterministic models were used in the development of the Alberta Beef Production Simulation System (ABPSS) in Canada by Pang *et al.* (1999). The ABPSS included herd inventory, nutrient requirements, forage production, and economic sub-models that simulate the effects of production traits, and management strategies on the economic efficiency of the production system. The performance traits used to describe beef performance were cow's mature weight, milk production, body condition score, calf birth weight, weaning weight, pre-weaning, and post-weaning weight, calving, and weaning rates, and mortality. Banga (2009) used a deterministic model to develop breeding objectives for the high-input dairy cattle production system in South Africa. The traits included in the breeding objectives developed for this high-input system were: production (yield of milk, fat, and protein, and live weight), somatic cell count, longevity, and calving interval. Inchaisri *et al.* (2010) used a stochastic, and dynamic simulation model to compare the economic consequences of different scenarios (average and poor) of reproductive performance of dairy cows in the Netherlands. The reproductive measures evaluated included ovulation rate, oestrus detection rate, conception rate, the incidence rate of postpartum disorders, embryonic death rate, and voluntary waiting period.

2.7.5. Application of bio-economic simulation models in system analysis

The application of bio-economic simulation models generally depends on two important approaches: i) positive approach, and ii) normative approach (Groen, 1989; Janssen & van

Ittersum, 2007). The implementation of each or the combination of these approaches is guided by the purpose/objective of the study. The features of these two approaches are presented herein.

The positive approach is aimed at modelling the interrelationships of the components of a production system, using complete or partial empirical data (Chai, 2005; Janssen & van Ittersum, 2007). Simulation of the bio-economic behaviour of a system, based on complete or partial empirical data, increases model reliability in representing the reality in the reference situation (Chai, 2005; Buysse *et al.*, 2007). The positive approach is descriptive, and non-optimizing in nature, and therefore, will not derive a solution for the problem facing the production system (Buysse *et al.*, 2007). It is suitable for the evaluation of the impact of the past, and prevailing management decisions on the measures of system performance, such as milk yield, and profitability.

On the other hand, the normative technique is an optimization approach, which determines what ought to happen to the system when it is subjected to alternative production options (Janssen & van Ittersum, 2007). It is prescriptive in nature, and can be used to search for the best or optimal alternative management options with regards to the problem facing the production system (Chai, 2005; Buysse *et al.*, 2007; Janssen & van Ittersum, 2007). The approach is based on prior knowledge of the reference system to develop appropriate alternative production norms (Dent & Blackie, 1979; Janssen & van Ittersum, 2007). The norms are the references that describe what the farmers ought to do, in order to achieve the desired production objectives (Janssen & van Ittersum, 2007). In the current study, both positive, and normative approaches were used, respectively, to determine the baseline herd model, and evaluate ex-ante alternative smallholder herd production models. The aim of using the positive approach was to simulate the real system as closely as possible, and to provide the reference situation for assigning the magnitude, and direction of change during normative analysis.

2.8. Conclusion

The smallholder sector needs effective production management strategies, where herd productivity, and profitability are of crucial importance. This will establish a viable smallholder sector that contributes effectively to food security, and socio-economic development. To address this need, information on the key factors affecting dairy herds' productivity, and profitability should be identified, recorded, and analysed to define the best production options. This review has therefore given an insight regarding indicators of dairy cow performance, and their fundamental roles in the dairy production system. The development of a profitable, and sustainable dairy farming enterprise requires a holistic approach that identifies potential areas for improvement in the production system. Productivity is best evaluated through benchmarking of the performance measures of the target production system, against its better performing counterparts with similar production objectives. Benchmarking aids in developing an understanding of the overall performance of the industry sub-sectors, and identifies performance levels that could be used to guide the improvement of the weaker sub-sector. Dairy or livestock production, in general is dynamic, and influenced by different bio-economic components. Understanding these components, and their effects on productivity, and economic efficiency is important for practical, and efficient decision making. Different types, and approaches of simulation models have been developed, which are capable of combining these diverse production components. In these models, the production system, and its underlying biological, and economic process are mimicked, and their effect on productivity, and economic efficiency are quantified. These models can also simulate the effect of alternative management decisions (e.g. feed intake, calving interval herd dynamics) on herd performance. It can be concluded that the elements, and factors referred to above, can influence dairy herds' productivity, and profitability, and should therefore be taken into consideration when investigating strategies for improvement of the smallholder production system.

2.9. References

Abdel Gader, A.Z, Ahmed, M.K.A., Musa, L.M.A. & Peters, K.J., 2007. Milk yield and reproductive performance of Friesian cows under Sudan tropical conditions. Arch Tierz (Anim. Breed). 50, 155-164.

Abera, M., Habte, T., Aragaw, K., Asmare, K. & Sheferaw, D., 2012. Major causes of mastitis and associated risk factors in smallholder dairy farms in and around Hawassa, Southern Ethiopia. Trop. Anim. Health. Prod. 44, 1175-1179.

AFRC (Agricultural & Food Research Council), 1993. Energy and protein requirements of ruminants. An advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients. CAB International, Wallingford, UK.

Agabriel, J. & Ingrand, S., 2004. Modelling the performance of the beef cow to build a herd functioning simulator. Anim. Res. 53, 347-361.

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

Ahmed, M.K., Teirab, A.B., Musa, L.A. & Peters, K.J., 2007. Milk production and reproduction traits of different grades of zebu x Friesian crossbreds under semi-arid conditions. Arch Tierz (Anim. Breed). 50, 240-249.

Akins, M.S., 2016. Dairy heifer development and nutrition management. Veterinary Clinics: Food Animal Pract. 32, 303-317.

Ali, B.M., Berentsen, P.B.M., Basttiaansen, J.W.M. & Lansink, A.O., 2018. A stochastic bio-economic pig farm model to assess the impact of innovation of farm performance. Anim. 12, 819-830.

Alphonsus, C. & Essien, I.C., 2012. The relationship estimates amongst milk yield and milk composition characteristics of Bunaji and Friesian × Bunaji cows. Afr. J. Biotechnol. 11, 8790-8793.

Andersen-Ranberg, I.M., Heringstad, B., Klemetsdal, G., Svendsen, M. & Steine, T., 2003. Heifer fertility in Norwegian dairy cattle: Variance components and genetic change. J. Dairy Sci. 86:2706-2714.

Anderson, J.R. & Dent, J.B., 1971. Agricultural systems analysis: retrospect and prospect. In: Systems Analysis in Agricultural Management. Eds: Dent, J.B. & Anderson, J.R., John Wiley & Sons Australasia Pty Ltd., Sydney, Australia, pp. 383-388.

Anderson, J.R., 1972. Economic models and agricultural production systems. Proc. Aust. Soc. Anim. Prod. 9, 77-83.

ARC (Agricultural Research Council), 1980. The nutrient requirements of grazing livestock. Commonwealth Agricultural Bureau, London.

ARC (Agriculture Research Council), South Africa (2016). National Milk Recording and Improvement Scheme. Milk Cattle Bulletin-2016. pp. 11-14. http://www.arc.agric.za/arc-api/Newsletter%20Library/Annual%20Milk%20Cattle%20Bulletin,%20Issue%2020,%202016.pdf.

Ash, A., Hunt, L., McDonald, C., Scanlan, J., Bell, L., Cowley, R., Watson, I., McIvor, J. & MacLeod, N., 2015. Boosting the productivity and profitability of northern Australian beef enterprises: exploring innovation options using simulation modelling and systems analysis. Agric. Syst. 139, 50-65.

Ashfield, A., Crosson, P. & Wallace, M., 2013. Simulation modelling of temperate grassland based dairy calf to beef production systems. Agric. Syst. 115, pp.41-50.

Ashfield, A., Wallace, M., Prendiville, R. & Crosson, P., 2014. Bioeconomic modelling of male Holstein-Friesian dairy calf-to-beef production systems on Irish farms. Ir. J. Agric. Food Res. 53, 133-147.

Ayalew W, Aliy M & Negussie E 2015: Milk production performance of Holstein Friesian dairy cows at Holetta Bull Dam Farm, Ethiopia. Livest. Res. Rural Dev. 27, Article #173. Retrieved April 5, 2018, from http://www.lrrd.org/lrrd27/9/wond27173.html.

Banga, C.B., 2002. Performance testing for the smallholder sector in South Africa. ARC Animal Improvement Institute. Irene, South Africa. pp, 1-7.

Banga, C.B., 2009. The development of breeding objectives for Holstein and Jersey cattle in South Africa. (Ph.D. thesis, University of the Free State, Bloemfontein, South Africa).

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

Barbano, D.M., Ma, Y. & Santos, M.V., 2006. Influence of Raw Milk Quality on Fluid Milk Shelf Life1, 2. J. Dairy Sci. 89, E15-E19.

Bauman, D.E. & Currie, W.B., 1980. Partitioning of nutrients during pregnancy and lactation: a review of mechanisms involving homeostasis and homeorhesis. J. Dairy Sci. 63, 1514-1529.

Beam, S.W. & Butler, W.R. 1999. Effects of energy balance on follicular development and first ovulation in postpartum dairy cows. J. Reprod. Fert. 54, 411-424.

Benhin, J. K. A. 2006. Climate change and South African agriculture: Impacts and adaptation options. Special series on climate change and agriculture in Africa. Centre for Environmental Economics and Policy in Africa, University of Pretoria, Pretoria, South Africa. CEEPA Discussion paper no. 21.

Berry, D.P., Horan, B. & Dillon, P. 2005. Comparison of growth curves of three strains of female dairy cattle. Anim. Sci. 80, 151-160.

Berry, D.P & Crowley, J.J, 2013. Genetics of feed efficiency in dairy and beef cattle. J. Anim. Sci. 91, 1594-1613.

Berry, D.P., Wall, E. & Pryce, J.E., 2014. Genetics and genomics of reproductive performance in dairy and beef cattle. Anim. 8, 105-121.

Berry, D.P., Friggens, N.C., Lucy, M. & Roche, J.R., 2016. Milk production and fertility in cattle. Annual review of anim. biosci, 4, 269-290.

Bindari, Y.R., Shrestha, S., Shrestha, N. & Gaire, T.N., 2013. Effects of nutrition on reproduction-A review. Adv. Applied Sci. Res 4, 421-429.

Boehlje, M.D. & Eidman, V.R. 1984. Farm management. John Wiley and Sons, New York, USA. pp, 806.

Bohan, A., Shalloo, L., Malcolm, B., Ho, C.K.M., Creighton, P., Boland, T.M., McHugha, N., 2016. Description and validation of the Teagasc Lamb Production Model. Agric. Syst. 148, 124-134.

Boichard, D. 1990. Estimation of the economic value of conception rate in dairy cattle. Livest. Prod. Sci. 24:187-204.

Bortolami, A., Fiore, E., Gianesella, M., Corro, M., Catania, S. & Morgante, M., 2015. Evaluation of the udder health status in subclinical mastitis affected dairy cows through bacteriological culture, somatic cell count and thermographic imaging. Pol. J. Vet. Sci. 18, 799-805.

Boujenane, I. & Hilal, B., 2012. Genetic and non genetic effects for lactation curve traits in Holstein-Friesian cows. Archiv Tierzucht. 55, 450-457.

Bourdon, R.M., 1998. Shortcomings of current genetic evaluation systems. J. Anim. Sci. 76, 2308-2323.

Brandt, M., Haeussermann, A. & Hartung, E., 2010. Invited review: Technical solutions for analysis of milk constituents and abnormal milk J. Dairy Sci. 93, 427-436.

Brascamp, E. W., 1978. Methods on economic optimization of animal breeding plans. Report B-134, Research Institute for Animal husbandry "Schoonoord", Zeist, The Netherlands.

Brascamp, E.W., Smith, C. & Guy, D.R., 1985. Derivation of economic weights from profit equations. Anim. Prod. 40, 175-180.

Brockington, N.R., Gonzalez, C.A., Veil, J.M., Vera, R.R., Teixeira, N.M. & De Assis, A.G., 1983. A bio-economic modelling project for small-scale milk production systems in South-East Brasil. Agric. Syst. 12, 37-60.

Brun-Lafleur, L., Cutullic, E., Faverdin, P., Delaby, L. & Disenhaus, C., 2013. An individual reproduction model sensitive to milk yield and body condition in Holstein dairy cows. Anim. 7, 1332-1343.

Bucek, P., Zottl, K., Kyntäjä, J., Miglior, F., Leclerc, H., van der Westhuizen, J., Kuwan, K., Lavon, Y., Haase, K., Trejo, C. & Radzio, D., 2015. World-wide trends in milk-recording in cattle. In ICAR Technical Workshop, Krakow, Poland. ICAR, Rome, Italy. pp. 107-119.

Butler, W.R., 2000. Nutritional interactions with reproductive performance in dairy cattle. Anim. Reprod. Sci. 60, 449-457.

Butler, W.R., 2001 Nutritional effects on resumption of ovarian cyclicity and conception rate in post-partum dairy cows. Anim. Sci. Occas. Publ. 26, 133-145.

Butler, A., Wallace, M. & Berentsen, P., 2002. Comparison of Different Studies to Analyse Adaptation on Dairy Farms. Paper prepared for presentation at the 13th International Farm Management Congress, July 7-12, 2002. Wageningen, The Netherlands.

Butler, W.R., 2003. Energy balance relationships with follicular development, ovulation and fertility in postpartum dairy cows. Livest. Prod. Sci. 83, 211-218.

Buysse, J., Van Huylenbroeck, G. & Lauwers, L., 2007. Normative, positive and econometric mathematical programming as tools for incorporation of multifunctionality in agricultural policy modelling. Agric. ecosys. environ. 120, 70-81.

Bytyqi, H., Fuerst-Waltl, B., Mehmeti, H. & Baumung, R., 2015. Economic Values for Production Traits for Different Sheep Breeds in Kosovo. Ital. J. Anim. Sci. 14, 603-609.

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

Cai, W., 2014. Making Comparisons Fair: How LS-Means Unify the Analysis of Linear Models. SAS Institute Inc. pp. S060.

Calderón-Robles, R.C., Flores-Domínguez, B., Ríos-Utrera, Á., Rosete-Fernández, J.V. & Lagunes-Lagunes, J., 2011. Reproductive performance of Holstein and Brown Swiss cows under intensive grazing in a humid subtropical climate. Trop. Subtrop. Agroeco 13, 429-435.

Cammack, K.M., Thomas, M.G. & Enns, R.M., 2009. Reproductive traits and their heritabilities in beef cattle. The Prof. Anim. Sci., 25, 517-528.

Carrillo-Casas E. & Miranda-Morales, R.E., 2012. Bovine mastitis pathogens: prevalence and effects on somatic cell count. In: Milk production-an up to-date overview of animal nutrition, management and health. Ed: Chaiyabutr, N., INTECH, New York, pp 359-374.

Cassandro, M., 2014. Genetic aspects of fertility traits in dairy cattle–review. Acta agraria kaposváriensis. 18, 11-23.

Cesaro, L., Marongiu, S., Arfini, F., Donati, M. & Capelli, M.G., 2008. Cost of production–Definition and concept. FP7 Project Farm Accountancy Cost Estimation and Policy Analysis of European Agriculture. INEA-Italy.

Chai, S.K., 2005. Rational Choice: Positive, Normative, and Interpretive. Paper presented at the Annual Meeting of the American Sociological Association, Marriott Hotel, Loews Philadelphia Hotel, Philadelphia, PA, Aug (Vol. 12, p. 2005).

Chebel, R. C., Mendonça, L.G.D. & Baruselli, P.S., 2018. Association between body condition score change during the dry period and postpartum health and performance. J. Dairy Sci. 101, 4595-4614.

Clark, D.A, Penno, J.W & Neil, P.G., 1997. Nutritional Merits and problems of pasture. In: Milk Composition, Production and Biotechnology. Eds: Welch, R.A.S., Burns, D.J.W., Davis, S.R., Popay, A.I. & Prosser, C.G., Cambridge: Cambridge University Press. pp. 397-418.

Coffey, E.L., Horan, B., Evans, R.D. & Berry, D.P., 2016. Milk production and fertility performance of Holstein, Friesian, and Jersey purebred cows and their respective crosses in seasonal-calving commercial farms. J. Dairy Sci. 99, 5681-5689.

Cooke, J. S., Cheng, Z., Bourne, N. E. & Wathes, D. C., 2013. Association between growth rates, age at first calving and subsequent fertility, milk production and survival in Holstein-Friesian heifers. Open J. Anim. Sci. 3, 1-12.

Crowe, M.A., Hostens, M. & Opsomer, G., 2018. Reproductive management in dairy cows-the future. Irish Vet. J. 71, 2-13.

Cunha, D.D.N.F.V., Pereira, J.C., Campos, O.F.D., Braga, J.L. & Martuscello, J.A., 2010. Evaluation of a dynamic simulation model for milk production systems. R. Bras. Zootec. 39, 903-912.

DAFF (Department of Agriculture, Forestry & Fisheries), 2015. A profile of the South African dairy market value chain 2015. Published by the Directorate of marketing of the Department of Agriculture, Forestry and Fisheries. Arcadia, Pretoria South Africa.

DAFF (Department of Agriculture, Forestry & Fisheries), 2017. A profile of the South African dairy market value chain. Compiled by the Directorate of Marketing of the Department of Agriculture, Forestry and Fisheries. Republic of South Africa, Pretoria.

Dalsted N.L. & Gutierrez P.H. 1990. Partial Budgeting. Service in action: Farm and Ranch Series, no. 3.760. Cooperative Extension. Colorado State University, Fort Collins, Colorado. USA.

Davis, S.R., 1997. Limits to productivity in dairy cows. In: Milk Composition, Production, and Biotechnology. Eds: Welch, R.A.S., Burns, D.J.W, Davis, S.R., Popay, A.I., & Prosser, C.G., CAB International, Wallingford, UK. pp, 533-544.

Dekkers, J.C.M., Ten Hag, J.H. & Weersink, A., 1998. Economic aspects of persistency of lactation in dairy cattle. Livest. Prod. Sci. 53, 237-252.

Dekkers, J., Gibson, J., Bijma, P. & van Arendonk, J., 2004. Design and optimization of animal breeding programmes. Lecture notes. Wageningen.

Dent, J.B. & Anderson, J.R., 1971. Systems Analysis in Agricultural Management. John Wiley, Sydney.

Dent, J.B. & Blackie, M.J., 1979. Systems Simulation in Agriculture. Springer, Applied Science, London.

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.

Detilleux, J.C., Leroy, P. & D. Volckaert. 1997. Alternative use of somatic cell counts in genetic selection for mastitis resistance. Interb. Bull. 15, 34-44

de Vries, F.P., 1977. Evaluation of simulation models in agriculture and biology: conclusions of a workshop. Agric. Syst. 2, 99-107.

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

Do, C., Wasana, N., Cho, K., Choi, Y., Choi, T., Park, B. & Lee, D., 2013. The effect of age at first calving and calving interval on productive life and lifetime profit in Korean Holsteins. Asian Austral. J. Anim. Sci. 26, 1511-1517.

Dobson, H., Smith, R.F., Royal, M.D., Knight, C.H. & Sheldon, I.M., 2007. The High-producing Dairy Cow and its Reproductive Performance. Reprod. Domest. Anim. 42, 17-23.

Dodd, F.H. & Booth, J.M., 2000. Mastitis and milk production. In: The Health of Dairy Cattle. Ed: Andrews, A.H., Blackwell Science, Oxford, UK. pp. 213-255.

Domecq, J.J., Skidmore, A.L., Lloyd, J.W. & Kaneene, J.B., 1997. Relationship Between Body Condition Scores and Milk Yield in a Large Dairy Herd of High Yielding Holstein Cows. J. Dairy Sci. 80, 101-112.

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. Anim. 9, 191-207.

El-Tarabany, M.S., Roushdy, E.M. & El-Tarabany, A.A., 2017. Production and health performance of Holstein, Brown Swiss and their crosses under subtropical environmental conditions. Anim. Prod. Sci. 57, 1137-1143.

Endris, M., Tumwasorn, S., Wongwan, C., Sopannarath, P. & Prasanpanich, S., 2012. Estimation of direct genetic effects on milk yield and lactation length in the Aownoi dairy cooperative. Agric. Nat. Res. 46, 546-553.

Esposito, G., Irons, P.C., Webb, E.C. & Chapwanya, A., 2014. Interactions between negative energy balance, metabolic diseases, uterine health and immune response in transition dairy cows. Anim. reprod. Sci. 144, 60-71.

Finlayson, J.D., Cacho, O.J. & Bywater, A.C., 1995. A simulation model of grazing sheep: I. Animal growth and intake. Agric. Syst. 48, 1-25.

Fisher, J.W., 2001. An economic comparison of production systems for sheep. Can. J. Agr. Econ. 49, 223-336.

Friggens, N.C., Brun-Lafleur, L., Faverdin, P., Sauvant, D. & Martin, O., 2013. Advances in predicting nutrient partitioning in the dairy cow: recognizing the central role of genotype and its expression through time. Anim. 7, 89-101.

Fuerst-Waltl, B. & Baumung, B.R., 2009. Economic values for performance and functional traits in dairy sheep. Ital. J. Anim. Sci. 8, 341-357.

Galvão, K.N., Federico, P., De Vries, A. & Schuenemann, G.M., 2013. Economic comparison of reproductive programs for dairy herds using estrus detection, timed artificial insemination, or a combination. J. Dairy Sci. 96, 2681-2693.

Ganie, A.A., Mir, I.A., Sehgal, J.P., Sheikh, G.G., Haq, M. & Pampori, Z.A., 2011. Feeding Systems - Efficient Tools to Alter Milk Composition-A Review. Agric. Rev. 32, 235-245.

Getaneha, A.M., Mekonnena, S.A. & Hogeveena, H., 2017. Stochastic bio-economic modeling of mastitis in Ethiopian dairy farms. Prev. Vet. Med. 138, 94-103.

Giordano, J.O., Fricke, P.M., Wiltbank, M.C. & Cabrera, V.E., 2011. An economic decision-making support system for selection of reproductive management programs on dairy farms. J. Dairy Sci. 94, 6216-6232.

Gonçalves, J.L., Tomazi, T., Barreiro, J.R., Beuron, D.C., Arcari, M.A., Lee, S.H.I., Martins, C.M.D.M.R., Junior, J.P.A. & dos Santos, M.V., 2016. Effects of bovine subclinical mastitis caused by Corynebacterium spp. on somatic cell count, milk yield and composition by comparing contralateral quarters. Vet. J. 209, 87-92.

Goni, S., 2014. Production and reproduction performance of Jersey and Fleckvieh× Jersey cows in a pasture-based system (Doctoral dissertation, Stellenbosch: Stellenbosch University).

Gonzalez-Recio, O, Perez-Cabal, M.A. & Alenda R., 2004. Economic value of female fertility and its relationship with profit in Spanish dairy cattle. J. Dairy Sci. 87, 3053-3061

Graham, J.M., 2008. The general linear model as structural equation modeling. J. Educ. Behav. Stat. 33, 485-506.

Groen, A.F., 1989. Cattle breeding goals and production circumstances. (Fokdoel in de rundveefokkerij en produktie-omstandigheden), (Ph.D. Thesis, Department of Farm Management and Department of Animal Breeding, Wageningen Agricultural University, Wageningen, The Netherlands).

Groen, A. F., Steine, T., Colleau, J. J., Pedersen, J., Pribyl, J. & Reinsch, N., 1997. Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-working group. Livest. Prod. Sci. 49, 1-21.

Groen, A.F., Jiang, X., Emmerson, D.A. & Vereijken, A., 1998. A deterministic model for the economic evaluation of broiler production systems. Poult. Sci. 77, 925-933.

Halasa, T., Nielen, M., De Roos, A.P.W., Van Hoorne, R., De Jong, G., Lam, T.J.G.M., Van Werven, T. & Hogeveen, H., 2009. Production loss due to new subclinical mastitis in Dutch dairy cows estimated with a test-day model. J. Dairy Sci. 92, 599-606.

Hamann, J. 2005. Diagnosis of mastitis and indicators of milk quality. In: Proceedings of the 4th International Dairy Federation (IDF), Mastitis in Dairy Production: Current Knowledge and Future Solutions. Ed: Hogeveen, H., Wageningen Academic Publication, Wageningen, The Netherlands. pp. 82-91.

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. Arch. Zootec. 13, 60-82.

Hammoud, M.H. & Salem, M.M.I., 2013. The genetic evaluation of some first lactation traits of Holstein cows in Egypt. Alex J. Agric. Res. 58, 1-8.

Harris, B.L. & Freeman, A.E., 1993. Economic weights for milk yield traits and herd life under various economic conditions and production quotas. J. Dairy Sci. 76, 868-879.

Harsh, S.B., Conner L. J. & Schwab G.D., 1981. Managing the farm business. Prentice-hall, INC., Eaglewood Cliffs, New Jersey. U.S.A.

Hassan, F. & Khan, M.S., 2013. Performance of crossbred dairy cattle at military dairy farms in Pakistan. J. Anim Plant Sci, 23, 705-714.

Hearnshaw, H., Archer, J.A. & Barlow, R., 2002. Evaluation of Hereford and first-cross cows on three pasture systems: cow survival and reasons for disposal under different culling regimes. Livest. Prod. Sci. 75, 183-197.

Heinrichs, A.J. & Vazquez-Anon, M., 1993. Changes in first lactation dairy herd improvement records. J. Dairy Sci. 76, 671-675.

Heins, B.J., Hansen, L.B. & Seykora, A.J., 2006. Production of pure Holsteins versus crossbreds of Holstein with Normande, Montbeliarde, and Scandinavian Red. J. Dairy Sci. 89, 2799-2804.

Heins, B.J., Hansen, L.B., Seykora, A.J., Johnson, D.G., Linn, J.G., Romano, J.E. & Hazel, A.R., 2008. Crossbreds of Jersey× Holstein compared with pure Holsteins for production, fertility, and body and udder measurements during first lactation. J. Dairy Sci. 91, 1270-1278.

Heins, B.J. & Hansen, L.B., 2012. Fertility, somatic cell score, and production of Normande× Holstein, Montbéliarde× Holstein, and Scandinavian Red× Holstein crossbreds versus pure Holsteins during their first 5 lactations. J. Dairy Sci. 95, 918-924.

Hering, P., Kopunecz, P., Hanuš, O., Tomáška, M., Klimešová, M., Jedelská, R. & Kopecký, J., 2016. Development to Ensure the Result Reliability of Production Indicators in the Milk Recording During its Computerization. Acta Univ. Agric. Silvic. Mendel. Brun. 64, 791-801.

Herrero, M., Fawcett, R.H. & Dent, J.B., 1999. Bio-economic evaluation of dairy farm management scenarios using integrated simulation and multiple-criteria models. Agric. syst. 62, 169-188.

Hossein-Zadeh, N.G., 2013. Factors affecting lactation length and effect of current lactation length on the subsequent production and reproduction in Iranian Holsteins. Arch. Anim. Breed. 56, 873-881.

Hudson, C.D., Bradley, A.J., Breen, J.E. & Green, M.J., 2012. Associations between udder health and reproductive performance in United Kingdom dairy cows. J. Dairy Sci. 95, 3683-3697.

Huirne, R.B.M. & Dijkhuizen, A.A., 1997. Basic methods of economic analysis. In: Animal health economics-principles and applications. Eds: Dijkhuizen, A.A. & Morris, R.S., University of Sydney. Sydney, Australia. pp. 25-40.

IBM Corp., 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.

ICAR (International Committee for Animal Recording), 2014. International agreement of recording practices. ICAR Recording Guidelines approved by the General Assembly held in Berlin, Germany, on May 2014. ICAR. Roma, Italy

ICAR (International Committee for Animal Recording), 2017. Cattle Milk Recording, Version October 2017: In: Guidelines for Dairy Cattle Milk Recording, The global standard for livestock data, Rome Italy. pp 2.

Ilatsia, E.D., Muasya, T.K., Muhuyi, W.B. & Kahi, A.K., 2007. Milk production and reproductive performance of Sahiwal cattle in semi-arid Kenya. Trop. Sci. 47, 120-127.

Inchaisri, C., Jorritsma, R., Vos, P.L.A.M., Van der Weijden, G.C. & Hogeveen, H., 2010. Economic consequences of reproductive performance in dairy cattle. Theriogen. 74, 835-846.

Inchaisri, C., Jorritsma, R., Vos, P.L.A.M., Van Der Weijden, G.C. & Hogeveen, H., 2011. Analysis of the economically optimal voluntary waiting period for first insemination. J. Dairy Sci. 94, 3811-3823.

Interbull, 2001. Interbull Guidelines for National and International Genetic Evaluation Systems in Dairy Cattle with Focus on Production Traits. International Bull Evaluation Service. Uppsala, Sweden. Bull. no. 28.

Iooss, B. & Lematre, P., 2015. A review on global sensitivity analysis methods. In: Uncertainty management in simulation–optimization of complex systems: algorithms and applications. Eds: Meloni, C. & Dellino, G., Springer, New York. pp. 101-122.

Iraguha, B., Hamudikuwanda, H. & Mushonga, B., 2015. Bovine mastitis prevalence and associated risk factors in dairy cows in Nyagatare District, Rwanda. Journal of the S. Afr. Vet. Assoc. 86, 1-6.

Jalvingh, A.W., Dykhuizen, A.A. & Van Arendonk, J.A.M., 1991. Dynamic livestock modelling as a tool for on-farm decision support in herd health and management control programs. International Symposia on Veterinary Epidemiology and Economics proceedings, ISVEE 6: Proceedings of the 6th International Symposium on Veterinary Epidemiology and Economics, Ottawa, Canada, Modelling and systems analysis session, pp. 544-546.

Jalvingh, A.W., 1993. Dynamic livestock modelling for on farm decision support. (PhD thesis. Department of Farm Management and Department of Animal Breeding, Wageningen Agricultural University, Wageningen).

Janssen, S. & Van Ittersum, M.K., 2007. Assessing farm innovations and responses to policies: a review of bio-economic farm models. Agric. syst. 94, 622-636.

Jílek, F., Pytloun, P., Kubešová, M., Štípková, M., Bouška, J., Volek, J., Frelich, J. & Rajmon, R., 2008. Relationships among body condition score, milk yield and reproduction in Czech Fleckvieh cows. Czech J. Anim. Sci. 53, 357-367.

Jones, J.W., Antle, J.M., Basso, B.O., Boote, K.J., Conant, R.T., Foster, I., Godfray, H.C.J., Herrero, M., Howitt, R.E., Janssen, S., Keating, B.A., Munoz-Carpena, R., Porter, C.H., Rosenzweig, C. & Wheeler, T.R., 2016. Brief history of agricultural system modeling. Agric. Syst. 155, 240-254.

Jones, J.W., Antle, J.M., Basso, B., Boote, K.J., Conant, R.T., Foster, I., Godfray, H.C.J., Herrero, M., Howitt, R.E., Janssen, S. & Keating, B.A., 2017. Toward a new generation of agricultural system data, models, and knowledge products: State of agricultural systems science. Agric. syst. 155, 269-288.

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.

Katsande, S., Matope, G., Ndengu, M. & Pfukenyi, D.M., 2013. Prevalence of mastitis in dairy cows from smallholder farms in Zimbabwe. Onderstepoort J. Vet. Res. 80, 00-00.

Kebreab, E., Reed, K.F., Cabrera, V.C., Vadas, P.A., Thoma, G., & Tricarico, J.M., 2019. A new modeling environment for integrated dairy system management. Anim. Front. 9, 25-32.

Kikuhara, K., Kumagai, H. & Hirooka, H., 2009. Development and Evaluation of a Simulation Model for Dairy Cattle Production Systems Integrated with Forage Crop Production. Asian Austral. J. Anim. Sci. 22, 57-71.

Kitilit, J.K., Cheruiyot, A.C. & Kios, D.K., 2016. Effects of Negative Energy Balance on Health and Milk Yield of Lactating Dairy Cattle. Egerton J. Sci. Technol. 15, 1-10.

Kleijnen, J.P.C., 2009. Sensitivity Analysis of Simulation Models. CentER Discussion Paper, 2009-2011.

Kollalpitiya, K.M.P.M.B., Premaratne, S. & Peiris, B.L., 2012. Reproductive and productive performance of up-country exotic dairy cattle breeds of Sri Lanka. Tropical Agricultural Research, 23(4). Trop. Agric. Res., 23: 319-326.

Konandreas, P.A. & Anderson, F.M., 1982. Cattle herd dynamics: an integer and stochastic model for evaluating production alternatives. ILRI (aka ILCA and ILRAD).

Kumar, N., Alemayehu, E., Abreha, T. and Yizengaw, H.A., 2014a. Productive performance of indigenous and HF crossbred dairy cows in Gondar, Ethiopia. Vet. World, 7, 177-181.

Kumar, N., Eshetie, A., Gebrekidan, B. and Gurmu, E.B., 2014b. Reproductive performance of indigenous and HF crossbred dairy cows in Gondar, Ethiopia. J. Agric. Vet. Sci. 7, 56-61.

Kunz, P. L., Blum, J.W., Hart, I.C., Bickel, H. & Landis, J., 1985. Effects of different energy intakes before and after calving on food intake, performance and blood hormones and metabolites in dairy cows. Anim. Prod. 40, 219-231.

Kusumastuti, T.A., Widiati, R. & Bintara, S., 2018. Partial Budget Analysis to Determine Additional Income of Etawa Crossbred Goat Farmers Using Breeding System in Kulon Progo Regency, Yogyakarta, Indonesia. Adv. Eng. Res. 172, 57-61.

Lacto data, 2019 Statistics: A Milk SA publication compiled by the milk producers' organization. 22, 1-32. www.milksa.co.za.

Lai, J., Widmar, N.J.O., Gunderson, M.A., Widmar, D.A & Ortega, D.L., 2018. Prioritization of farm success factors by commercial farm managers. Int. Food and Agribusiness Mgt. Rev. 21, 817-832.

Langrell, S., Ciaian, P. & y Paloma, S.G., 2012. Sustainability and Production Costs in the Global Farming Sector: Comparative Analysis and Methodologies (No. JRC70116). European Commission, Joint Research Centre (Seville site). Report EUR 25436 EN.

Lassen, B. J., 2012. Dairy Production in South Africa-impressions, Country Report 2012/1. http://www.agribenchmark.org/fileadmin/Dateiablage/BDairy/Country_Report/12_country_information_SA.pdf.

Lau, H.C.W., Lau, P.K.H., Fung, R.Y.K., Chan, F.T.S. & Ip, R.W.L., 2005. "A virtual case benchmarking scheme for vendors' performance assessment", Benchmarking: Int. J. 12, 61-80.

Lavon, Y., Leitner, G., Voet, H. & Wolfenson, D., 2010. Naturally occurring mastitis effects on timing of ovulation, steroid and gonadotrophic hormone concentrations, and follicular and luteal growth in cows. J. Dairy sci. 93, 911-921.

Leinonen, I., Williams, A.G. & Kyriazakis, I., 2016. Potential environmental benefits of prospective genetic changes in broiler traits. Poult. Sci. 95, 228-236.

Le Maréchal, C., Thiéry, R., Vautor, E. & Le Loir, Y., 2011. Mastitis impact on technological properties of milk and quality of milk products-a review. Dairy Sci. Technol. 91, 247-282

León-Velarde, C.U. & Quiroz, R., 2001. Modeling cattle production systems: integrating components and their interactions in the development of simulation models. In:

Proceedings-Third International Symposium on Systems Approaches for Agricultural Development (SAAD III), International Potato Center (CIP), Lima Peru. pp. 8.

Lin, C.Y., McAllister, A.J., Batra, T.R., Lee, A.J., Roy, G.L., Vesely, J.A., Wauthy, J.M. & Winter, K.A., 1988. Effects of Early and Late Breeding of Heifers on Multiple Lactation Performance of Dairy Cows1. J. Dairy sci. 71, 2735-2743.

Llewellyn, S., Fitzpatrick, R., Kenny, D.A., Murphy, J.J., Scaramuzzi, R.J. & Wathes, D.C., 2007. Effect of negative energy balance on the insulin-like growth factor system in pre-recruitment ovarian follicles of postpartum dairy cows. Reprod. 133, 627-639.

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.

Lotthammer, K.H., 1991. Influence of nutrition on reproductive performance of the milking/gestating cow in the tropics, In: Feeding Dairy Cows in the Tropics. Eds: Speedy, A., & Sansoucy, R., Food and Agriculture Organization of the United Nations, Rome. pp. 36-45.

Louhichi, K., Janssen, S., Kanellopoulos, A., Li, H., Borkowski, N., Flichman, G., Hengsdijk, H., Zander, P., Fonseca, M.B., Stokstad, G. & Athanasiadis, I.N., 2010. A generic farming system simulator. In: Environmental and Agricultural Modelling Springer Netherlands. pp. 109-132.

Lucy, M.C., 2000. Regulation of ovarian follicular growth by somatotropin and insulin-like growth factors in cattle. J. Dairy Sci. 83, 1635-1647.

Macciotta, N.P.P., Vicario, D. & Cappio-Borlino, A., 2005. Detection of different shapes of lactation curve for milk yield in dairy cattle by empirical mathematical models. J. Dairy Sci. 88, 1166-177.

Macciotta, N.P., Dimauro, C., Rassu, S.P., Steri, R. & Pulina, G., 2011. The mathematical description of lactation curves in dairy cattle. Ital. J. Anim. Sci. 10, 213-223.

Madalena, F.E., De Matos Lemos, A. & Teodoro, R.L., 1992. Consequences of removing the variation in lactation length on the evaluation of dairy cattle breeds and crosses. Rev. Bras. Genet. 15, 585-585.

Madouasse, A., 2009. An Evaluation of Milk Recording, Somatic Cell Count and Reproductive Performance in a Large Cohort of Dairy Herds in England and Wales. (PhD Thesis. University of Nottingham, Nottingham, UK).

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.

Manning, L., Baines, R. & Chadd, S., 2008. Benchmarking the poultry meat supply chain. Benchmarking: Int. J. 15, 148-165.

Martin, G., Martin-Clouaire, R. & Duru, M., 2013. Farming system design to feed the changing world. A review. Agron. Sust. Dev. 33, 131-149.

Mateus, M.D. & Franz, G., 2015. Sensitivity Analysis in a Complex Marine Ecological Model. Water. 7, 2060-2081.

McKnight, L. & Ibeagha-Awemu, E., 2019. Modeling of livestock systems to enhance efficiency. Anim. Front. 9, 3-5.

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. S. Afr. J. Anim. Sci. 43, 282-297.

Mellado, M., Coronel, F., Estrada, A. & Ríos, F.G., 2011. Lactation performance of Holstein and Holstein x Gyr cattle under intensive condition in a subtropical environment. Trop. Subtrop. Agroecosyst. 14, 927-931.

Metaxas, L., 2016. The production performance of Holstein and Fleckvieh x Holstein cows in an intensive feeding system. (MSc (Animal Sciences) Thesis, University of Stellenbosch, Stellenbosch, South Africa).

Meyer, M.J, Everett, R.W. & van Amburgh, M.E., 2004. Reduced age at first calving: effects on lifetime production, longevity, and profitability. In: 'Dairy Day 2004'. Ed: Srevenson, J.S., Kansas State University: Tempe, AZ. pp. 42-52.

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 South Africa (SA). 2013. The Milk SA guide to dairy farming in South Africa, 2nd edition, Pretoria, South Africa.

Morrison, S.J. & Patterson, D.C., 2007. The effects of offering a range of forage and concentrate supplements on milk production and dry matter intake of grazing dairy cows. Grass Forage Sci. 62, 332-345.

Mostert, B.E. 2007. The suitability of test-day models for genetic evaluation of dairy cattle in South Africa (Doctoral dissertation, University of Pretoria Pretoria).

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.

Mourits, M.C.M., Huirne, R.B.M., Dijkhuizen, A.A., Kristensen, A.R. & Galligan, D.T., 1999. Economic optimization of dairy heifer management decisions. Agric. syst. 61, 17-31.

Mucina, L. & Rutherford, M.C., 2006, The vegetation of South Africa, Lesotho and Swaziland, Strelitzia 19, South African National Biodiversity Institute, Pretoria.

Muehlhoff, E., Bennett, A. & McMahon, D., 2013. Milk and dairy products in human nutrition. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Mulindwaa, H., Galukande, E., Wurzinger, M., Ojango, J., Okeyo, A.M. & Sölkner, J., 2011. Stochastic simulation model of Ankole pastoral production system: Model development and evaluation. Ecol. Mod. 222, 3692-3700.

Muller, C.J.C., Potgieter, J.P. & Cloete, S.W.P., 2014. The Fertility of South African Holstein and Jersey Heifers. In 10th World Congress on Genetics Applied to Livestock Production, Vancouver, BC, Canada.

Musa, L.A., Ahmed, M.K., Peters, K.J., Zumbach, B.I.R.G.I.T. & Gubartalla, K.E., 2005. The reproductive and milk performance merit of Butana cattle in Sudan. Arch. Anim. Breed. 48, 445-459.

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.

Neville, M.C., McFadden, T.B. & Forsyth, I., 2002. Hormonal regulation of mammary differentiation and milk secretion. J. Mammary Gland Biol Neoplasia. 7, 49-66.

Nilforooshan, M.A. & Edriss, M.A., 2004. Effect of age at first calving on some productive and longevity traits in Iranian Holsteins of the Isfahan province. J. Dairy Sci. 87, 2130-2135.

NRC (National Research Council), 2001. Nutrient Requirements of Dairy Cattle, 7th revised edition. National Academy Press, Washington, DC.

Ogola, H., Shitandi, A. & Nanua, J., 2007. Effect of mastitis on raw milk compositional quality. J. Vet. Sci. 8, 237-242.

Ojango, J.M.K., Mrode, R., Okeyo, A.M., Rege, J.E.O., Chagunda, M.G.G. & Kugonza, D.R. 2017. Improving smallholder dairy farming in Africa. In: Achieving sustainable production of milk. Safety, quality and sustainability. Ed: Belzen, N. van, Cambridge, UK: Burleigh Dodds Science Publishing Limited. 2, 371-396.

Olori, V.E., Meuwissen, T.H.E. & Veerkamp, R.F., 2002. Calving interval and survival breeding values as measure of cow fertility in a pasture-based production system with seasonal calving. J. Dairy Sci. 85, 689-696.

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

Opsomer, G., 2015. Interaction between metabolic challenges and productivity in high yielding dairy cows. Jap. J. Vet. Res. 63, S1-S14.

Palmer, A.R. & Ainslie, A.M., 2005. Grasslands of South Africa. In: Grasslands of the world, Plant production and protection series 34. Eds: Suttie, J.M., Reynolds, S.G. & Batello, C., Food and Agriculture Organization of the United Nations, Rome. pp. 77-120.

Paneru, U., Sharma, M., Kolachhapati, M.R. & Shrestha, B.S., 2016. Evaluation of Productive and Reproductive Performance of Cattle in Major Dairy Production Area of Chitwan and Nawalparasi Districts. J. Agric Sci. Tech. 6, 69-75.

Pang, H., Makarechian, M., Basarab, J.A. & Berg, R.T., 1999. Structure of a dynamic simulation model for beef cattle production systems. Can. J. Anim. Sci. 79, 409-417.

Park, Y.W. & Haenlein, G.F.W., 2013. Milk and dairy products in human nutrition: production, composition and health. Wiley-Blackwell. Iowa, USA. Pages?

Pärna, E., Kiiman, H., Viinalass, H. & Vallas, M., 2005. Bioeconomical model application in cattle breeding. Acta Agric. Slov. 86, 117-124.

Penev, T., Vasilev, N., Stankov, K., Mitev, J. & Kirov, V., 2014. Impact of heifer's age at first breeding and first calving on some parameters of economic effectiveness at dairy cattle farms. Int. J. Curr. Microbiol. App. Sci, 3, 772-778.

Philipsson, J. & Lindhé, B., 2003. Experiences of including reproduction and health traits in Scandinavian dairy cattle breeding programmes. Livest. Prod Sci. 83, 99-112.

Pirlo, G., Miglior, F. & Speroni, M., 2000. Effect of age at first calving on production traits and on difference between milk yield returns and rearing costs in Italian Holsteins. J. Dairy Sci. 83, 603-608.

R Core Team, 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Rahman, M.H., Ali, M.Y., Juyena, N.S. & Bari, F.Y., 2017. Evaluation of productive and reproductive performances of local and crossbred cows in Manikgonj district of Bangladesh. Asian J. Med. Biol. Res. 3, 330-334.

Reeves, A., Salman, M.D., & Hill, A.E., 2011. Approaches for evaluating veterinary epidemiological models: verification, validation and limitations. Rev. Sci. tech. off. Int. Epiz. 30, 499-512.

Reinmuth, E. & Dabbert, S., 2017. Toward more efficient model development for farming systems research–An integrative review. Comput. Electron. Agric. 138, 29-38.

Remppis, S., Steingass, H., Gruber, L. & Schenkel, H., 2011. Effects of energy intake on performance, mobilization and retention of body tissue, and metabolic parameters in dairy cows with special regard to effects of pre-partum nutrition on lactation-A Review. Asian Austral. J. Anim. Sci. 24, 540-572.

Rios-Utrera, A., R.C. Calderon-Robles, J.R. Galaviz-Rodriguez, V.E. Vega-Murillo &J. Lagunes-Lagunes, 2013. Effects of breed, calving season and parity on milk yield, body weight and efficiency of dairy cows under subtropical conditions. Int. J. Anim. Vet. Adv., 5, 226-232.

Roche, J.R., Friggens, N.C., Kay, J.K., Fisher, M.W., Stafford, K.J. & Berry, D.P., 2009. Invited review: Body condition score and its association with dairy cow productivity, health, and welfare. J. Dairy Sci. 92, 5769-5801.

Royal, M.D., Darwash, A.O., Flint, A.P.F., Webb, R., Woolliams, J.A. & Lamming, G.E., 2000. Declining fertility in dairy cattle: changes in traditional and endocrine parameters of fertility. Anim. Sci. 70, 487-501.

Sanders, J.O. & Cartwright, T.C., 1979. A general cattle production systems model. Part 2-Procedures used for simulating animal performance. Agric. Syst. 4, 289-309.

Sandhu, Z.S., Tariq, M.M., Baloch, M.H. & Qaimkhani, M.A., 2011. Performance analysis of Holstein-Friesian cattle in intensive management at dairy farm Quetta, Balochistan, Pakistan. Pak. J. Life Soc. Sci. 9, 128-133.

SAS Institute Inc. 2015. SAS/STAT® 14.1 User's Guide. Cary, NC. USA.

Schukken, Y.H., Wilson, D.J., Welcome, F., Garrison-Tikofsky, L. & Gonzalez, R.N., 2003. Monitoring udder health and milk quality using somatic cell counts. Vet. Res. 34, 579-596.

Seegers, H., Fourichon, C. & Beaudeau, F., 2003. Production effects related to mastitis and mastitis economics in dairy cattle herds. . Vet. Res. 34, 475-491.

Silvestre, A.M., Martins, A.M., Santos, V.A., Ginja, M.M., & Colao, J.A. 2009. Lactation curves for milk, fat and protein in dairy cows: A full approach. Livest. Sci. 122, 308-313.

Singh, R., Randhawa, S.N.S. & Randhawa, C.S., 2015. Body condition score and its correlation with ultrasonographic back fat thickness in transition crossbred cows. Vet. World, 8, 290-294.

Sørensen, J.T., 1990. Validation of livestock herd simulation models: a review. Livest. Prod. Sci. 26, 79-90.

Sørensen, J.T., 1997. Modelling and simulation in applied livestock production science. In: Agricultural Systems Modelling and Simulation. Eds: Peart, R.M. & Curry, R.B., Marcel Dekker Inc, New York, USA, pp. 475-494.

Spedding, C.R.W. 1988. An introduction to agricultural systems. (2nd Ed). Elsevier Applied Science, New York. Pages?

Stádník, L., Bezdíček, J., Makarevich, A., Kubovičová, E., Louda, F., Fellnerová, I., Hegedüšová, Z. & Holásek, R., 2017. Ovarian activity and embryo yield in relation to the postpartum period in superovulated dairy cows. Acta Vet. Brno. 86, 51-57.

StataCorp. 2013. Stata: Release 13. Statistical Software. College Station, TX: StataCorp LP.

Strandberg, E. & Lundberg, C., 1991. A note on the estimation of environmental effects on lactation curves. Anim. Prod., 53, 399-402.

Syrstad, O., 1993. Milk yield and lactation length in tropical cattle. World Anim Rev. 74, 68-72.

Talbi, A. & Madidi, S.E., 2016. Effect of some environmental factors on milk production of primiparous Holstein raised in the Souss-massa region in Morocco. Env. Res. J. 10, 271-290.

Tas, B.M., Taweel, H.Z., Smit, H.J., Elgersma, A., Dijkstra, J. & Tamminga, S., 2005. Effects of perennial ryegrass cultivars on intake, digestibility, and milk yield in dairy cows. J. Dairy Sci. 88, 3240-3248.

Taylor, G.J., 2007. Factors affecting the production and reproduction performance of tropically adapted beef cattle in Southern Africa (Doctoral dissertation, University of Pretoria).

Tazangi, M.E. & Mirzaei, A., 2015. The effect of body condition loss and milk yield on the efficiency of Ovsynch in cycling Holstein dairy cows. Revue de Medec Vet. 166, 345-349.

Tess, M. W., G. L. Bennett, & G. E. Dickerson, 1983. Simulation of genetic changes in life cycle efficiency of pork production. I. A bio-economic model. J. Anim. Sci. 56, 336-353.

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, R., 1990. Generalized linear models and applications to animal breeding. In: Advances in statistical methods for genetic improvement of livestock Springer, Berlin, Heidelberg. pp. 312-328.

Thompson, B., 1998. Five methodological errors in educational research: The pantheon of statistical significance and other faux pas. Invited address at the annual meeting of the American Educational Research Association, San Diego, CA.

Thornton, P.K. & Herrero, M., 2001. Integrated crop-livestock simulation models for scenario analysis and impact assessment. Agric. Syst. 70, 581-602.

Tozer, P.R. & Heinrichs, A.J., 2001. What affects the costs of raising replacement dairy heifers: A multiple- component analysis. J. Dairy Sci. 84, 1836-1844.

Ural, D.A.2012. The Analysis of Milk Yield and Reproductive Traits of Holstein Cows Raised at a Private Dairy Farm in Bozdoğan County of Aydın, Turkey. Anim. Hlth. Prod. Hyg. 1, 116-122.

VandeHaar, M.J., Armentano, L.E., Weigel, K., Spurlock, D.M., Tempelman, R.J. & Veerkamp, R., 2016. Harnessing the genetics of the modern dairy cow to continue improvements in feed efficiency. J. Dairy Sci. 99, 4941-4954.

Van der Lee, J., Udo, H.M.J. & Brouwer, B.O, 1993. Design and Validation of an Animal Traction Module for a Smallholder Livestock systems Simulation Model. Agric. Syst. 43, 199-227.

Van der Westhuizen, J., Scholtz, M.M. & Mamabolo, M.J., 2006. Importance of infrastructure and system for livestock recording and improvement in developing countries. In: The role of biotechnology in animal agriculture to address poverty in Africa: Opportunities and challenges. Eds; Rege, J.E.O., Nyamu, A.M. & Sendalo, D., Proceedings of the 4th All Africa Conference on Animal Agriculture and the 31st annual meeting of Tanzania Society for Animal Production (TSAP), 20-24 September 2005. Arusha, Tanzania. pp. 345-350.

Van Doormal, B.J., Schaeffer, L.R. & Kennedy, B.W., 1985. Estimation of genetic parameters for stayability in Canadian Holsteins. J. Dairy Sci. 68, 1763-1769.

Veerkamp, R. F., Hill, W. G., Stott, A. W., Brotherstone, S. & Simm, G., 1995. Selection for longevity and yield in dairy cows using transmitting abilities for type and yield. Anim Sci. 61, 189-197.

Viira, A.H., Omel, R., Värnik, R., Luik, H., Maasing, B. and Põldaru, R., 2015. Competitiveness of the Estonian dairy sector, 1994-2014. Agraarteadus. 26, 84-104.

Visscher, P.M., Bowman, P.J. & Goddard, M.E., 1994. Breeding objectives for pasture based dairy production systems. Livest. Prod. Sci. 40, 123-137.

Vollema, A.R. & Groen, A.F., 1996. Genetic parameters of longevity traits of an upgrading population of dairy cattle. J. Dairy Sci. 79, 2261-2267.

Wahinya, P.K., Okeno, T.O., Kosgey, I.S. & Kahi, A.K., 2015. Economic and Biological Values for Pasture-Based Dairy Cattle Production Systems and their Application in Genetic Improvement in the Tropics. J. Anim. Pro. Adv. 5, 664-675.

Waldner, D.N., Stokes, S.R., Jordan, E.R. & Looper, M.L., 2005. Managing milk composition: normal sources of variation. Oklahoma Cooperative Extension Fact Sheets, 12. http://www.osuextra.com.

Wall, E., Brotherstone, S., Woolliams, J.A., Banos, G. & Coffey, M.P., 2003. Genetic evaluation of fertility using direct and correlated traits. J. Dairy Sci. 86, 4093-4102.

Wathes, D.C., Fenwick, M., Cheng, Z., Bourne, N., Llewellyn, S., Morris, D.G., Kenny, D., Murphy, J. & Fitzpatrick, R., 2007. Influence of negative energy balance on cyclicity and fertility in the high producing dairy cow. Theriogen. 68, S232-S241.

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

Wilson, K. & Morren, G.E.B., 1990. Systems Approaches for Improvement in Agricultural and Resource Management, Macmillan Publishing Company, New York. Pages?

Wolf, J., Wolfová, M. & Krupa E., 2013. User's Manual for the program Package ECOWEIGHT (C Programs for Calculating Economic Weights in Livestock), Version 6.0.4. Part 1: Programs EWBC (Version 3.0.4) and EWDC (Version 2.2.3). Research Institute of Animal Production. Prague Uhříněves. pp. 222.

Wolfenson, D., Leitner, G. & Lavon, Y., 2015. The disruptive effects of mastitis on reproduction and fertility in dairy cows. Ital J. Anim. Sci. 14, 4125.

Wolfová, M., Wolf, J., Kvapilík, J. & Kica, J., 2007. Selection for profit in cattle: I: Economic weights for purebred dairy cattle in the Czech Republic. J. Dairy Sci. 90, 2442-2445.

Wondifraw, Z., Thombre, B.M. & Bainwad, D.V., 2013. Effect of non-genetic factors on milk production of Holstein Friesian Deoni crossbred cows. Int. J. Livest. Prod. 4, 106-112.

Wood, P.D.P., 1967. Algebraic model of lactation curve in cattle. Nat. 216, 164-165.

Worku, D., Alemayehu, K. & Melekote, M.H., 2016. Comparative reproductive performance evaluation of Holstein Friesian cattle breeds in two different agro ecological conditions, Oromia region, Ethiopia. Anim. Genet. Res. 58, 31-42.

Wu, J.J., Wathes, D.C., Brickell, J.S., Yang, L.G., Cheng, Z., Zhao, H.Q., Xu, Y.J. & Zhang, S.J., 2012. Reproductive performance and survival of Chinese Holstein dairy cows in central China. Anim. Prod. Sci. 52, 11-19.

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.

Zereu, G. & Lijalem, T., 2016. Production and Reproduction Performances of Local Dairy Cattle: In the Case of Rural Community of Wolaita Zone, Southern Ethiopia. J. Fish. Livest. Prod. 4, 176. doi: 10.4172/2332-2608.1000176.

Zwald, N.R., Weigel, K.A., Chang, Y.M., Welper, R.D. and Clay, J.S., 2004. Genetic selection for health traits using producer-recorded data. II. Genetic correlations, disease probabilities, and relationships with existing traits. J. Dairy Sci. 87, 4295-43.

CHAPTER III

Comparative performance of dairy cows in low-input smallholder and high-input production systems in South Africa

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Abstract

The aim of this study was to benchmark the performance of dairy cows in the low-input smallholder system against their counterparts in the high-input system, in South Africa. Data comprised of cow performance records from the national dairy recording scheme. Performance measures included production (305-day yields of milk, fat and protein), lactation length, Somatic cell count (SCC), and reproductive traits, represented by age at first calving (AFC) and calving interval (CI). Least squares means of each trait were compared between the two systems, and lactation curves for production traits and SCC were plotted for each production system. Mean yields of milk, fat, and protein were significantly ($P<0.05$) lower in the smallholder (4,097±165, 174±5.1, and 141±4.5 respectively) compared to the high-input system (6,921±141, 298±4.7, and 245±4.1, respectively). Mean lactation length was significantly ($P<0.05$) shorter for the smallholder (308±15.1) than the high-input system (346±12.8). Log-transformed somatic cell count (SCS) was, however, significantly ($P<0.05$) higher in the smallholder (2.41±0.01) relative to the high-input system (2.27±0.01). Cows in high-input herds showed typical lactation curves, in contrast to the flat and low peaking curves obtained for the smallholder system. Cows on smallholder herds had their first calving significantly ($P<0.05$) older (30±0.5) than those in the high-input system (27±0.5). There was, however, no significant difference ($P<0.05$) in CI between the two systems. These results highlight large room for improvement of dairy cow performance in the smallholder system, and could assist in decision-making aimed at improving the productivity of the South African dairy industry.

Keywords: lactation curve, production, reproduction, somatic cell count

3.1. Introduction

The importance of livestock production for food security and socio-economic development has been widely recognized (Ndambi *et al.*, 2007; Swanepoel *et al.*, 2010). In this regard, development of dairy production systems could be considered as an effective means to improve food security, and income generation. Dairy farming is an important socio-economic sector in South Africa (SA), consisting of approximately 2.7 million dairy cows (DAFF, 2016), with the main breeds being Ayrshire, Guernsey, Holstein, and Jersey (Maiwashe *et al.*, 2006). However, the domestic supply of milk has not been able to meet the continuously increasing national demand. According to DAFF (2016), the importation of milk, and milk products increased by 12.7%, from 35 674 tons during 2013, to 40 199 tons during 2014.

The South African dairy industry is heterogeneous, ranging from a low-input low-output smallholder system to a high-input, highly productive production system. The smallholder system is characterized by small herd sizes of between 2 and 50 cows per herd and low levels of production management. Feeding systems on these herds are generally constrained, influenced by agroecological factors, and the farmer's socio-economic status. Natural pasture is the main feed source in smallholder systems, with limited supplementation. The high-input system, on the other hand, is highly developed and characterized by large herd sizes, exceeding a hundred cows per herd, with high levels of feeding, and management (Lacto Data, 2016). The main feeding systems for dairy cattle on high-input herds are total mixed ration (TMR), supplemented pasture-based systems or a combination of both (Theron & Mostert, 2009).

Efforts have been in place for decades to improve dairy production in South Africa. A national dairy animal improvement Scheme (NDAIS) was established in SA in 1917 (Banga, 2000). This scheme was initially exclusive to stud and high-input commercial dairy cattle farmers. However, policy changes were initiated in recent years to include smallholder farmers in the scheme, with the aim of recording individual cow performance and ultimately implementing herd improvement programs (Banga, 2000).

Information on the performance of the smallholder sector is virtually non-existent. This is in contrast to the high-input system, which has been studied extensively, and for which most phenotypic, genetic and economic parameters have been reported. This study forms part of a broader project, which aims to evaluate alternative smallholder dairy herd production models in South Africa. The aim of the current study was to benchmark the productive, and reproductive performance, as well as udder health status, of dairy cows on smallholder herds against their counterparts in the high-input commercial production system.

3.2. Materials and Methods

Herds from both production systems were widely distributed in the various agro-ecological zones across South Africa. Data comprised of 305-day lactation and test-day records of multi-breed dairy cows (Holstein, Jersey, Ayrshire, Guernsey, Dairy Shorthorn, Brown Swiss, Crossbreds) from smallholder (SH) and high-input (H) herds participating in the National Dairy Animal Improvement Scheme (NDAIS) during the period 2004 and 2016. Lactation yields of milk, fat and protein were standardized to 305 days by considering production at 305 days in milk for lactations longer than 305 days, and actual production for lactations shorter than 305 days. All cows that did not meet the following criteria were removed from analyses: missing milk, fat, protein or SCC records, missing birth date, calving date or having AFC less than 18 months or more than 55 months of age, and test day data recorded less than 5 days after calving. A random sample of 10% of the high-input herds was selected for analysis, due to the large size of the dataset. The lactation length was measured as the number of days between calving date, and the last censor lactation date within parity. The distribution of somatic cell count (SCC) (cells/ml) was skewed; hence it was transformed to $\log_{10}$ (SCC) or somatic cell score (SCS). The Statistical Analysis System version 9.4 (SAS Institute Inc. 2016) was used in data editing, and removal of outliers. The final edited data set respectively consisted of 3,723, and 33,686 for 305-day lactation records, 18,972, and 106,446 test-day records of 1,450, and 28,677 cows from 57 smallholder, and 103 high input herds respectively. The structures of the 305-day lactation and test-day datasets, after editing, are presented in Table 3.1.

Table 3.1. Structure of 305-day lactation and test-day data-set for smallholder and high-input production systems after editing

Dataset	Components	Smallholder	High input system
305 days lactation records			
	Milk yield (kg)	3,723	62,917
	Fat yield (kg)	3,580	59,524
	Protein yield (kg)	3,555	60,225
Test-day records			
	Milk yield (kg)	18,972	106,446
	Fat (%)	17,106	105,377
	Protein (%)	16,945	105,674
	Somatic cell count (cell/ml)	17,231	103,640
Reproductive records			
	Age at first caving	1,450	28,677
	Calving interval	658	18,973

3.2.1. Statistical analyses

The mean cow performance as measured by production (305-day yields of milk, fat and protein), lactation length, reproduction (age at first calving and calving interval), and udder health (SCS) were adjusted for the fixed effects, and compared between the two systems, using the generalized linear model (GLM) procedure of the Statistical Analysis System (SAS, 2016). The model used is presented below in a matrix notation:

$$y = \mu + Xb + \varepsilon \qquad [3.1]$$

Where;

$\mathbf{y}$: Vector of an observation for a performance trait,

$\boldsymbol{\mu}$: Overall population mean (performance traits),

$\mathbf{b}$: Vector of the fixed effects,

$\mathbf{X}$: Incidence matrix relating observations to fixed effects,

$\boldsymbol{\varepsilon}$: Random residual error, which, is assumed to be normally, independently and identically distributed with mean 0 and variance $\boldsymbol{\sigma_e^2}$ $\left(\mathbf{i.e.\ e \sim N(0, I\sigma_e^2)}\right)$.

The fixed effects for production, lactation length, and CI were herd year season (HYS) of calving, breed, production system, and parity (excluded in the evaluation of CI). For AFC, the fixed effects were herd year season (HYS) of birth, breed, and production system. The fixed effects for SCS were herd test-date, parity, lactation stage, breed, and production system. The number of the contemporary groups varied for different traits, and ranged from 181 to 973 and 836 to 1915, in smallholder, and high-input systems, respectively.

Lactation curves for the production traits and SCS were plotted for each production system, using the test-day data. The curves were obtained by regressing the means of each performance trait on days in milk.

3.3. Results

This study aimed to benchmark the performance of smallholder dairy cows against their counterparts in the high-input production system. Unequal records and breeds used may have influenced the results of this study. These results provide baseline information on the production performance of dairy cows in the two production systems. The estimated least squares means with standard errors for the studied traits are presented in Table 3.2.

Table 3.2. Least squares means, and standard errors (LSM ± SE) for, 305-day yields of milk (MY), fat (FY), and protein (PY), somatic cell score (SCS), age at first calving (AFC), and calving interval (CI) for cows in smallholder (SH), and high-input (H) commercial systems in South Africa

System	MY(kg)	FY(kg)	PY(kg)	LL (d)	SCS	AFC(mn)	CI (d)
SH	4 097±165[a]	174±5.1[a]	141±4.5[a]	308±15.1[a]	2.41±0.0[a]	30±0.5[a]	444±6.9[a]
H	6 921±141[b]	298±4.7[b]	245±4.1[b]	346±12.8[b]	2.27±0.0[b]	27±0.5[b]	433±6.3[a]

Means within the same column with different subscripts are significantly different (P<0.05)

d: days; mn: month

On average, dairy cows in the high-input system produced 40.8%, 41.7% and 42.5%, more milk, fat, and protein (kg), respectively, per 305-day lactation than those in the smallholder system. Figure 3.1 to 3.3 presents the respective average lactation curves of monthly test-day milk yield, and composition (fat and protein percent) in the two production systems. Milk yield lactation curve (Figure 3.1) for cows in the smallholder had a much lower peak, compared to their counterpart in the high-input production system. As expected, fat, and protein percentage (Figures 3.2 and 3.3), showed an opposite pattern to milk yield.

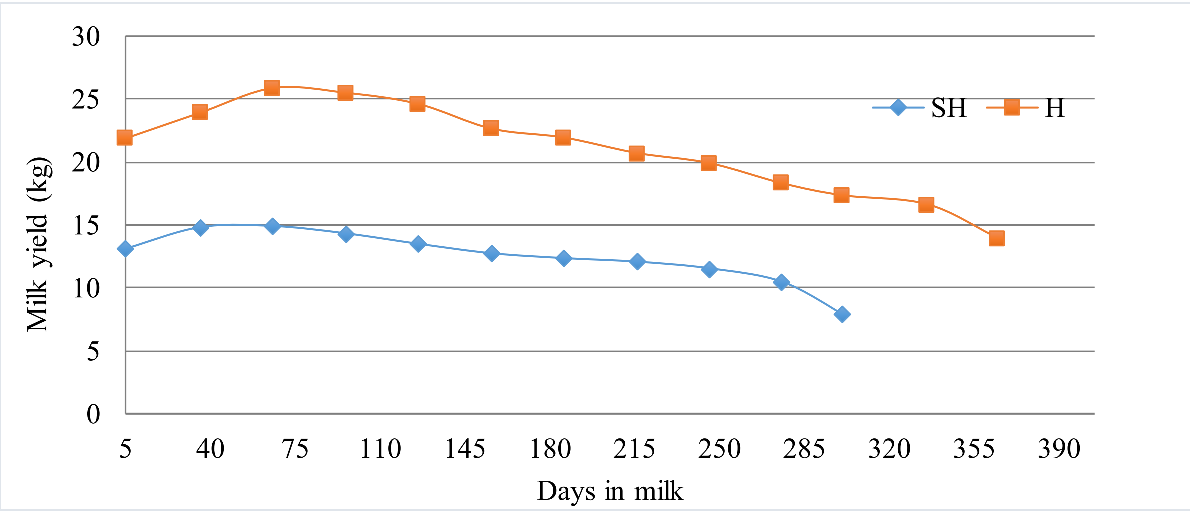

Figure 3.1: Lactation curves for the average test-day milk yield of smallholder (SH), and high-input (H) dairy cow

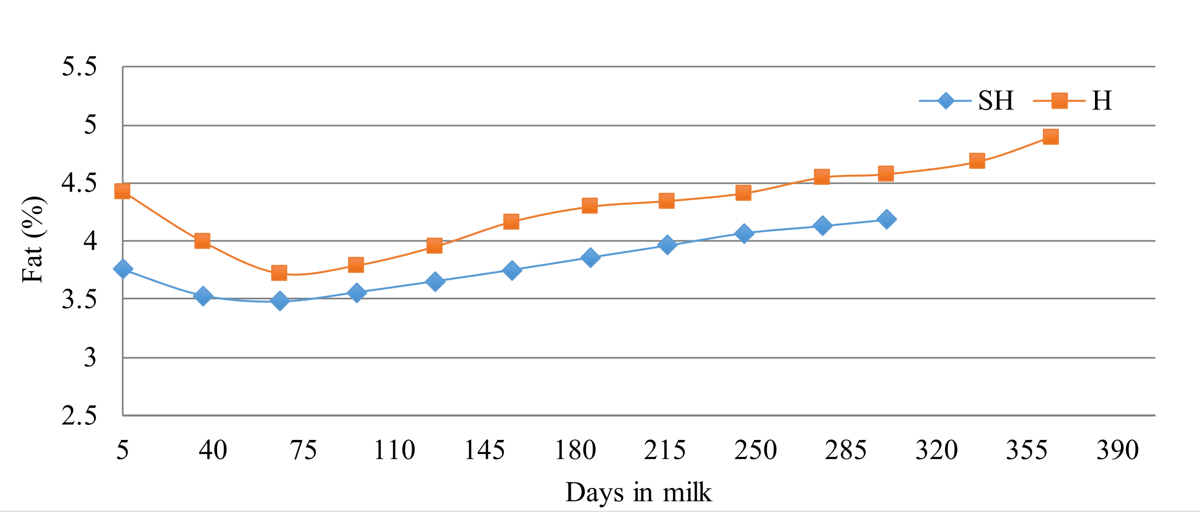

Figure 3.2: Lactation curves for the average test-day fat content of smallholder (SH), and high-input (H) dairy cows

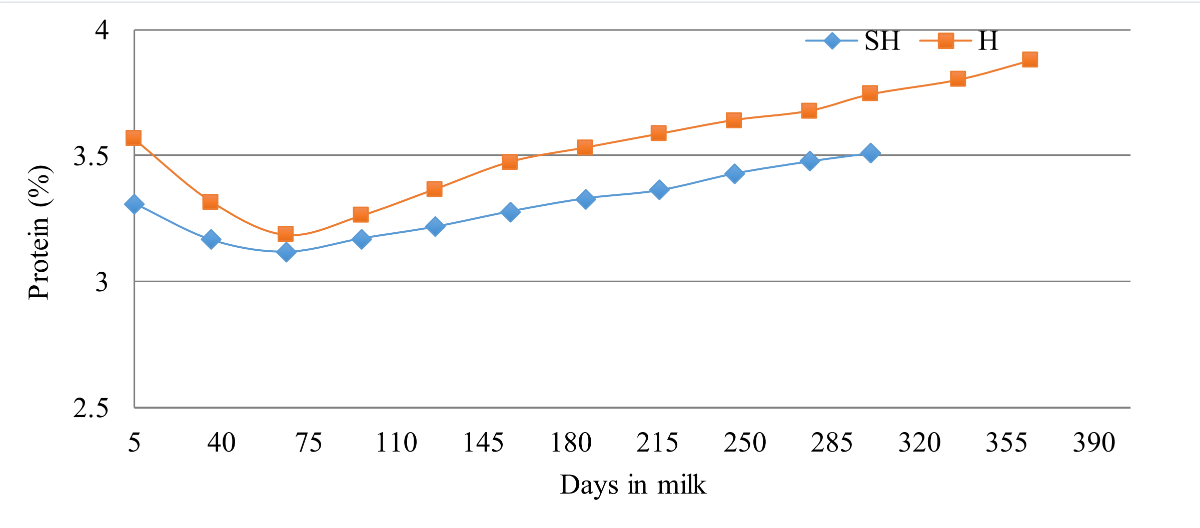

Figure 3.3: Lactation curves for the average test-day protein content of smallholder (SH), and high-input (H) dairy cows

The means of SCS was significantly ($P<0.05$) higher by 5.7% in the smallholder system (2.41±0.01), compared to the high-input system (2.27±0.01). These means are equivalent to the means SCC (cells/ml) of $257x10^3$ and $186x10^3$, for smallholder, and high-input systems, respectively. Lactation curves of SCS decreased in the first 10 weeks after calving, and then increased with progressing lactation in both systems, with a higher peak observed in the smallholder system (Figure 3.4).

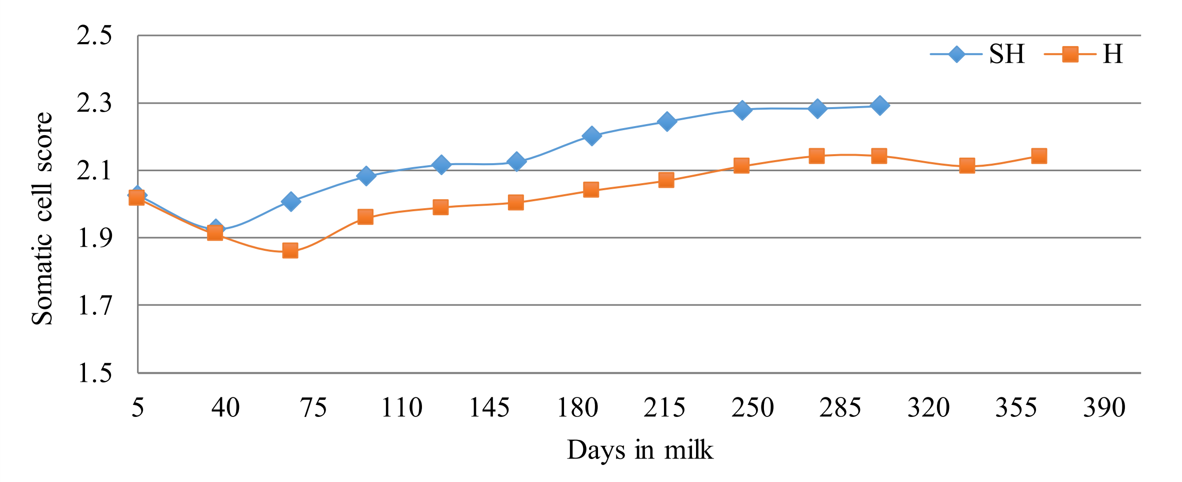

Figure 3.4: Lactation curves for the average somatic cell score of smallholder (SH), and high-input (H) dairy cows

Mean AFC differed significantly (P>0.05), with heifers in the smallholder system calving for the first time at an older age (30±0.5 months), compared to those in the high-input system (27±0.5 months). Means for CI did not differ significantly (P>0.05) between the two systems.

3.4. Discussion

Optimum production performance of a dairy cow is a pre-requisite for profitable, and sustainable farming. For this reason, smallholder dairy cows' performance needs to be benchmarked against its competitive counterpart to determine their production potential, identifying production lag, and setting up goals to assist in management for improvement of farming business. Benchmarking may entail a number of standard reports comparing cows' production, and reproductive performance (Frandsen, 2015).

Milk production may be measured per lactation (usually standardized to 305 days) or as daily yield (Mostert, 2007). Cows in the smallholder system had produced significantly (P>0.05) less milk and milk components than those in the high-input system Cows in the smallholder system also produced less kilogram of milk, fat, and protein per 305-day lactation compared to estimates reported in previous studies for South African dairy cattle. Theron and Mostert (2009) obtained least squares means (kg) of 5,347±1 156, and 8,147±2,260 for milk yield, 251±54, and 310±83 for fat yield, and 200±43, and 262±70 for protein yield for South African Jersey, and Holstein breeds, respectively. Recently, Goni (2014) reported least squares means (kg) of 5,398±95, and 6,141±10 for milk yield, 246±3.0, and 272±4.0 for fat yield, and 194±2, and 246±3 respectively for Jersey, and Fleckvieh x Jersey cows in South African herds. On the other hand, the estimated means 305-day milk, fat, and protein yields (kg), for the high-input system are within the estimates reported by Theron and Mostert (2009), and generally higher than those reported by Goni (2014).

The flat, and low peak lactation curves of cows in the smallholder system are a typical manifestation of inadequate feeding management (Burke et al., 2010). Usually, such cows are in poor body condition with low body reserves at calving, and are also not fed adequately during lactation. Even if they have the genetic potential for high production, cows may fail to express such potential due to insufficient energy or protein intake (Remppis *et al.*, 2011; Urdl *et al.*, 2015). The demand for energy is particularly high within 100 days after calving, when peak milk yield normally occurs. If this energy demand exceeds dry matter intake, as commonly in smallholder systems, this will affect both milk production and the animal's body condition. Delaby *et al.* (2009) highlighted the sensitivity of milk yield to variation in feed intake, and body reserves of dairy cows, and indicated that feeding strategies have profound effects on milk quantity, and quality, particularly in terms of peak yield, and lactation. The observed lactation curves reflected the better feeding strategies in the high-input system.

Lactation length (LL) is an indicator of the persistency of milk production (Syrstad, 1993), which, is of particular importance in the tropics. The harsh tropical production environment adversely affects milk yield, which often results in high proportions of short lactations (Hossein-Zadeh, 2013). The mean lactation lengths of cows in both systems were relatively longer than the standard 305-day lactation periods. However, the mean lactation length differed significantly (P>0.05) between the studied systems. Cows in high-input herds, on average, milked for 38 days more than those in the smallholder system.

The low production performance of cows in the smallholder system is thus attributable to the flat and relatively short lactation curves. Peak production is one of the most important factors influencing lactation yield (Němečková *et al.*, 2015). There is also a positive association between the length of lactation, and production (Alphonsus and Essien, 2012).

The routine recording of somatic cell count (SCC) in dairy recording schemes provides a means to reduce economic losses through the monitoring of udder health, milk quality, and genetic selection (Mostert, 2007; Logar & Jeretina, 2015). High levels of SCC affect the price paid for milk, and increase milk wastage. Elevated levels of SCC are also associated with higher culling rates (Sewalem *et al.*, 2006), and thereby increase replacement costs. Banga *et al.*, (2014) found SCC to be among the most important traits in the breeding objectives of South African Holstein and Jersey cattle. The cows in the smallholder system had 5.7% higher lactation average SCC than those in the high-input system. The observed mean SCC of 257x103 cells/ml is higher than the recommended threshold (200x103 cells/ml), indicating a high risk of udder infection among cows in the smallholder herds. On the other hand, the mean SCC for the high-input system was less than 200x103 cells/ml, indicating a lower rate of udder infection.

The difference in udder health between the two systems was apparent in the trends of SCS lactation curves. The elevated levels of SCS, in the current study, could be associated with the mammary gland defense mechanism, following parturition. As lactation progresses, the risk of udder infection increases, and this may lead to extremely high levels of SCC, if cow udder health is not properly managed. Elevated levels of SCS observed in the smallholder system could be attributed to poor udder health management, which may also contribute to the lower production of cows on these herds, compared to those in the high-input system.

A number of measures, including AFC, CI, inseminations per conception, conception rate, and non-return rate have been used to evaluate the reproductive performance of dairy cattle (Nieuwhof *et al.*, 1989; Cassandro, 2014). Age at first calving, and CI were used in the current study as they were the only ones available from the routinely recorded data. They are indicators of the female's age at reproductive maturity as well as its ability to conceive, calve and re-calve in the prevailing environment.

The mean AFC observed in the high-input system (27±0.48 months) is lower, while that for the smallholder system (30±0.47 months) is higher than the estimate of 29.4±5.2 months, reported by Muller et al., (2014) for South African Holstein heifers, and 26.2±3 months reported by Goni (2014) in a crossbred Fleckvieh, and Jersey breed in South Africa. The mean AFC (months) for cows in the present study (30±0.47 and 27±0.48) were higher than the optimum age range of 22.5 to 23.5 months for a maximum lifetime profit (Meyer *et al.*, 2004; Do *et al.*, 2013).

Declining female fertility, indicated by an increasing trend in calving interval, has previously been cited as a problem in South African dairy cattle herds (Makgahlela *et al.*, 2008). Poor body condition as a result of a negative energy balance at calving, is associated with a poor postpartum ovarian activity or poor fertility. The poor body condition at calving of cows in the smallholder system, which can be inferred from the flat lactation curves, points to impaired fertility. This may partly explain the longer calving for cows in this system, compared to those on high-input herds.

In conclusion, these results have highlighted a comparably lower production performance, poor under health due to high SCC, and late AFC in smallholder system, compared to the high input system. Longer CI was observed in cows in the smallholder compared to the high-input system, although the difference was not significant. These results now provide baseline information on these indicators of cow performance, which is essential for identifying key focus areas or opportunities to improve smallholder dairy production. In addition, herds in each production system can be benchmarked on these performance indicators, in order to determine and monitor their performance vis-à-vis the average for the production system. Smallholder farmers need to select sires of appropriate genetic merit, and adopt improved feeding strategies to increase cows' production, and reproductive performance. Improved heifer rearing will result in a reduction in AFC, while optimum body condition score at calving will result in cows achieving high-peaking, and longer lactations, as well as shorter CI. The smallholder farmers need to follow sound udder health management practices to reduce the relatively high level of SCC. Further research is underway to evaluate alternative management strategies to improve the performance of the smallholder dairy system.

3.5. References

Alphonsus, C. & Essien, I.C., 2012. The relationship estimates amongst milk yield and milk composition characteristics of Bunaji and Friesian? Bunaji cows. African Journal of Biotechnology, 11, 8790-8793.

Banga, C.B., 2000. Milk recording for the smallholder sector in South Africa. In: Dairy Herd Improvement in South Africa. Eds: Loubser, L.F.B., Banga, C.B., Scholtz, M.M. and Hallowell, G.J., Agricultural Research Council, Animal Improvement Institute, Irene, South Africa.

Banga, C.B., Neser, F.W.C. & Garrick, D.J., 2014. The economic value of somatic cell count in South African Holstein and Jersey cattle: short communication. South African Journal Animal Science, 44, 173-177.

Burke, C.R., Williams, Y.J., Hofmann, L., Kay, J.K., Phyn, C.V.C. & Meier, S., 2010. Effects of an acute feed restriction at the onset of the seasonal breeding period on reproductive performance and milk production in pasture-grazed dairy cows. Journal of dairy science, 93, 1116-1125.

Cassandro, M., 2014. Genetic aspects of fertility traits in dairy cattle-review. Acta Agraria Kaposváriensis, 18, 11-23.

DAFF (Department of Agriculture, Forestry and Fisheries), 2016. Trends in the Agricultural Sector, 2015. Published by, Directorate: Communication Services of the Department of Agriculture, Forestry and Fisheries. Pretoria-South Africa.

Delaby, L., Faverdin, P., Michel, G., Disenhaus, C. & Peyraud, J.L., 2009. Effect of different feeding strategies on lactation performance of Holstein and Normande dairy cows. Animal, 3, 891-905.

Do, C., Wasana, N., Cho, K., Choi, Y., Choi, T., Park, B. & Lee, D., 2013. The effect of age at first calving and calving interval on productive life and lifetime profit in Korean Holsteins. Asian-Australian Journal Animal Science, 26, 1511-1517.

Frandsen, J. 2015. Benchmarking in dairy production: "How to transform data to valuable decision support" In: Performance recording in the genotyped world, Kowalski, Z., Petreny, N., Burke, M., Bucek, P., Journaux, L., Coffey, M., Hunlun, C. and Radzio, D. (editors), Technical Series, 19, pp.63-67. Proceedings of the ICAR Technical Meeting held in Krakow, Poland, 10-12 June 2015. ICAR

Goni, S., 2014. Production and reproduction performance of Jersey and Fleckvieh× Jersey cows in a pasture-based system (Doctoral dissertation, Stellenbosch: Stellenbosch University).

Hossein-Zadeh, N.G., 2013. Factors affecting lactation length and effect of current lactation length on the subsequent production and reproduction in Iranian Holsteins. Tierzucht, 56, 873-881.

Lacto data, 2016. Statistics: A Milk SA publication compiled by Coetzee, 2016, 19(1): 1-31. www.milksa.co.za/sites/default/files/BIPLAC020%20May%202015.pdf.

Logar, B. & Jeretina, J., 2015. Web advisory tools to support dairy production in Slovenian herds. In: Performance recording in the genotyped world, Kowalski, Z., Petreny, N., Burke, M., Bucek, P., Journaux, L., Coffey, M., Hunlun, C. and Radzio, D. (editors), ICAR Technical Series 2015, No.19, pp.73-78. Proceedings of the ICAR Technical Meeting held in Krakow, Poland, 10-12 June, 2015.

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. South African Journal Animal Science, 36, 50-57.

Makgahlela, M.L., Banga, C.B., Norris, D., Dzama, K. & Ngambi, J.W., 2008. Genetic analysis of age at first calving and calving interval in South African Holstein cattle. Asian Journal of Animal and Veterinary Advances, 3, 197-205.

Meyer, M.J, Everett, R.W, & van Amburgh, M.E. 2004. Reduced age at first calving: effects on lifetime production, longevity, and profitability. In ‘Dairy Day 2004’. (Ed. JS Srevenson) pp. 42–52. (Kansas State University: Tempe, AZ).

Mostert, B.E. 2007. The suitability of test-day models for genetic evaluation of dairy cattle in South Africa (Doctoral dissertation, University of Pretoria Pretoria).

Muller, C.J.C., Potgieter, J.P. & Cloete, S.W.P., 2014. The Fertility of South African Holstein and Jersey Heifers. In 10th World Congress on Genetics Applied to Livestock Production, Vancouver, BC, Canada.

Ndambi O.A, Hemme, T., & Latacz-Lohmann, U. 2007. Dairying in Africa-Status and recent developments. Livestock Research for Rural Development. Volume 19, Article #111. Retrieved February 13, 2017, from http://www.lrrd.org/lrrd19/8/ndam19111.htm.

Něměcková, D., Stádník, L. & Čítek, J., 2015. Associations between milk production level, calving interval length, lactation curve parameters and economic results in Holstein cows. Mljekarstvo: časopis za unaprjeđenje proizvodnje i prerade mlijeka, 65, 243-250.

Nieuwhof, G.J., Powell, R.L. & Norman, H.D., 1989. Ages at calving and calving intervals for dairy cattle in the United States. Journal of Dairy Science, 72, 685-692.

Remppis, S., Steingass, H., Gruber, L., & Schenkel, H. 2011. Effects of energy intake on performance, mobilization and retention of body tissue, and metabolic parameters in dairy cows with special regard to effects of pre-partum nutrition on lactation-A Review. Asian-Australian Journal of Animal Science, 24, 540-572.

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

Statistical Analysis System (SAS) (2016) Statistical Analysis System User’s Guide, Version 9.1.3. SAS Institute Inc, Raleigh, North Carolina, USA.

Swanepoel, F., Stroebel, A., & Moyo, S. 2010. The role of livestock in developing communities: enhancing multifunctionalities. University of the Free State and CTA. Cape Town, South Africa.

Syrstad, O., 1993. Milk yield and lactation length in tropical cattle. World Animal Review, 74/75, 68-78.

Theron, H.E. & Mostert, B.E. 2009. Production and breeding performance of South African dairy herds. South African Journal Animal Science, 39, 206-210.

Urdl, M., Gruber, L., Obritzhauser, W. & Schauer, A. 2015. Metabolic parameters and their relationship to energy balance in multiparous Simmental, Brown Swiss and Holstein cows in the periparturient period as influenced by energy supply pre-and post-calving. Journal of Animal Physiology and Animal Nutrition, 99, 174-189.

CHAPTER IV

Development of a simulation model for a smallholder dairy herd

Abstract

A positive, and normative model was developed to simulate a typical herd in the South African smallholder dairy cattle production system. The modelling process involved calibration of the parameters using the results of a survey, and individual cow performance records collected through the National Dairy Animal Recording Scheme. Where data were not available, parameters from literature were utilized, and or logical assumptions were made. Algorithmic matrices previously used to simulate an average herd in the high-input dairy cattle production system in South Africa were adapted to simulate the biological factors underlying the production processes within the smallholder herds. The model simulated the current smallholder dairy herd structure, animals' biological activities in different stages of the production cycle, and their impact on nutrient energy intake, production costs, revenues and gross margin per year as a function of management decisions. Estimated total cost and revenue were R 16 461 per cow/year and R 18 087 per cow/year, respectively. Feeding Cost (78% of total costs), and milk revenue (91.7% of total revenue) appeared to be the most critical factors that influenced the gross margin of the simulated herds. The estimated gross margin (GM) was positive, implying profitable milk production under the simulated smallholder management practices. Economic efficiency is likely the most important objective for the smallholder farmers, and so profit maximization is critical to offset any production risks. A bio-economic herd model of this nature forms a suitable base for evaluation, and identification of alternative production options for improvement of herd profitability.

Keywords: deterministic model, herd, normative, smallholder

4.1. Introduction

An important step towards improving the productive, and economic efficiencies of a system is to gain an understanding of the factors influencing the production processes (Walters *et al.*, 2016; Kebreab *et al.*, 2019). A farming system, such as a smallholder dairy enterprise, is complex, and operates under a wide range of production factors (Ojango *et al.*, 2017). These factors mostly include the animals' inherent production potential, management (breeding methods, feeding systems, health, and labor), and the marketing system (Kavoi *et al.*, 2010;

Manzana *et al.*, 2014; Mbilu, 2015). The efficiency with which these factors are used, and interact will influence the productivity, and economic efficiency of the system.

A system approach, through bio-economic simulation modelling, is a reliable tool for studying such complex processes (Dent & Thornton, 1988; Herrero *et al.*, 1999). Bio-economic simulation models have been used in analyses of different livestock production systems, including chicken (Leinonen *et al.*, 2015), pigs (Ali *et al.*, 2018), sheep (Bohan *et al.*, 2016); beef cattle (Krejčí *et al.*, 2019), and dairy cattle (Kebreab *et al.*, 2019). In cattle production systems, bio-economic analyses have been carried out through the development of a model of an average herd as the management unit (Sørensen, 1990; Banga, 2009; Bekara & Bareille, 2019). An accurate description of the production management practices is important, in order to mimic the reference herd in the real system (Mayer *et al.*, 1996; León-Velarde & Quiroz, 2001; Kebreab *et al.*, 2019). This includes the description of the biological dynamic occurring within a herd, along with its economic input-outputs response (Dezetter *et al.*, 2017). The current study was carried out to develop a model of a typical smallholder dairy herd in South Africa, using bio-economic simulation modelling.

4.2. Materials and methods

4.2.1. Model development

Banga (2009) developed a normative, and deterministic (positive) bio-economic herd model, simulating an average high-input commercial dairy herd in South Africa. This modelling framework was adapted in the current study to represent a typical smallholder dairy herd. It is flexible, and capable of quantifying the underlying biological relationships, and their effect on the distribution of costs, and benefits over different stages of the animal's productive life. A ClickCharts Diagram and Flowcharts software was used to create a visual representation of the simulated smallholder dairy herd model. Figure 4.1 presents the structure of the simulated baseline herd model, calibrated to reflect average management, and production performance of dairy cows within the smallholder production system.

The inputs used in the simulation of a smallholder dairy cattle herd were obtained from several data sources. The performance records were obtained from the INTERGIS (Integrated Registration and Genetic Information System) for 59 smallholder dairy herds that participated in the national dairy animal improvement Scheme (NDAIS), from 1 January to 31 December 2017. The economic inputs, and management practices were obtained from a survey (and supplementary personal communications) conducted on smallholder dairy farmers by the

Agricultural Research Council (ARC) of South Africa (Muntswu *et al.*, 2017). Some assumptions had to be made in cases where there was a complete lack of information, and these are indicated where applicable.

The developed model, shown in Figure 4.1, consists of four primary input sub-models. Sub-model (i) presents the herd structure in blue colour. Sub-model (ii) provides the performance response of different animal groups within the herd as a function of management practices in orange. Sub-model (iii) contains the feeding required to support the animals' biological activities in green. Feeding requirements were calculated for cows, and replacement heifers. Sub-model (iv) links, and translates the outputs from the first three sub-models into economic values (i.e. input costs, revenues and gross margins) in yellow. A detailed description of each of the sub-models is presented below.

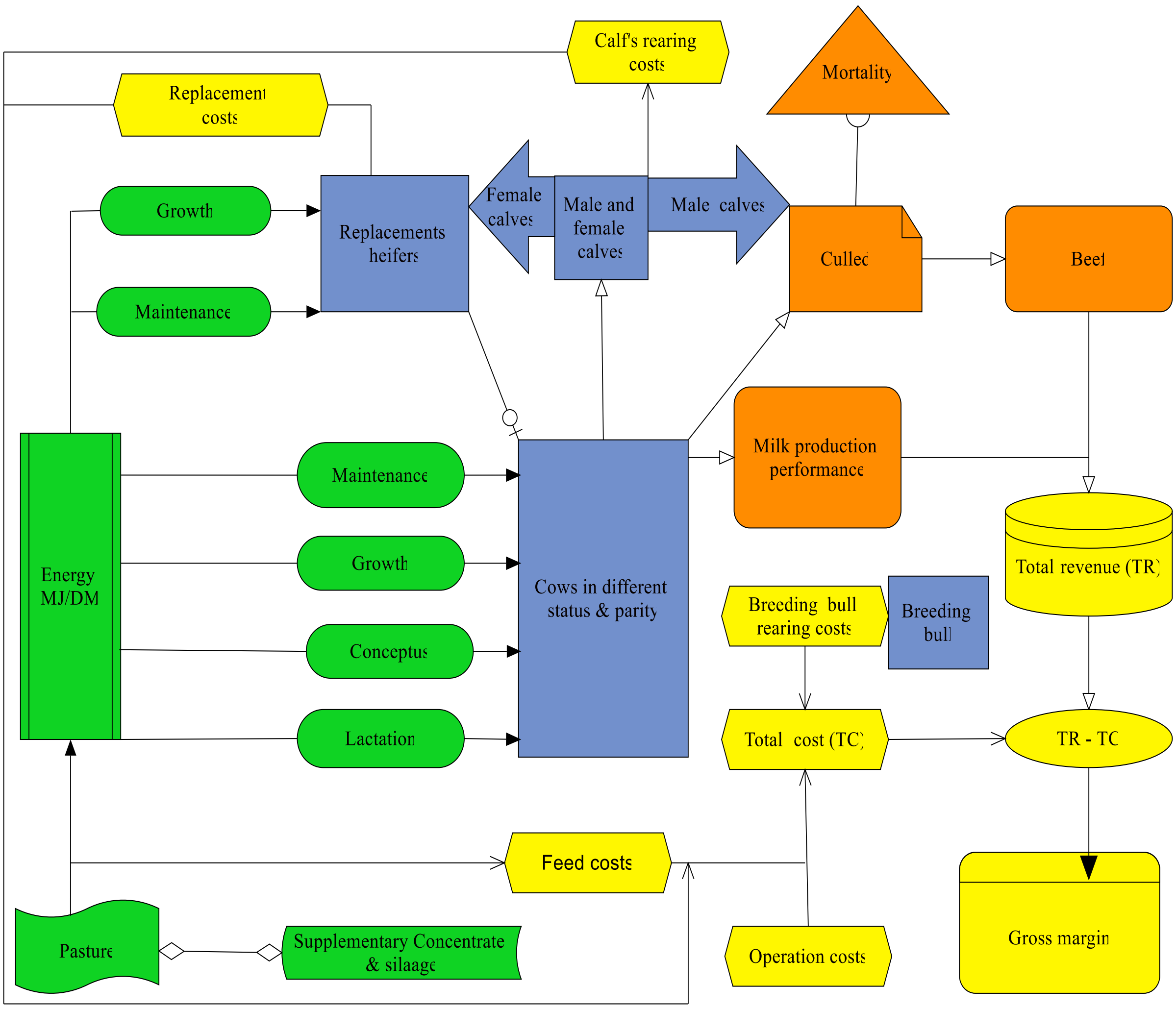

Figure 4.1: Schematic presentation of the simulated smallholder dairy herd model

4.2.2. Herd structure sub-model

The simulated herd structure is composed of four interdependent groups of animals, viz: (i) cows, (ii) calves, (iii) replacement heifers, and (iv) breeding bulls (Figure 4.1). Group (i) forms the primary component of the dairy production unit, which provides the basis for the herd composition, and production performance. The biological processes within this group are dynamic in nature, and the transition from one stage to the other is contingent on a set of biological events (breeding, pregnancy, calving and lactation), and management decisions such as culling, and replacement rates. The simulated herd was assumed to be in steady-state, and each cow within the herd had the opportunity of having seven reproductive cycles. Old, and open cows were assumed to be culled at the end of each year to maintain the desired herd size through the introduction of replacement heifers.

Survey data indicated that smallholder farmers bought their replacement heifers as weaners, yearlings, pregnant heifers, and or used female calves produced on-farm as replacements. A general scenario of on-farm reared replacement heifers was considered in the simulation of an average herd. Excess heifers if available, were assumed to be sold at 21 months to correspond with the average age at first calving (AFC) of 29 months as observed from the INTERGIS records. All male calves were sold at a fixed price as being practiced by the majority of the smallholder farmers in the survey.

Year-round breeding, and use of bulls for breeding purposes were the common practices among the smallholder farms according to the survey, and therefore were included in the current herd model. The average productive life of the cows started at 29 months of age, with a 420-day inter-calving period (Table 4.1). Average herd size for smallholder herds participating in the National Dairy Animal Recording Scheme was used to determine the number of cows. The herd model consisted of a non-specific breed of 20 milking cows in various parities as shown in Figure 4.2.

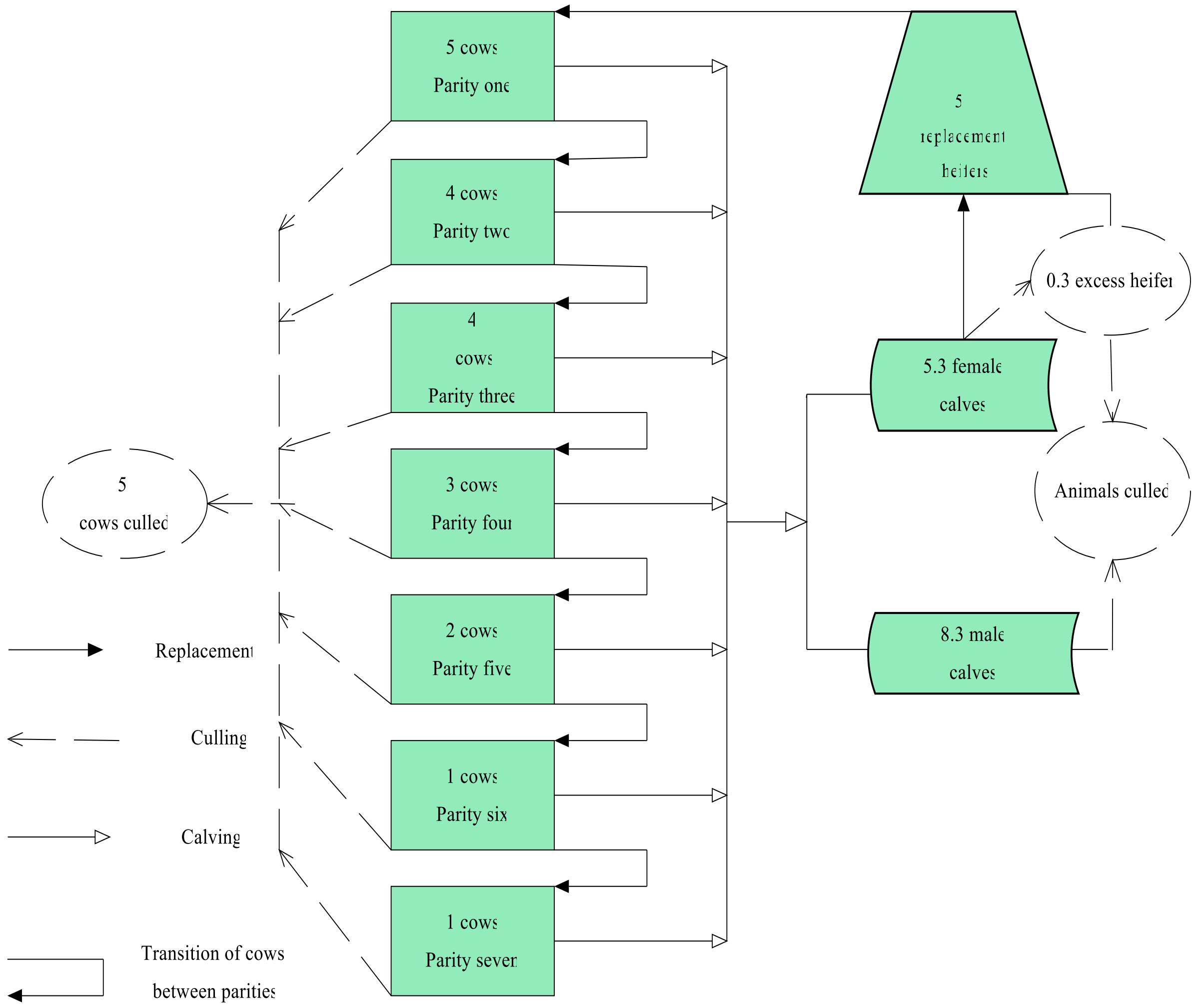

Figure 4.2: Simulated herd dynamic of an average smallholder dairy cattle herd in South Africa

4.2.3. Average cow performance

Individual cow performance data, comprising lactation yields of milk, fat, and protein, as well as age at first calving, and calving interval, were obtained from the INTERGIS. Culling rate was estimated from the information received from the survey, which was based on the herd structure of an average herd of 20 lactating cows shown in Appendix A.1. Average gestation length was assumed to be 280 days. The average cow mature live weights used by Banga (2009) for a pasture-based system were applied, since no information on live-weights was available for the smallholder system in South Africa. Table 4.1 contains the averages for measures of cow performance in the simulation of an average smallholder dairy herd in South Africa.

Table 4.1. Average performance of dairy cows used in simulation of an average smallholder dairy herd in South Africa

Parameter	**Abbreviation**	**Value**
Milk yield (kg/year)	MY	3 798.0
Milk yield (l/year)	ML	3 687.4
Fat yield (kg/year)	FY	187.7
Protein yield (kg/year)	PY	165.1
Mature live weight (kg)	LW	441.6
Gestation length (days)	GL	280.0
Age at first calving (months)	AFC	29.0
Calving interval (days)	CI	420.0
Calf birth weight (kg)	cbw	28.0
Cow's culling rate (%)	cr	25.0
Calf mortality rate (%)	cmr	9.0

Calf birth weight: Calf birth weight is necessary to predict the animal's live weight at different stages of growth. This weight was not available, hence it was estimated using the equation proposed by Roy (1980), considering the mature body weight of a dam (Equation 4.1):

$$W_c(kg) = (W_m^{0.73} - 28.89)/2.064 \quad [4.1]$$

Where;

$W_c(kg)$: Weight of a calf in kilograms,

$W_m(kg)$: Mature body weight of a dam in kilograms.

Prediction of live weight: The animal's live weight is important for the onset of puberty and management decisions, such as mating dates. It is also required for the estimation of the nutritional requirements of an animal at various ages and physiological states. Live weight was predicted for each month of age, starting from the first month after weaning (month 3), using the von Bertalanffy growth function proposed by Bakker & Koops (1978) as shown in Equation 4.2:

$$LW = M\{1 - (1 - (w_0/M)^{1/3})e^{-kt}\}^3 \quad [4.2]$$

Where;

$\boldsymbol{M}$: Mature weight (kg),

w_0 : Birth weight (kg),

k : Growth rate parameter,

t : Age (months).

4.2.4. Metabolizable energy requirements of a cow

The common sources of feeds, and feeding management obtained via the survey were utilized as a base for calculation of metabolizable energy (ME) requirements for both cows and replacement heifers. Natural pasture feeding was the major feeding system practiced among smallholder dairy farmers. This feeding regime generally included an additional 2 kg of concentrate per day per cow. During winter (June to July), an extra 2 kg of silage per day were given to the cows, to complement the decline in pasture quantity. Feed requirements of an individual cow (Kg dry matter) were calculated using ME content of the feed. Similar to other simulation studies (Banga, 2009; Demeter *et al.*, 2011), it was assumed that nutrients other than energy were adequate in the diet.

Objective measures of dry matter (DM) yields, and ME content of feed rations were not obtainable, since smallholder dairy cows are fed on a wide range of pasture, and supplementation. To obtain a reasonable estimate of these measures, an average DM yield of 6 ton per hectare (ha) of pasture, taken from a range of DM yields across South African pasture lands, was used as the baseline (Palmer & Ainslie, 2005). In the case of feed energy content, it was assumed that pasture, concentrate, and silage, respectively, contained 7.5, 9.5 and 10.2 MJ ME /kg DM as these were minimum values reported by Stewart *et al.* (2016). These values were used to reflect the general characteristics of poor feed quality in the smallholder production system.

Energy requirements (kg DM per cow per year) were estimated for maintenance, growth, pregnancy and production (lactation), less fasting, and energy metabolism during fat mobilization. Fat mobilization often occurs in dairy cows postpartum, due to an involuntary reduction in dry matter intake around parturition, and subsequent negative energy balance after calving (NRC, 2001; Opsomer, 2015). Total energy requirement was divided by the energy content of the feed (MJ ME/kg DM) to estimate the total DM requirements per cow per year.

Energy (MJ ME) required by an individual animal was computed, using a specific energy conversion efficiency (k) also known as Efficiency of energy utilization (Table 4.2) for each physiological function following the principle recommended by the Agriculture, and Food

Research Council Technical Committee (AFRC, 1993). The metabolizable energy requirement was calculated using Equations 4.3.1 to 4.3.4 (AFRC, 1993).

$$km = 0.35qm + 0.503 \quad [4.3.1]$$

$$kg = 0.95kl \quad [4.3.2]$$

$$kc = 0.78qm + 0.006 \quad [4.3.3]$$

$$kl = 0.35qm + 0.420 \quad [4.3.4]$$

Where;

$\boldsymbol{k}$: Efficiency of converting ME in net energy for $\boldsymbol{m, g, c, and\ l}$

$\boldsymbol{qm}$: Metabolisability of gross energy at maintenance,

$\boldsymbol{m}$: Metabolisability of gross energy for maintenance,

$\boldsymbol{g}$: Metabolisability of gross energy for growth,

$\boldsymbol{c}$: Metabolisability of gross energy for conceptus,

$\boldsymbol{l}$: Metabolisability of gross energy for lactation,

Table 4.2. Efficiency of energy utilization (k-values) for different biological functions assuming a value of 0.6 for gross energy at maintenance

ME requirement	k value[1]
Maintenance	0.70
Heifer growth	0.45
Cow growth	0.59
Pregnancy[1]	0.133
Lactation	0.62

[1]k-value assigned constant value, with no influence of q_m implied (Adapted from Banga, 2009)

Requirements for maintenance: The metabolizable energy for maintenance is required to maintain the normal metabolism of an animal, at equilibrium or fasting metabolism. It includes the energy required to support and maintain different physiological activities, which include breathing, maintenance of body temperature, digestion, and absorption of food, and physical activities such as walking, sleeping, and grazing (VandeHaar *et al.*, 2016). The requirements for maintenance (ME_m) were calculated per month of age, for each parity, using equation 4.4 (AFRC, 1993).

$$ME_m(MJ/d) = (F + A)/K_m \quad [4.4]$$

Where;

F : Fasting metabolism,

A : Correction factor for activity allowance to account for the management system

Equation 4.4.1 was used to calculate fasting metabolism as a function of the predicted average live weight (LW) for each respective lactation group, and month of age as given by ARC (1980):

$$F(MJ/d) = C_2\{0.53(LW/1.08)^{0.67}\} \quad [4.4.1]$$

The value of 1.08 is a factor that converts LW to body weight at fasting, as given by ARC (1980) and adopted by AFRC (1993). Accordingly, the value of 0.011 LW was used for activity allowance.

Requirements for cow growth: Metabolizable energy requirement for cow growth (ME_g) were calculated for each month of age, within each parity group, using Equation 4.5 (AFRC, 1993):

$$ME_g(MJ/kg) = (\Delta LW \times [EV_g])/kg \quad [4.5]$$

Where;

$\boldsymbol{EV_g}$: Energy value of 1 unit of live body gain,

$\boldsymbol{\Delta LW}$: Change in live body weight.

The energy value of 1 unit of live body gain was calculated as follows (AFRC, 1993):

$$\mathrm{EV_g(MJ/kg) = \{1.3(4.1 + 0.0332W_t - 0.000009W^2{}_t)\}/\{1 - 0.1475LWG\}} \quad [4.5.1]$$

Requirements for conceptus: Metabolizable energy requirements for conceptus (ME_c), were predicted for each week of pregnancy, up to 40 weeks of gestation, as a function of the expected calf birth weight, and days of gestation, using equation 4.6.

$$ME_c = E_c/K_c \quad [4.6]$$

Where;

E_c : Energy retained for fetal growth (MJ/day), which was obtained by:

$$E_c\ (MJ) = 0.025W_0(E_t \times 0.0201e^{-0.000057t}) \quad [4.6.1]$$

Where;

W_0 **:** Calf's birth weight in kg, which was calculated using Equation 4.1,

$E_t(MJ)$ **:** Energy retention at time t $(MJ, days)$ in the gravid fetus, which is given by:

$$log_{10}(E_t) = 151.665 - 151.64(e^{-0.0000576t}) \quad [4.6.2]$$

Where;

t : Days of gestation.

Requirements for lactation: The amount of energy required to produce a unit kilogram of milk depends on the quantity, and composition of the milk produced (Holmes *et al.*, 2000; Woldegebriel *et al.*, 2017). As a result, the metabolizable energy (ME_l) required for milk production was determined based on milk energy value, corrected for fat, and protein yields, per lactation, for each parity, using equation 4.7.

$$ME_l(MJ) = (Y \times [EV_l])/K_l \quad [4.7]$$

Where;

$\boldsymbol{Y}$: Lactation milk yield (kg),

$\boldsymbol{EV_l}$: Energy value of milk (MJ/kg).

The energy value of milk was calculated using equation 4.7.1 as proposed by Tyrell & Reid (1965), and recommended by AFRC (1990):

$$EV_l(MJ) = 0.0376(F) + 0.0209(P) + 0.94 \quad [4.7.1]$$

Where;

$\boldsymbol{F}$: Butterfat yield (kg),

$\boldsymbol{P}$: Protein yield (kg).

The energy content of milk components was assumed to be 56.1 MJ ME per kg milk fat, 31.8 MJ ME per kg protein, and 1.84 MJ ME per liter of milk, following Holmes *et al.* (2000).

4.2.5. Metabolizable energy requirements of a replacement heifer

Energy requirements for replacement heifers were calculated for growth, and maintenance, using Equation 4.8 (AFRC, 1993). Heifers were fed pasture supplemented with 2 kg concentrate per day for the whole calendar year. During winter (June to July), an extra 2 kg DM of silage per day were given to the heifers, to complement the decline in pasture quantity and quality. These energy requirements were calculated from weaning up to 29 months of age before calving. Energy requirements for excess heifers were calculated from weaning up to 21 months of age.

$$ME_r(MJ) = (E_m/K) \times ln\{B/(B - R - 1)\} \quad 4.8$$

Where;

E_m : Sum of fasting metabolism (F) and activity allowance (A) appropriate for particular feeding system

$$B = K_m/(K_m - K_c) \quad 4.8.1$$

$$K = K_m \times ln(K_m/K_c) \quad 4.8.2$$

Scaled energy retention (R) is given by:

$$R = E_f/K_m \quad 4.8.3$$

E_f, was calculated from:

$$E_f(MJ/d) = C_4(EV_g \times \Delta W) \quad 4.8.4$$

Where;

$\boldsymbol{C_4 = 1.10}$, which is a correction factor for activity allowance in heifers

$\boldsymbol{\Delta W}$: Weight gain,

$\boldsymbol{EV_g}$: Energy value of gain, which was calculated as:

$$EV_g(MJ/kg) = 1.30(4.1 + 0.0332LW - 0.000009LW^2)/(1 - 0.1475\Delta LW) \quad 4.8.5$$

4.2.6. Economic sub-model

The economic sub-model was linked to the feeding, and biological sub-models to estimate the gross margins (GM) generated from the production operation. The GM was estimated by accounting for the total net revenues of milk produced; net value of male calves, and excess female calves, salvage value of culled cows less the total production costs (Equation 4.9). The production costs, and revenues were estimated based on the average prices obtained from the survey, and personal communications.

$$GM = T_r - T_C \quad [4.9]$$

$\boldsymbol{GM}$: Gross margin,

$\boldsymbol{T_r}$: Total revenue received from the sale of outputs,

$\boldsymbol{T_c}$: Total costs associated with the production of outputs.

Total revenue: Total revenue was defined as the total financial incentive received from selling an output X at a certain price P. Gross margin: (GM) was calculated, using Equation 4 .9.1.

$$T_r = \sum PX_n \quad [4.9.1]$$

$\boldsymbol{P}$: Price of output,

$\boldsymbol{X}$: Type of outputs,

$\boldsymbol{n}$: Number of output, from1 to n^{th}.

The average prices used to calculate revenue from the sale of milk, and culled animal were obtained from the survey. The price of the male calves was set per head, while the prices for excess heifers, and culled cows were calculated per kg of dressed body weight (Table 4.3).

Table 4.3. Average prices of outputs from smallholder dairy herd obtained from the survey

Type of output	unit	Price (ZAR)
Milk	Liter	4.00
Male calf	head	510.00
Culled female calf	kg	28.00
Culled cow	kg	22.50

Total production costs: Total production costs were calculated using Equation 4.9.2.

$$T_c = (F_c + V_c) \quad [4.9.2]$$

$\boldsymbol{T_c}$: Total production costs,

$\boldsymbol{V_c}$: Variable feed cost,

$\boldsymbol{F_c}$: Fixed operation costs excluding overhead costs (housing and other capital investment costs).

Variable costs were mainly generated from feeding. The costs of feeding were estimated using the actual feed costs of dry matter (kg) consumed from silage (sil), concentrate (conc), and the opportunity cost of pasture (pas) feeding per year. The estimated average price (R/kg) of pasture, concentrate and silage received from the survey were 1.1, 5.6, and 3.5, respectively.

4.2.7. Model verification, validation and sensitivity analyses

Model verification, validation, and sensitivity analysis are essential steps in model development, and simulation studies. The purpose of verification is to check the reliability of the setup of a model or equations to ensure the accuracy of prediction (Richardson *et al.*, 2008). Model validation is performed through calibration, using field data, in order to verify its accuracy in reproducing the observed behavior, and response of the real system (Dent & Blackie, 1979; Richardson *et al.*, 2008). Sensitivity analysis is conducted to enhance decision-making, and recommendations for ex-ante production alternatives or risk assessment of production uncertainties, by inducing changes to the biological, economic, and or management parameters (Dent & Blackie, 1979; Groen, 1989). The developed model was verified by checking the correctness of mathematical matrices, and consistency of any logical assumptions throughout the modelling process. It was adapted, with minor modifications, from a previous model developed, and validated by Banga (2009). The sensitivity analysis of this herd model, to determine its robustness to varying production, and economic circumstances, will be conducted in the simulation of alternative herd production practices in Chapter 5.

4.3. Results

This section presents the results of the main outputs of the resultant model, which mainly comprise of nutrient energy requirement for animals' performance, production costs, revenue streams, and the gross marginal returns expressed per cow per year. It is important to note that these results presented in Figure 4.3, and Table 4.4, are based on an average herd, and variation within the whole production system was not assessed. Average dairy cows' performances, particularly milk production levels, and the equivalent mature body weight at a different stages of the production cycle were used to estimate the requirements for maintenance, growth, reproduction/pregnancy, and milk production/lactation (Figure 4.3). Among these physiological activities, lactation/milk production accounted for the highest proportion of total energy intake per year (22,603.1 MJ), followed by maintenance (21,683.7 MJ/year), pregnancy (1,482.4 MJ/year), and growth (529.7 MJ/year). The energy utilized for maintenance, and growth of a heifer was estimated at 10,282.5 MJ of ME per year. The total metabolizable energy intake for all these physiological activities was estimated at 56,581.5 MJ per cow per year (Table 4.4). This translates to a dry matter consumption of 7,225 kg per cow per year (Table 4.4).

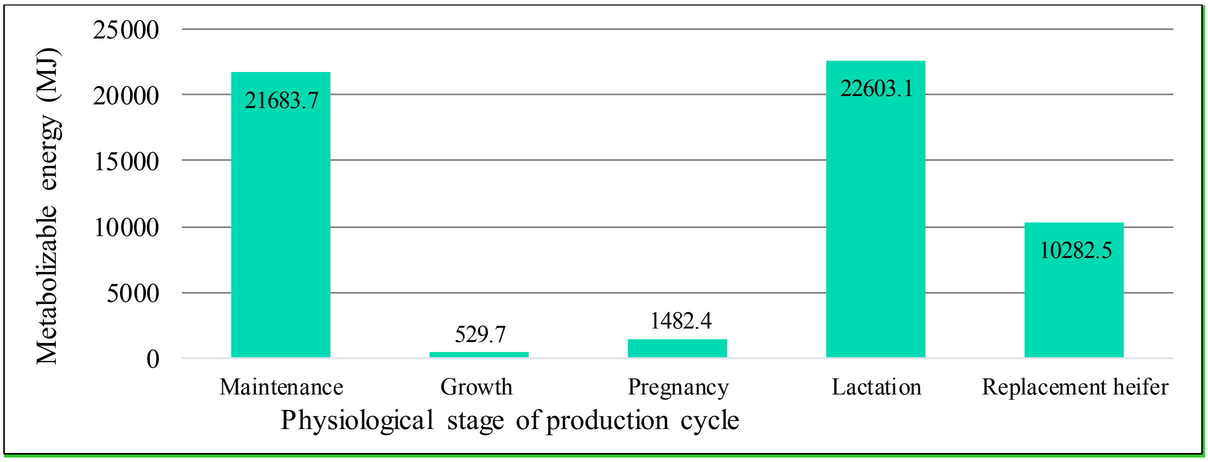

Figure 4.3: Estimated metabolizable energy requirements (MJ) of a cow and replacement heifer per year in an average smallholder dairy cattle herd in South Africa

The calculated annual production costs (C), revenues (R), and the gross margin (GM) per cow are presented in Table 4.4. The calculated total annual production cost was R 16,460.7 per cow per year. A total revenue of R 18 087.3 was estimated per cow per year. A positive annual gross margin of R 1 627 per cow was forecasted for an average smallholder farmer.

Table 4.4. The simulated metabolizable energy requirements, dry matter intake, production costs, revenues and gross margin per cow and year

Item	Value
Total energy requirement (MJ)	56 581.5
Total dry matter consumed (kg)	7 225.0
Cost (ZAR/Rand)	
Cow's health	358.0
Heifer's health	212.0
Breeding bull	1 272.2
Cow's feeding (R/head)	10 012.4
Heifer's Feeding	2740.1
Calf's Feeding (R/head)	105.0
Labor cost	1 146.0
Electricity	91.0
Recording and other logistics	235.0
Transport	289.0
Total cost	16 460.7
Revenue (ZAR)	
Milk sale	16 593.4
Culled animals (cow, male and female calves)	1 493.9
Total revenue per head	18 087.3
Gross margin (R/head)	1 626.6

4.4. Discussion

The results from the current study are crucial for understanding the potential impact of management decisions on the key factors affecting the animals' performance, and the economic efficiency of smallholder dairy cattle herds. Several extrinsic factors have been reported to have an effect on cows' performance, but nutritional factors appeared to be a major factor with the greatest effect on dairy cows' performance (Burke *et al.*, 2010; Remppis *et al.*, 2011; Urdl *et al.*, 2015). This was evident in the study conducted by Abin *et al.* (2018); where the performance of dairy cows in the smallholder herds was poor, reflecting low nutritional levels compared to their counterparts in the high-input production system.

Dairy cows in the low-input smallholder systems are often offered veld or natural pasture-based feeds, supplemented with small amount of concentrates, and silage during pasture shortage as in the case of the current study. Pasture-based feeds (especially natural veld) are mostly low in metabolizable energy content (Clark *et al.*, 1997; Kolver, 2003; Mucina & Rutherford, 2006), and if not improved (e.g. using N fertilizer) or supplemented with high quality concentrates will impair the potential performance of dairy cows (Dillon *et al.*, 1997; Peres *et al.*, 2012; Macdonald *et al.*, 2017). As a result, feed metabolizable energy (ME) (MJ/kg DMI) was used to simulate the impact of feeding management on the biological processes that influence the performance of dairy cattle in the current study. The metabolizable energy consumed by an individual dairy animal is generally partitioned for maintenance, and growth in heifers, and for reproduction, and lactation in mature cows (AFRC, 1993; MacDonald *et al.*, 2008; Bach *et al.*, 2020). The first priority of a dairy cow is to satisfy its energy requirement for maintenance (Bauman *et al.*, 1980; Lucy, 2000). Thereafter, the energy retained will be partitioned for other physiological activities with a greater proportion directed towards milk production (Lucy, 2000; Bauman *et al.*, 2004; Vandehaar *et al.*, 2016).

The total dry matter intake (DMI) in this study is higher than the reported results of 4 982.0 kg by Lopez-Villalobos *et al.* (2000), and 3 313.0kg to 4 511.0kg of DM by Khan (2009) respectively. These differences could be explained by the difference in milk production levels, and mature live weights in the different systems (Macdonald *et al.*, 2008). Additionally, these comparative studies were performed in New Zealand (Lopez-Villalobos *et al.,* 2000), and Bangladesh (Khan, 2009), which made use of planted pastures with much higher nutritive values. Natural veld, and even unimproved pastures in South Africa have low protein, and energy levels, which decrease even further in the dry season (De Waal, 1990; Williams *et al.*, 2016). Cows that are fed a lower quality feed (low energy density) have to consume a greater quantity of DM, in order to fulfil their basal nutrient energy requirements (Korver, 1982; Dong *et al.*, 2015a & b). Cows of different mature body weights have different sized of internal organs, and therefore, different energy requirements for maintenance. For example, a dairy cow of a larger body size has large internal viscera/liver mass that increases its metabolic rate, and energy requirement for maintenance (Oldenbroek, 1988; Ortigues & Visseiche 1995; Manafiazar *et al.*, 2012).

The aim of the economic analysis was to assess the financial performance (strengths and / or weaknesses) of the smallholder dairy cattle production system using gross margin (GM) analysis. In this study, GM was defined as the difference between the annual revenue received from the gross output, and the total production costs that are directly associated with the production operation. The total annual production cost incurred to produce 3 687.4 liter of milk, 187.7 kg of fat and 165.1 kg of protein from an average cow of 450 kg mature live weight was R 16 460.7. Approximately 78% of this total production cost could be apportioned to feeding costs. Similarly, feeding was cited as the major contributor of production costs in dairy farmi ng systems in South Africa, Morocco, Uganda, and Cameroon by Ndambi & Hemme (2009), and smallholder dairy cattle in Kenya by Kibiego *et al*. (2015). These results demonstrated that irrespective of country, and production system, feed costs remained the most expense input in dairy farming.

The estimated total annual revenue received from the sales of milk, and animals (culled cows, excess heifers and male calves) was R 18 087.3. The largest proportion of this revenue was received from the sale of milk with animals/carcasses contributing only 8.3% to the total revenue. This result is consistent with the findings of Ndambi & Hemme (2009), who reported that a higher proportion of total revenue of dairy farms in South African, Uganda, and Cameroon came from the sale of milk.

The estimated gross margin for the simulated smallholder herds was positive, implying a profitable farming operation. However, given the inherent risks of the production conditions (high volatility of input costs vis-à-vis reduced gate price of milk sales) in the dairy industry, the estimated GM of R 1 626.6 may not be optimum to offset an upward shift in production costs. Additionally, it was difficult to accurately include all the direct costs of the key input factors such as feeding, supplementation, and veterinary service in the smallholder dairy cattle production system. These factors may have led to an underestimation of production costs, and an overestimation of the GM.

4.5. Conclusion and recommendations

In this chapter, a normative, and deterministic bio-economic model was developed, which simulate an average South African smallholder dairy herd. The structure of the developed model included biological, and economic sub-models. The biological sub-model simulated animals' growth as a function of birth, and mature body weights, herd's mortality, culling rate, and replacement events. The model also computed nutrient requirements for maintenance, growth, pregnancy, and milk production. The economic model calculated the related production costs, revenues, and gross margin of the smallholder dairy farming operation. This model provides a baseline for evaluation of the alternative production options for SH herds.

Such analyses should focus on generating knowledge required to develop tactical plans that would benefit farmers in the short, and long-term. This could include investigating the impact of changing factors such as herd size, and herd structure, feeding strategies, cow production, and reproductive performance on herd profitability.

4.6. Reference

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. 50, 1479-1484.

Ali, B.M., Berentsen, P.B.M., Basttiaansen, J.W.M. & Lansink, A.O., 2018. A stochastic bio-economic pig farm model to assess the impact of innovation of farm performance. Anim. 12, 819-830.

AFRC (Agricultural & Food Research Council), 1990. Technical Committee on Responses to Nutrients. Report no 5. Nutritive requirements of ruminant animals: Energy. Nutrition Abstracts and Reviews, Series B, 60 (10). 729-804. CAB International, Wallingford, UK.

AFRC (Agricultural &Food Research Council), 1993. Energy and protein requirements of ruminants. An advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients. CAB INTERNATIONAL, Wallingford, UK.

ARC (Agricultural Research Council), 1980. The nutrient requirements of grazing livestock. Commonwealth Agricultural Bureau, London.

Bach, A., Terré, M. & Vidal, M., 2020. Symposium review: Decomposing efficiency of milk production and maximizing profit. J. Dairy Sci. 103, 5709-5725.

Bakker, H. & Koops, W.J., 1978. An approach to the comparison of growth curves of Dutch Friesian, British Friesian and Holstein Friesian cows. In Patterns of growth and development in cattle Springer, Dordrecht. pp. 705-715.

Banga, C.B., 2009. The development of breeding objectives for Holstein and Jersey cattle in South Africa. Ph.D. thesis, University of the Free State, Bloemfontein, South Africa.

Bauman, D.E. & Currie, W.B., 1980. Partitioning of nutrients during pregnancy and lactation: a review of mechanisms involving homeostasis and homeorhesis. J. Dairy Sci. 63, 1514-1529.

Bauman, D., Lock, A., Baumgard, L. & Collier, R., 2004. Nutrient partitioning and milk yield: constraints and opportunities in the 21st century. In Proceedings, Cornell Nutrition Conference, pp. 107-121.

Bekara, M.E.A. & Bareille, N., 2019. Quantification by simulation of the effect of herd management practices and cow fertility on the reproductive and economic performance of Holstein dairy herds. J. Dairy Sci. 102, 9435-9457.

Bohan, A., Shalloo, L., Malcolm, B., Ho, C.K.M., Creighton, P., Boland, T.M., McHugha, N., 2016. Description and validation of the Teagasc Lamb Production Model. Agric. Syst. 148, 124-134.

Burke, C.R., Williams, Y.J., Hofmann, L., Kay, J.K., Phyn, C.V.C. & Meier, S., 2010. Effects of an acute feed restriction at the onset of the seasonal breeding period on reproductive performance and milk production in pasture-grazed dairy cows. Journal of dairy science, 93, 1116-1125.

Clark, D.A, Penno, J.W. & Neil, P.G., 1997. Nutritional Merits and problems of pasture. In Milk Composition, Production and Biotechnology, [RAS Welch, DJW Burns, SR Davis, AI Popay and CG Prosser, editors]. Cambridge: Cambridge University Press. pp. 397-418.

Demeter, R.M., Kristensen, A.R., Dijkstra, J., Lansink, A.O., Meuwissen, M.P.M. & van Arendonk, J.A.M., 2011. A multi-level hierarchic Markov process with Bayesian updating for herd optimization and simulation in dairy cattle. J. Dairy Sci. 94, 5938-5962.

Dent, J.B. & Blackie, M.J., 1979. Systems Simulation in Agriculture. Springer, Applied Science, London. Pages?

Dent, J.B. & Thornton, P.K., 1988. The role of biological simulation models in farming systems research. Agric. Admin. Exten. 29, 111-122.

De waal, H.O., 1990. Animal production from native pasture (veld) in the Free State Region-A perspective of the grazing ruminant. S. Afr. J. Animal Sci. 20, 1-9.

Dezetter,C., Bareille, N., Billon, D., Côrtes, C., Lechartier,C. & Seegers, H., 2017. Changes in animal performance and profitability of Holstein dairy operations after introduction of crossbreeding with Montbéliarde, Normande, and Scandinavian Red. J. Dairy Sci. 100, 8239-8264.

Dillon, P., Crosse, S. & O'Brien, B., 1997. Effect of concentrate supplementation of grazing dairy cows in early lactation on milk production and milk processing quality. Irish Journal of agricultural and food research, pp.145-159.

Dong, L.F., Yan, T., Ferris, C.P. & McDowell, D.A., 2015a. Comparison of maintenance energy requirement and energetic efficiency between lactating Holstein-Friesian and other groups of dairy cows. J. Dairy Sci. 98, 1136-1144.

Dong, L.F., Ferris, C.P., McDowell, D.A. & Yan, T., 2015b. Effects of diet forage proportion on maintenance energy requirement and the efficiency of metabolizable energy use for lactation by lactating dairy cows. J. Dairy Sci. 98, 8846-8855.

Groen, A.F., 1989. Cattle breeding goals and production circumstances. (Fokdoel in de rundveefokkerij en produktie-omstandigheden), (Ph.D. Thesis, Department of Farm Management and Department of Animal Breeding, Wageningen Agricultural University, Wageningen, The Netherlands).

Herrero, M., Fawcett, R.H. & Dent, J.B., 1999. Bio-economic evaluation of dairy farm management scenarios using integrated simulation and multiple-criteria models. Agric. syst. 62, 169-188.

Holmes, C.W., Brookes, I.M., Garrick, D.J., Mackenzie, D.D.S., Parkinson, T.J. & Wilson, G.F., 2000. Milk Production from pasture. Massey University, Palmerston North, New Zealand.

Khan, M.K.I., 2009. Development of models for the genetic improvement of dairy cattle under cooperative dairying conditions in Bangladesh: a thesis presented in partial fulfillment of the requirements for the degree of Doctor of Philosophy in animal Breeding and Genetics at Massey University, Palmerston North, New Zealand. Pages?

Kavoi, M.M., Hoag, D.L. & Pritchett, J., 2010. Measurement of economic efficiency for smallholder dairy cattle in the marginal zones of Kenya. J. Dev. Agric. Econ. 2, 122-137.

Kebreab, E., Reed, K.F., Cabrera, V.C., Vadas, P.A., Thoma, G., & Tricarico, J.M., 2019. A new modeling environment for integrated dairy system management. Anim. Front. 9, 25-32.

Kibiego, M., Lagat, J. & Bebe, B., 2015. Competitiveness of Smallholder Milk Production Systems in Uasin Gishu County of Kenya. J. Econ. Sustain. Dev, 6, 39-45.

Kolver, E.S., 2003. Nutritional limitations to increased production on pasture-based systems. Proc. Nutr. Soc. 62, 291-300.

Korver, S., 1982. Feed intake and production in dairy breeds dependent on the ration (Doctoral Thesis, Departments of Animal Breeding and Animal Nutrition of the Agricultural University, Wageningen, The Netherlands).

Krejčí, I., Moulis, P., Pitrová, J., Tichá, I., Pilăr, L. & Rydval, J., 2019. Traps and Opportunities of Czech Small-Scale Beef Cattle Farming. Sust. 11, 2-26.

Leinonen, I., Williams, A.G. & Kyriazakis, I., 2016. Potential environmental benefits of prospective genetic changes in broiler traits. Poult. Sci. 95, 228-236.

León-Velarde, C.U. & Quiroz, R., 2001. Modeling cattle production systems: integrating components and their interactions in the development of simulation models. In Proceedings-Third International Symposium on Systems Approaches for Agricultural Development, SAAD III International Potato Center (CIP), Lima Peru. pp. 8.

Lopez-Villalobos, N., Garrick, D.J., Holmes, C.W., Blair, H.T. & Spelman, R.J., 2000. Profitabilities of some mating systems for dairy herds in New Zealand. J. Dairy Sci. 83, 144-153.

Lucy, M.C., 2000. Regulation of ovarian follicular growth by somatotropin and insulin-like growth factors in cattle. J. Dairy Sci. 83: 1635-1647.

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.

Macdonald, K.A., Penno, J.W., Lancaster, J.A.S., Bryant, A.M., Kidd, J.M. & Roche, J.R., 2017. Production and economic responses to intensification of pasture-based dairy production systems. J. Dairy Sci. 100, 6602-6619.

Manafiazar, G., McFadden, T., Goonewardene, L., Okine, E. & Wang, Z., 2012. Factors That Affect Energy Efficiency and Indirect Response of Selection for Efficiency on Related Traits. In Milk Production-An Up-to-Date Overview of Animal Nutrition, Management and Health. InTech., pp.121-138.

Manzana, N.P., McCrindle, C.M., Sebei, P.J. & Prozesky, L., 2014. Optimal feeding systems for small-scale dairy herds in the North West Province, South Africa. J. SA. Vet. Assoc. 85, 1-8.

Mayer, D.G., Belward, J.A. & Burrage, K. 1996. Use of advanced techniques to optimize a multidimensional dairy model. Agric. syst. 50, 239-253.

Mbilu, A.P., 2015. Smallholder dairy farmers' technical efficiency in milk production: case of EPINAV dairy project in Njombe district, Tanzania (Doctoral dissertation, Sokoine University of Agriculture).

Mucina, L. & Rutherford, M.C., 2006, The vegetation of South Africa, Lesotho and Swaziland, Strelitzia 19, South African National Biodiversity Institute, Pretoria.

Muntswu, E.A., Chitura, T., Abin, S.A. & Banga, C.B. 2017. Characterization of emerging and smallholder dairy production systems in South Africa. In: Proc. of the 50th Annual Congress of the SA Society for Animl Science, Port Elizabeth, 18-21 September 2017.

Ndambi, O.A. & Hemme, T., 2009. An economic comparison of typical dairy farming systems in South Africa, Morocco, Uganda and Cameroon. Trop. Animal Hlth. Prod. 41, 979-994.

NRC (National Research Council), 2001. Nutrient Requirements of Dairy Cattle. 7th revised edition. National Academy Press, Washington, DC.

Ojango, J.M.K., Mrode, R., Okeyo, A.M., Rege, J.E.O., Chagunda, M.G.G. & Kugonza, D.R. 2017. Improving smallholder dairy farming in Africa. In: Achieving sustainable production of milk Volume 2: Safety, quality and sustainability. Ed: Belzen, N. van, Cambridge, UK: Burleigh Dodds Science Publishing Limited. http://dx.doi.org/10.19103/AS.2016.0005.38.

Oldenbroek, J.K., 1988. Feed intake and energy utilization in dairy cows of different breeds. (Doctoral Thesis), Research Institute for Animal Production, Wageningen, The Netherlands.

Opsomer, G., 2015. Interaction between metabolic challenges and productivity in high yielding dairy cows. Japanese J. Vet Res. 63, S1-S14.

Ortigues, I. & Visseiche, A.L., 1995. Whole-body fuel selection in ruminants: Nutrient supply and utilization by major tissues. Proc. Nutr. Soc. 54, 235-251.

Palmer, A.R. & Ainslie, A.M., 2005. Grasslands of South Africa. In: Grasslands of the world, Plant production and protection series 34. Eds: Suttie, J.M., Reynolds, S.G. & Batello, C., Food and Agriculture Organization of the United Nations, Rome. pp. 77-120.

Peres, A.A.D.C., Carvalho, C.A.B.D., Carvalho, M.I.D.A.B., Vasquez, H.M., Silva, J.F.C.D., Clipes, R.C. & Morenz, M.J.F., 2012. Production and quality of milk from Mantiqueira dairy cows feeding on Mombasa grass pasture and receiving different sources of roughage supplementation. Revista Brasileira de Zootecnia, 41, 790-796.

Remppis, S., Steingass, H., Gruber, L. & Schenkel, H., 2011. Effects of energy intake on performance, mobilization and retention of body tissue, and metabolic parameters in dairy cows with special regard to effects of pre-partum nutrition on lactation-A Review. Asian Austral. J. Anim. Sci. 24, 540-572.

Richardson, J.W., Schumann, K.D. & Feldman, P.A. 2008. SIMETAR®. Simulation for Excel to Analyze Risk College Station, TX: Agricultural and Food Policy Center, Department of Agricultural Economics, Texas A&M University.

Roy, J.H.B., 1980. The calf. 4th ed. Butterworths. London, UK.

Sørensen, J.T., 1990. Validation of livestock herd simulation models: a review. Livest. Prod. Sci. 26, 79-90.

Stewart, P.G., Jones, R.I. & Dugmore, T.J., 2016. Practical Feeding of the Dairy Cow. In: Agricultural Guidelines of the Department of Agriculture and Rural Development, KwaZulu-Natal (KZNDARD). www.kzndard.gov.za/resource-centre/guideline-documents.

Tyrrell, H.F., & Reid, J. T., 1965. Prediction of the energy value of cow's milk. J. Dairy Sci. 48:1215-1223.

Urdl, M., Gruber, L., Obritzhauser, W. & Schauer, A. 2015. Metabolic parameters and their relationship to energy balance in multiparous Simmental, Brown Swiss and Holstein cows in the periparturient period as influenced by energy supply pre-and post-calving. Journal of Animal Physiology and Animal Nutrition, 99, 174-189.

VandeHaar, M.J., Armentano, L.E., Weigel, K., Spurlock, D.M., Tempelman, R.J. & Veerkamp, R., 2016. Harnessing the genetics of the modern dairy cow to continue improvements in feed efficiency. J. Dairy Sci. 99, 4941-4954.

Walters, J.P., Archer, D.W., Sassenrath, G.F., Hendrickson, J.R., Hanson, J.D., Halloran, J.M., Vadas, P. & Alarcon, V.J., 2016. Exploring agricultural production systems and their fundamental components with system dynamics modelling. Ecol. model. 333, 51-65.

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.

Woldegebriel, D., Udo, H., Viets, T., van der Harst, E. & Potting, J., 2017. Environmental impact of milk production across an intensification gradient in Ethiopia. Livestock Science, 206, 28-36.

CHAPTER V

Evaluation of alternative herd production models for improvement of smallholder dairy herd profitability

Abstract

The main aim of this study was to evaluate alternative herd production models for the improvement of smallholder (SH) dairy herd profitability in South Africa. This was achieved by a partial budget approach, through stepwise changes to the base (average) SH herd model. Alternative models were developed by simulating different levels of cow performance, and herd management practices, and the profitability of each model was determined. Milk yield (MY), live weight (LW), age at first calving (AFC), and calving interval (CI) were used as indicators of cow performance. Herd management practices studied were herd size (HS), replacement rate (RR), feeding system (FS), breeding methods (natural service vs artificial insemination), and source of herd replacement heifers (raising vs buying in). Improvements in profitability were attained by increasing MY or increasing herd size, using small to medium sized cows, reducing AFC, CI or RR. Break-even points were 3 687.4 l/year, 500 kg, 29 months, 420 days, and 25% for MY, LW, AFC, CI, and RR, respectively. The effects of cow performance on profitability were mostly sensitive to the prices of milk, and feed. In general, profitability was either negative or extremely low, if the price of milk dropped below R4.50/l or the cost of feed exceeded R5.60/kg DM. Relying on natural pasture only for feed was non-viable, and supplementation of pasture with concentrate was the most profitable feeding system. Feeding systems based on supplementation of pasture with concentrate, and silage were resilient to fluctuations in the price of milk, remaining profitable even when the price dropped to R4.10/l. Adoption of artificial insemination, and buying herd replacement heifers are additional management strategies that minimize production cost, and increase dairy farming profitability.

Keywords: alternative, partial budget, production model, profitability

5.1. Introduction

An agricultural production system is an aggregate of components, which must function jointly within the prescribed boundaries to achieve specific objectives of its beneficiaries (Dillon, 1992). The smallholder dairy production system is such a system, with farmers, and consumers as its beneficiaries. A clear objective of modern dairy farming is to improve cow performance in order to maximize profit (Goddard & Grainger, 2004; Masuku & Belete, 2014; Bach *et al.*, 2020). In South Africa (SA), and Sub-Saharan Africa (SAA) in general, the performance of smallholder dairy cows is poor (Ojango *et al.*, 2017; Abin *et al.*, 2018), which impacts negatively on herd profitability. It is, therefore, important to develop management strategies that would improve the performance of smallholder dairy cows, in order to increase herd profitability. Models depicting the most profitable cow performance levels, and herd management practices are valuable in guiding the development of such strategies.

In the past, bio-economic simulation models have been used to support decision making intended to address management problems of economic importance in dairy farming (Banga, 2009; Ashfield *et al.*, 2014; Diakité *et al.*, 2019). In these models, animals' biological components, herd management, and the associated economic parameters were studied simultaneously. The bio-economic simulation models for dairy cattle mostly focused on improvement of economically important traits such as milk yield, mature live weight, and calving interval (Kahi & Nitter, 2004; Banga, 2009; Seyedsharifi *et al.*, 2018). Cow performance of these traits represented the primary biological indicators for productivity, and the economic efficiency of the herd.

Additional management factors such as herd size, replacement rate, feeding systems, breeding, and rearing methods also influence herd productivity, and should be optimized in order to maximize profit. An evaluation of the effect of changes in all these production factors is important in determining the most profitable herd models (Kristensen *et al.*, 2008; Krpalkova *et al.*, 2016; Armengol & Fraile, 2018). Therefore, comparing the current versus alternative production models is necessary to support sound decision making. This can be achieved through the application of the deterministic, and normative simulation model (Groen, 1989; Dekkers, 1991, Banga, 2009; Mbuthia *et al.*, 2015). This model is normally combined with a profit function to calculate herd profit under the current, and alternative production conditions. The effect of varying production parameters or herd management practices on profit is determined through the use of either partial budgeting or partial differentiation, along with the profit function (Wolfová *et al.*, 2007; Mbuthia *et al.*, 2015; Sánchez *et al.*, 2020). The current study was carried out to evaluate the profitability of alternative SH dairy herd production models, using a deterministic, and normative modelling approach. The specific objectives were to firstly evaluate the economic impact of varying production, and reproductive performance levels, and secondly assess the effect of alternative herd management practices on SH herd profitability.

5.2. Materials and methods

A normative, and deterministic smallholder dairy herd model (SHDM), developed in chapter IV was used to determine the impact of varying cow performance levels, and alternative management practices on herd profitability. Information on dairy cows' performance, and its associated economic and management practices were used in the simulation of the SHDM. The performance records were obtained from the INTERGIS (Integrated Registration and Genetic Information System) for 59 smallholder dairy herds. The economic inputs, and management practices were obtained from a survey (and supplementary personal communications) conducted on smallholder dairy farmers by the Agricultural Research Council (ARC) of South Africa (Muntswu *et al.*, 2017). A ClickCharts Diagram and Flowcharts software was used in creating a visual representation of the SHDM. A brief overview of this model is provided here, as a detailed description has already been presented in chapter IV.

The model is made up of three components, which reflect the characteristics of an average SH dairy herd in South Africa, viz: i) a biological sub-model simulates herd structure, cow performance (production, reproduction, and longevity), and cow's mature live weight (LW); ii) a feeding sub-model, which estimates feed requirements based on nutrient energy requirements for maintenance, and growth of cows, and replacement heifers, pregnancy, and lactation (milk production); iii) an economic sub-model, which calculates herd profit (gross margins) based on production costs, and revenue streams.

A sensitivity analysis was conducted to explore how each production model responds to changes in prices of feed (R/kgDM), and milk (R/l) due to market fluctuations. This was performed by varying prices by ±20% for a specific parameter, while all other parameters remained constant. This is important to determine the robustness of the models to market changes (Groen, 1986).

5.2.1. Cow performance indicators

Cows' performance indicators that were used to model alternative herds, as well as their levels in the model at the base situation are presented in Table 5.1. Values for productive, and reproductive traits were obtained from data for SH dairy herds participating in the national milk recording scheme, and are summarized in an earlier study (Abin *et al.*, 2018). Birth, and mature weights were obtained from an earlier study by Banga (2009).

Table 5.1. Average performance of cows in the smallholder dairy production system of South Africa

Parameters	Abbreviation	Value
Milk yield (kg)	MY	3798
Milk yield (l)	ML	3687
Fat yield (kg)	FY	178
Protein yield (kg)	PY	149
Mature live weight (kg)	LW	450
Age at first calving (months)	AFC	29
Calving interval (days)	CI	420
Calf birth weight (kg)	cbw	28
Replacement rate (%)	RR	25

5.2.2. Alternative herd production models

Alternative herd models were simulated by varying one management factor (cow performance level or management practice), while all other management variables remained constant. The base situation (i.e. average herd) developed in chapter IV, was used as the benchmark. The alternative production models investigated are presented in Tables 5.2 to 5.8.

5.2.2.1. Milk production and live weight:

The effect of average annual milk production per cow on herd profitability was determined by varying milk yield by 5%, 10%, and 15% below and above the base situation (Table 5.2). The effect of average mature live weight was assessed in the same way (Table 5.2).

Table 5.2. Alternative levels of milk yield (volume), and mature live weight

Scenarios	Milk yield (l)/cow/year	Live weight(kg)
-15 %	3134.3	382.5
-10 %	3318.7	405.0
-5 %	3503.1	427.5
Base	*3687.4*	*450.0*
+5 %	3871.8	472.5
+10 %	4056.2	495.0
+15 %	4240.5	517.5

5.2.2.2. Reproduction:

Age at first calving and calving interval were used to simulate the effect of reproductive performance on SH dairy herd profitability. The two traits were varied by incremental, and decremental intervals of 30, and 60 days, relative to the base situation (Table 5.3).

Table 5.3**.** Alternative levels of age at first calving and calving interval

Scenarios	**Unit**
Age at first calving	Months (Mn)
-60 days	27
-30 days	28
Base	*29*
+30 days	30
+60 days	31
Calving interval (CI)	Days (d)
-60 days	460
-30 days	390
Base	*420*
+30 days	450
+60 days	480

5.2.2.3. Replacement rate (longevity):

Replacement rate was defined as the proportion of animals required to replace those culled to maintain a steady herd size, per year. Thus, replacement rate was a reflection of cow longevity, and was altered by 5%, 10%, and 15% below, and above the base situation (Table 5.4).

Table 5.4. Alternative levels of replacement rate

Scenarios	**Unit**
Replacement rate (RR)	Percentage (%)
-15 %	21.3
-10 %	22.5
-5 %	23.8
Base	*25.0*
+5 %	26.3
+10 %	27.5
+15 %	28.8

5.2.2.4. Herd size:

Alternative herd sizes were simulated to determine the effect of varying herd size on herd profitability per cow per year (Table 5.5). The herd structure was kept similar to that in the base situation. Herd structure here refers to the proportion of lactating cows in each parity (i.e. 1 to 7 parity).

Table 5.5. Alternative size for the smallholder dairy herd

Scenarios	**Unit**
Herd size	Number of cows
-50 %	10
-25 %	15
Base	*20*
+25 %	25
+50 %	30

5.2.2.5. Feeding systems

Feed quality, and cost are major factors limiting milk yield, and herd profitability (Roche *et al.*, 2006). Farmers may supplement natural pasture with purchased feeds to maximize the dry matter intake of their cows and improve milk production. Different supplementation strategies were simulated to evaluate their effectiveness in improving milk production, and herd profitability.

Three alternative feeding strategies were simulated by changing the feeding system of the base situation. Based on total energy consumed by the cow, each feeding system had the effect of increasing or decreasing milk yield relative to the base situation. The estimated milk yield (l/cow/year) under these feeding systems are shown in Table 5.6. The base model assumed that natural pasture contained 7.5 MJ of ME/kg of DM, and that purchased silage, and concentrate contained 9.2 and 10.5 MJ of ME/kg of DM, respectively. The estimated ME of each kg of the feeding source and their respective price/kgDM, are shown in Table 5.7.

Table 5.6. Estimated milk yield from the different feeding systems simulated

Feeding system	Milk yield (l/cow/year)
Pure pasture-base (P)	2124.0
Pasture supplemented with silage (PS)	3067.9
Pasture supplemented with concentrate (PC)	3790.7
Pasture supplemented with silage* and concentrate	3687.4

* Silage was fed during dry season only.

The feeding system for the base situation (PSC) was assumed to contain 6 375 kg DM from pasture (P) supplemented with 730 kg DM of concentrate (C) per cow per year, plus 120 kg DM of silage (S) per cow during the dry season (2 months). The cost of pasture per hectare was divided by the estimated amount of DM produced per hectare to calculate its price per kg DM. The simulated alternative feeding systems were:

- Only pasture-based feeding, providing 7 225 kg DM per cow per year.
- Pasture supplemented with silage (PS), providing 6 375 kg DM of pasture and 730 kg DM of silage per cow per year, with an additional 120 kg DM of silage per cow during the dry season,
- Pasture supplemented with concentrates, providing 6 375 kg DM of pasture supplemented with 730 kg DM of concentrate per cow per year, with an additional 120 kg DM of concentrate per cow during the dry season.

Table 5.7. Metabolizable energy content and price of different feed sources

Feed source	Metabolizable energy (MJ/kgDM)	Price (R/kgDM)
Pasture	7.5	1.1
Silage	9.2	3.5
Concentrate	10.5	5.6

5.2.2.6. Breeding method:

The influence of the breeding method on herd profitability was assessed by comparing natural service, which is practiced in the base situation, with artificial insemination (AI) as an alternative. The price of AI varies depending on the quality of semen, and logistics involved with its delivery to the farm and its storage. In the current evaluation, a price of R 450 per insemination for average quality semen, including the charge for insemination was used (personal communication: Dr. Vincent Fhulufhelo Ramukhithi, ARC Animal Production, Irene). The number of AI services per conception was varied from 1 to 4, in order to determine the impact of the efficiency of AI on smallholder herd profitability,

5.2.2.7. Source of replacement heifers:

Two different heifer replacement strategies were evaluated for their impact on smallholder herd profitability, and these are presented in Table 5.8. The current practice of raising replacement heifers on farm was compared with buying-in replacement heifers of varying genetic quality. The genetic quality of the heifers was reflected in first lactation milk yield, and the heifer purchase price was commensurate with quality.

Table 5.8. Scenarios for the average first lactation milk yield of herd replacement heifers per year

Replacement source	Milk yield level (litres/cow/year)	Description of milk yield level
Raised	3 501.2	Base (average)
Bought in	3 501.2	Similar to base
	3 551.2	Replacement heifers superior to base by 50 litters
	3 601.2	Replacement heifers superior to base by 100 litters

5.3. Results

The results are mostly presented graphically, showing the revenue (TR) and costs (TC) associated with each scenario. Economic returns (gross margins) for each model are expressed as ZAR per cow in the herd per year. Detailed costs, and revenue items are contained in Appendices B.1- B.9 for more information.

5.3.1. Milk yield

Figure 5.1.1 shows the production costs, and revenues for varying levels of milk yield. Variation in revenue is attributable to the different quantities of milk available for marketing, and the costs associated with the production of those respective quantities is reflected by the total costs. Milk yield below 3 300 litres per cow is associated with negative gross margins (i.e. non-profitability). Positive gains in gross margins (GM) were achieved as milk yield per cow increased. This was due to the growth in revenue far outstripping the escalation in costs. A 15%

increase in milk yield per cow, resulted in a 13.8% increase in revenue, compared to a 2.7% increase in costs.

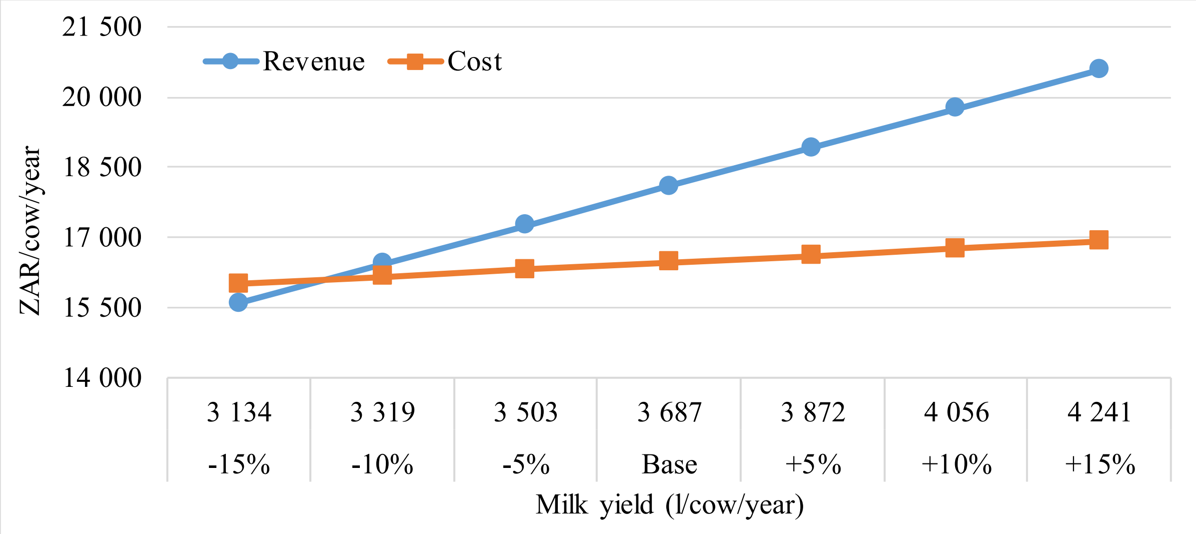

Figure 5.1.1: Effects of varying levels of milk yield per cow per year on production cost and revenue per cow per year

The sensitivity of gross margins to changes in prices of milk, and feed, for different levels of milk yield, are presented in Figure 5.1.2. At a milk price of R5.00/l all the simulated levels of milk yield are profitable (i.e. positive GM). The converse occurs if the price drops to R 4.10/l. On the other hand, all the simulated milk yield levels become profitable, when the feed price/kg DM is reduced to R 4.50/kgDM. At a feed price of R6.70/l only milk yields higher than 3 500 l/cow/year result in positive GM.

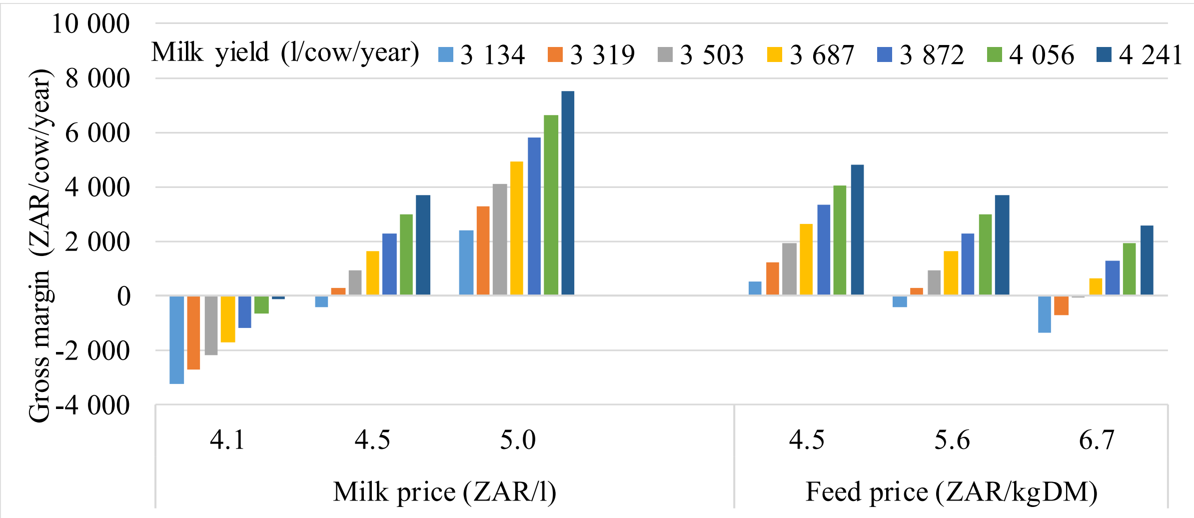

Figure 5.1.2: Sensitivity of gross margins for different levels of milk yield (l) to milk and feed prices

5.3.2. Live weight

Figure 5.2.1 presents the effects of cow live weight (LW) on herd profitability. Altering cow live weight remarkably influences herd profitability, with higher live weight being associated with lower herd profitability. Gross margins decrease from R1 626.60 to –R495.30 per cow per year as the cows' live weight increases from 450 to 517.5 kg. This is due to an exponential increase in cow maintenance costs, and marginal increase in revenue from the sale of cull cows. The break-even point is approximately 500 kg LW, demonstrating the maximum weight above which the enterprise becomes non-viable. On the other hand, GM increase exponentially from R1 626.60 to R3 761.60 per cow per year as LW decreases from 450 kg to 383 kg.

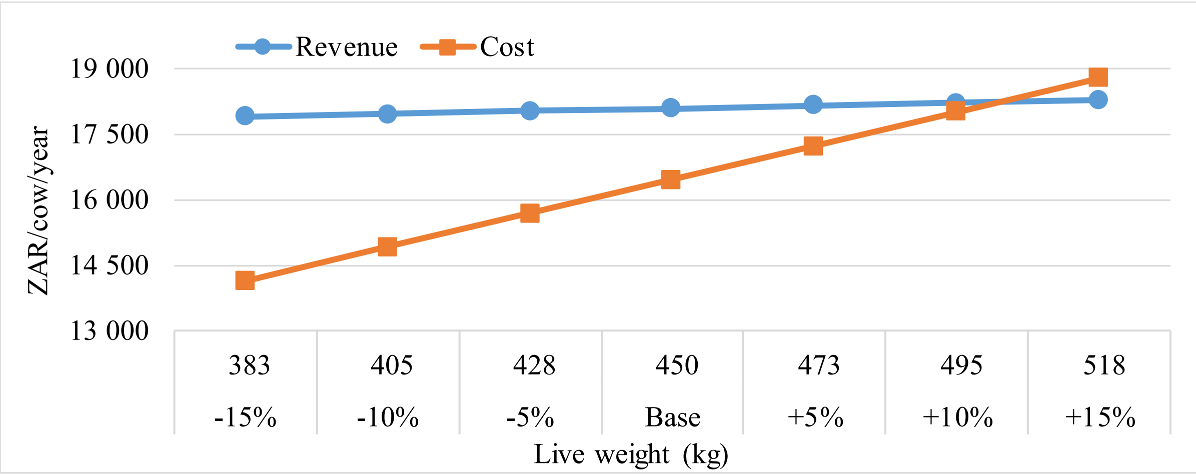

Figure 1.2.1: Effects of cow mature live weight on herd production cost, and revenue per cow per year

The sensitivity of LW to milk and feed prices is illustrated in Figure 5.2.2. If the milk price drops to R4.10/l, it would not be viable to farm with cows heavier than 450 kg. A feed price of R6.70/kg DM would, on the other hand, reduce the break-even point for live weight to 450 kg.

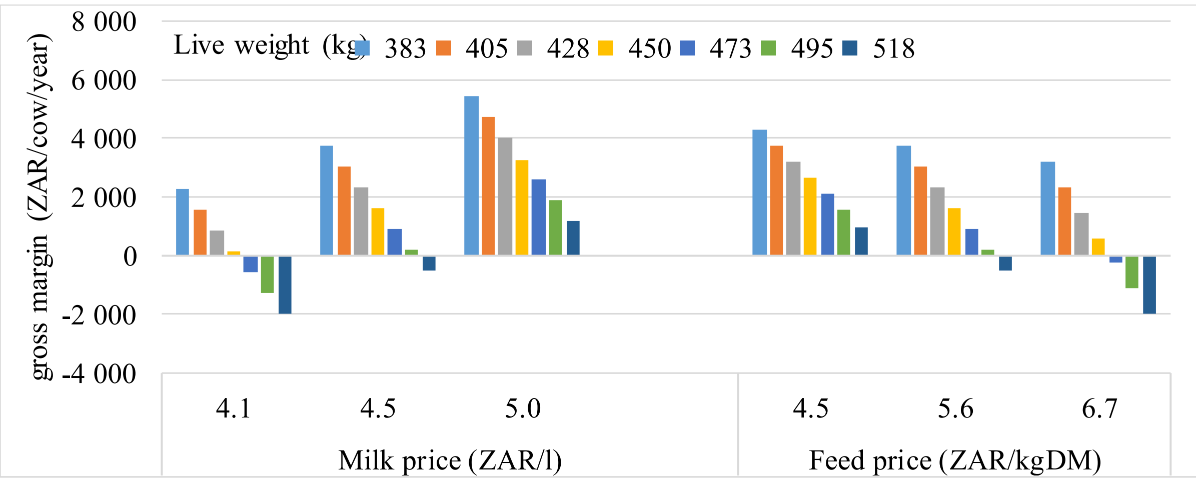

Figure 5.2.2: Sensitivity of gross margins of different cow live weights to milk and feed prices

5.3.3. Age at first calving and calving interval

The economic effects of varying AFC and CI are presented in Figure 5.3.1. According to the model used, revenue is not directly affected by changes in AFC and CI, hence the flat graph for revenue. An increase in AFC from 29 months (base situation) to 31 months decreases GM by R445.50/cow/year. Alternatively, extending calving interval by 60 days from the base situation (420 days) reduces GM by R543.50/cow/year.

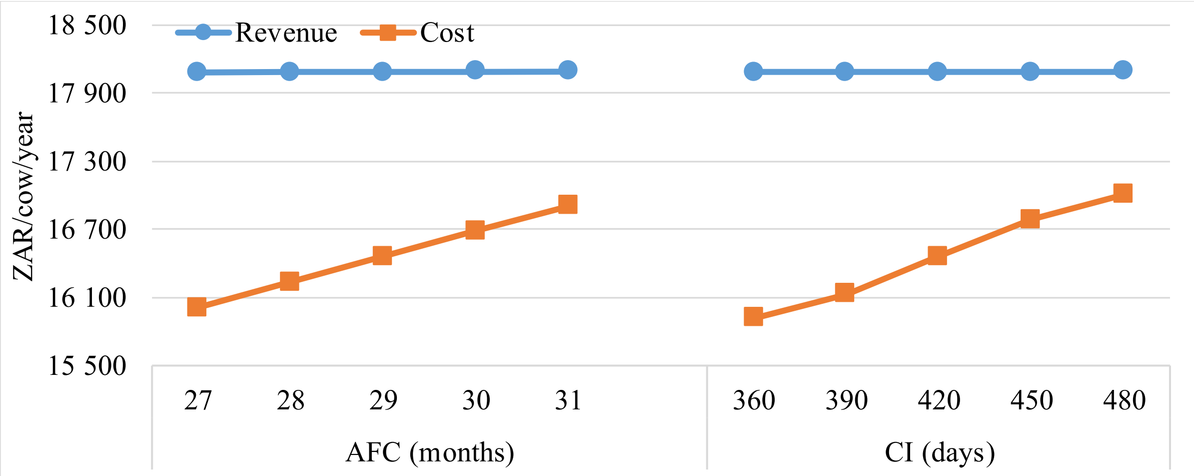

Figure 5.3.1: The effects of alternative age at first calving and calving interval on production cost and revenue per cow per year

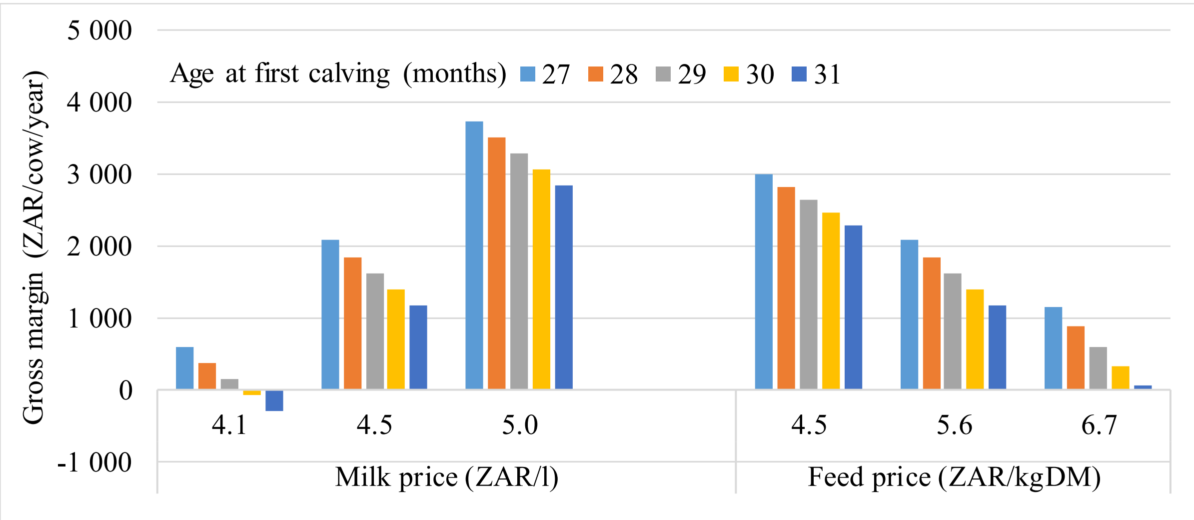

Figure 5.3.2: Sensitivity of gross margins of different ages at first calving to milk and feed prices

Both age at first calving, and calving interval are sensitive to the prices of milk, and feed (Figures 5.3.2 and 5.3.3). If the price of milk drops to R 4.10/l a positive GM would only be realized for AFC equal to or less than 29 months or CI less than or equal to 420 days. Although it results in a sharp decline in GM, a rise in feed price from R 5.60 to R 6.70/kgDM did not lead to non-profitability, for the AFC ranges simulated in the current study.

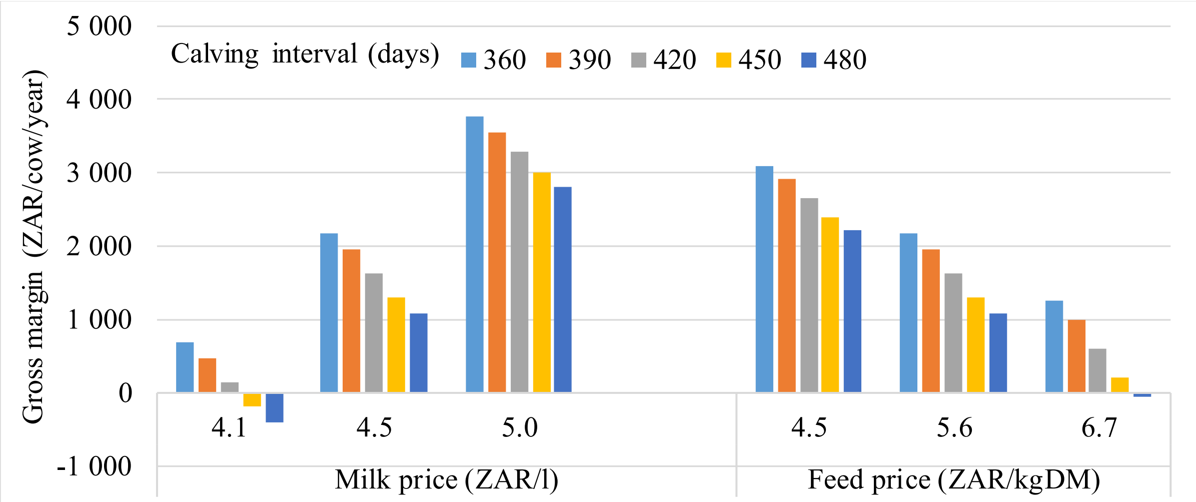

Figure 5.3.3: Sensitivity of gross margin for different calving intervals to milk and feed price

5.3.4. Replacement rate (longevity)

There is a direct relationship between herd replacement rate (RR), and cow longevity, as high culling rates (poor longevity) implies high replacement rates. This relationship is shown in Table 5.9, for the parameters used in the current study.

Table 5.9. Relationship between replacement rate and longevity (herd life)

Parameter	**Base**	**Alternative**					
Replacement rate (%)	25.0	21.3	22.5	23.75	26.3	27.5	28.8
Longevity / herd life (months)	56.7	57.8	57.5	57.2	56.4	56.1	56.0

The effect of replacement rate on gross margin/cow per year is presented in Figure 5.4.1. A decrease in replacement rate (i.e. increased longevity) was associated with an improvement in herd GM, while increasing replacement rate from 25% (base situation) to 28.8% resulted in an erosion of R 601 (37%) in GM. Every 5% increase in longevity, compared to the base situation, resulted in an approximate 13% improvement in GM.

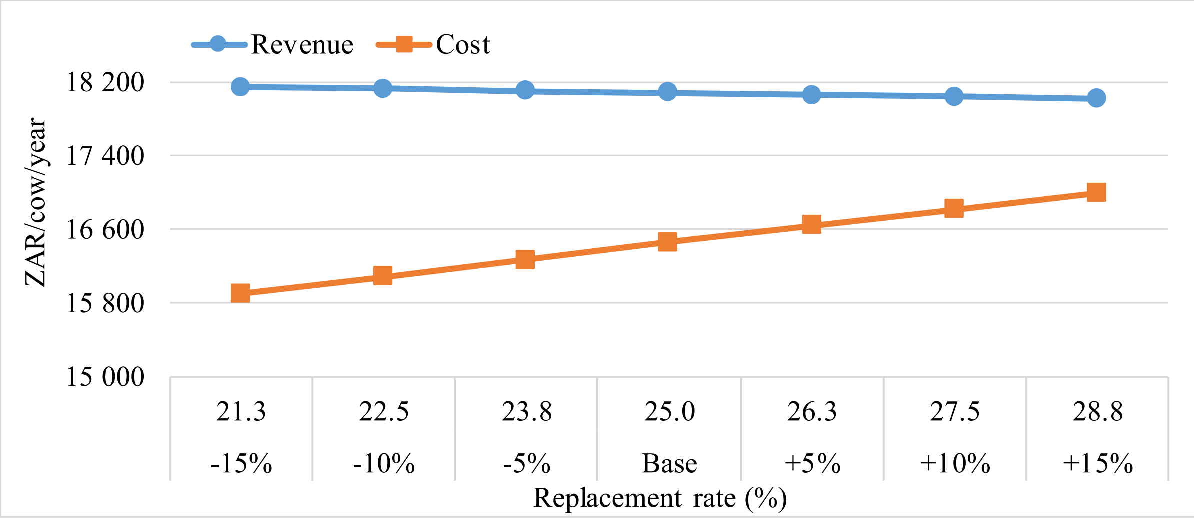

Figure 5.4.1: The effect of replacement rate on herd production cost, and revenue per cow per year

The sensitivity of gross margins for different replacement rates to changes in prices of milk and feed is shown in Figure 5.4.2. Gross margins decreased sharply as the milk price declined, becoming negative for all replacement rates higher than 25%, at the price of R4.10/l. Feed price, on the other hand, only resulted in non-profitability if it increased to R 6.70/Kg DM, and culling rate was higher than 27.5%.

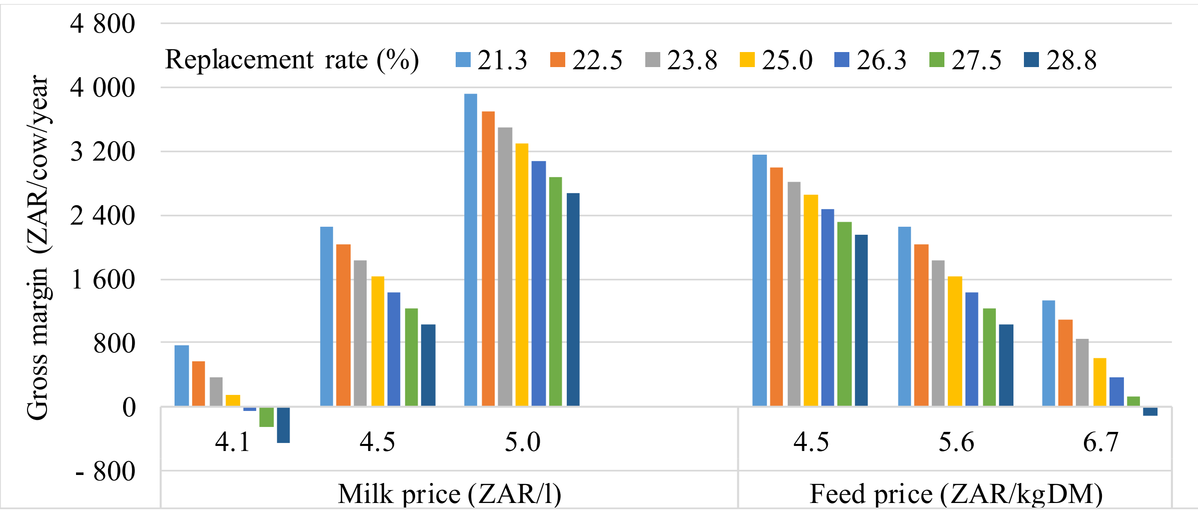

Figure 5.4.2: Sensitivity of gross margins for different replacement rates to milk and feed prices

5.3.5. Herd size

Figure 5.5.1 presents the effects of herd size on production costs and revenue. The difference between revenue and production costs increases exponentially as the number of cows per herd grows. An expansion of the herd size from 20 (base situation) to 30 results in a rise in GM from R1 626.60/cow/year to R1 884.70/cow/year (15.9%).

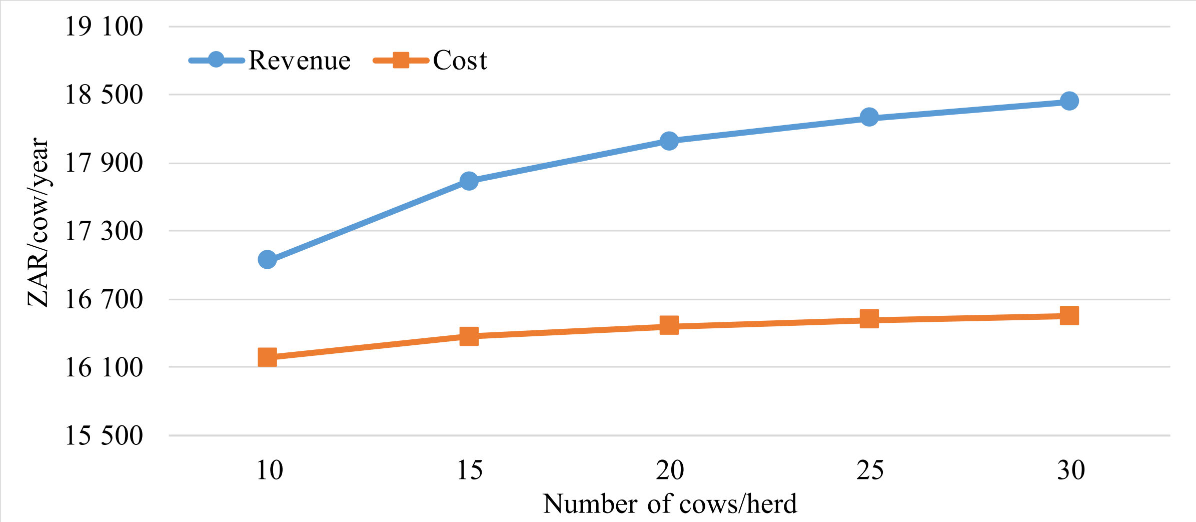

Figure 5.5.1: The effects of alternative herd size on production cost and revenue per cow per year

Figure 5.5.2 demonstrates the impact of variation in prices of milk/l, and feed/kgDM on gross margins of different herd sizes. Only herds with 20 cows or more are viable if the price of milk drops to R4.10/l. On the other hand, if the feed price increases to 6.70/kg DM, a herd with 10 cows or less will not be profitable.

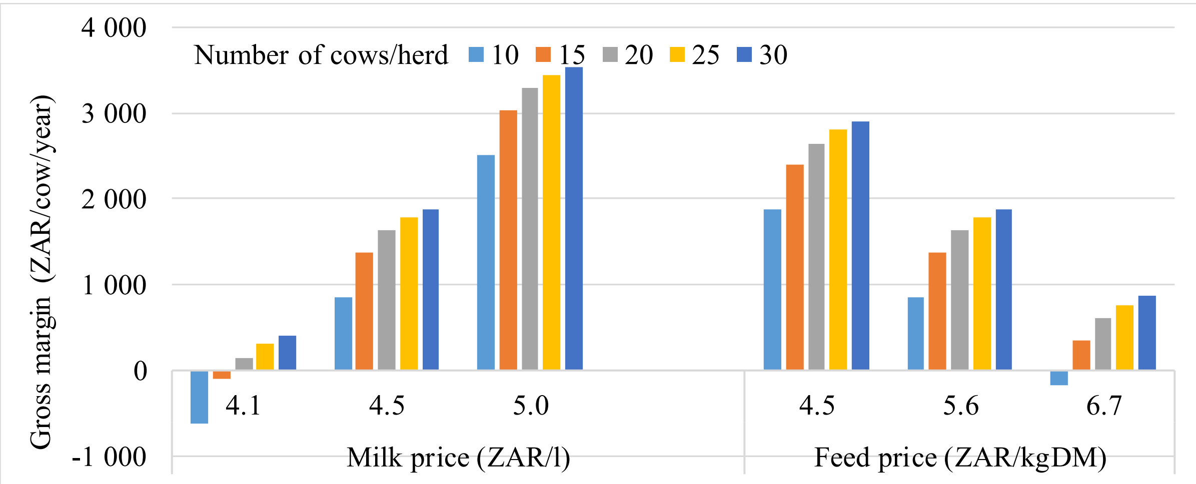

Figure 5.5.2: Sensitivity of gross margins for variable herd sizes to milk and feed prices

5.3.6. Feeding systems

The effect of different feeding systems on herd profitability are shown in Figure 5.6.1. The pasture only feeding system (P) results in a loss of R871/cow/year. The feeding system for the base situation (PSC) yields gross margins of R1 627/cow/year. On the other hand, the pasture plus silage (PS) feeding system has GM of R755/cow/year. The highest gross margins (R1 712/cow/year) were obtained for the PC system (pasture supplemented with concentrate).

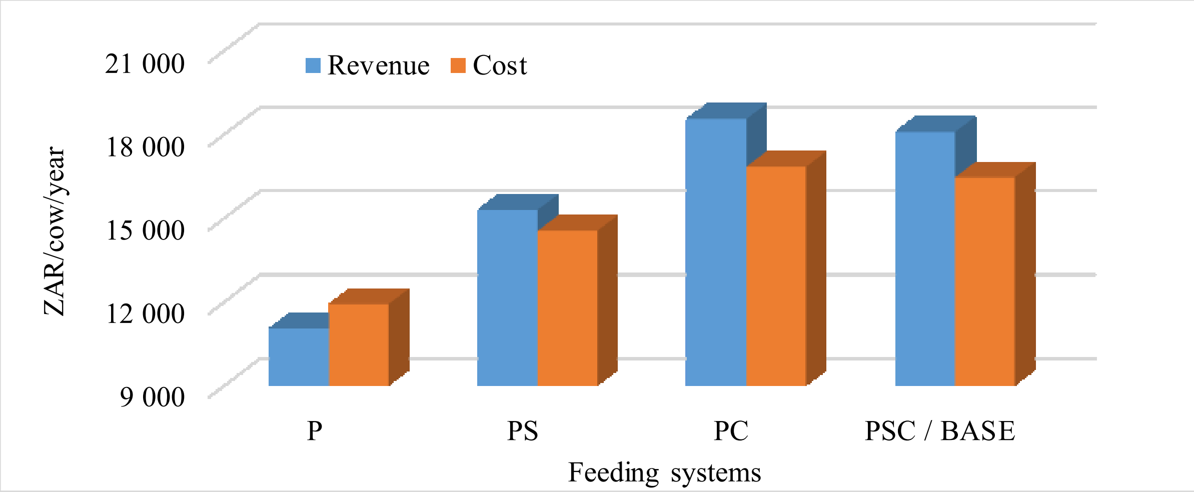

Figure 5.6.1: The effects of different feeding systems on production cost and revenue per cow per year

The sensitivity of profitability of the different feeding systems to variation in prices of milk (ZAR/l) and feed (ZAR/kgDM) is illustrated in Figure 5.6.2. A reduction in the milk price to R4.10/l results in the P and PS systems being unprofitable, with the P system only becoming profitable at R5 per liter. As expected, increasing the price of feed had a negative effect on profitability, for all feeding systems. The P system was the most affected, followed by PC.

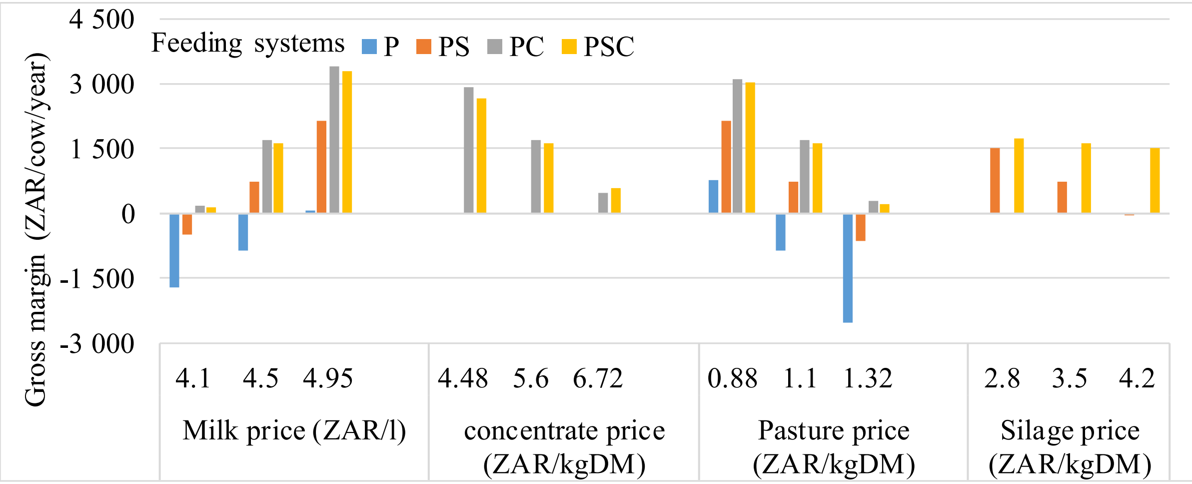

Figure 5.6.2: Sensitivity of gross margins of alternative feeding systems to milk and feed prices

5.3.7. Breeding methods

Figure 5.7.1 presents the annual herd revenue and production costs per cow, when using either natural service (NS) or artificial insemination (AI) for breeding. Since the breeding method will not have an immediate effect on production levels, revenue was assumed to be the same across all the breeding methods and scenarios. The estimated annual gross margin is R1 627/cow/year for NS. The estimated annual gross margins for different scenarios of AI are R2

449, R1 999, R1 549 and R1 099/ cow/year for 1, 2, 3 and 4 services per conception, respectively.

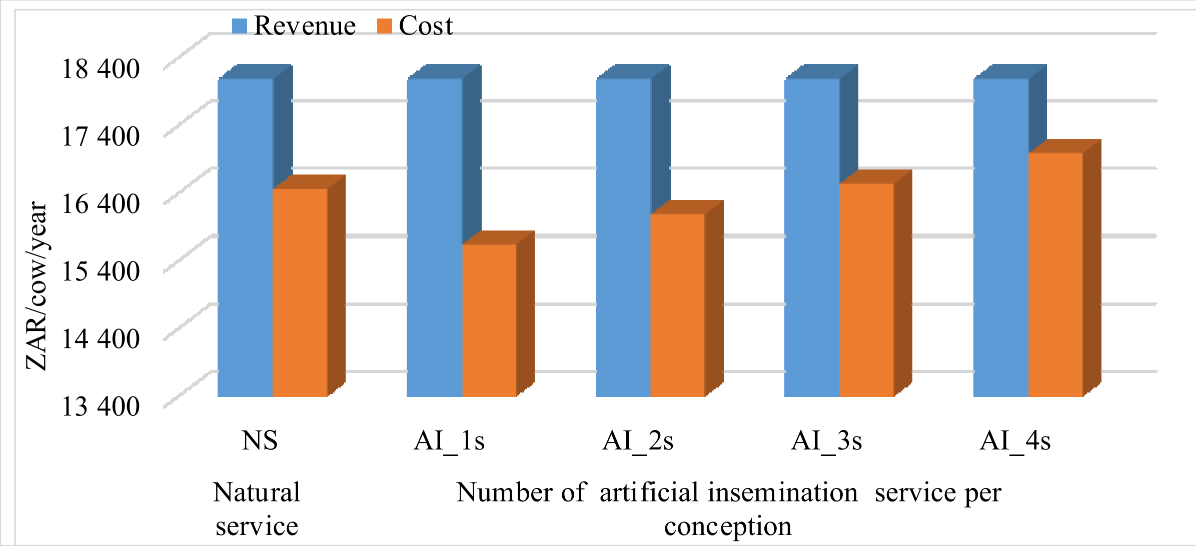

Figure 5.7.1: The effects of natural service and different number of artificial insemination per conception on production cost and revenue per cow per year

The sensitivity analysis showing the effects of variation in milk price and feed cost on the gross margins for NS and AI is shown in Figure 5.7.2. Higher milk prices and lower feed costs increased the economic benefit of both breeding methods. Four or more inseminations per conception leads to non-viability, when the milk price is low (R 4/l) and/or feed cost is high (R 6.70/kg DM).

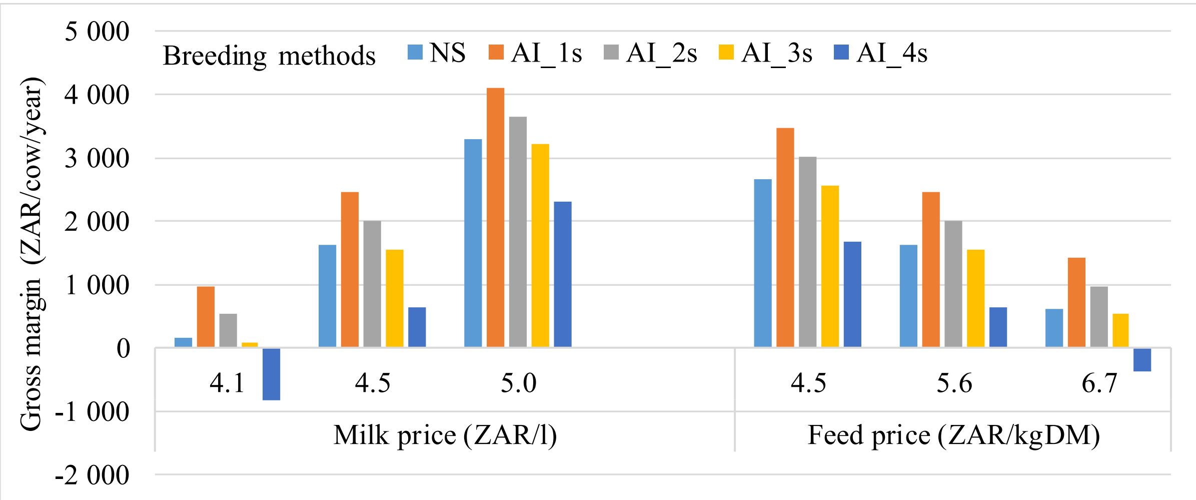

Figure 5.7.2: Sensitivity of gross margins for natural service and artificial insemination to milk and feed prices

5.3.8. Source of replacement heifers:

Figure 5.8.1 shows the effects of raising and buying-in herd replacement heifers on SH dairy herd economic performance. Differences in milk yield levels, and costs of herd replacements explain the variation in gross margins across the different scenarios. Raising replacement heifers results in lower gross margins compared to buying them in. If the bought-in heifers are of similar genetic merit to those reared on farm, the gross margins are R1 627/cow/year, and R2 034/cow/year, respectively, for raising, and buying in. The economic advantage of buying in replacement heifers increases as the genetic merit (i.e. milk yield) of the bought-in heifers improves.

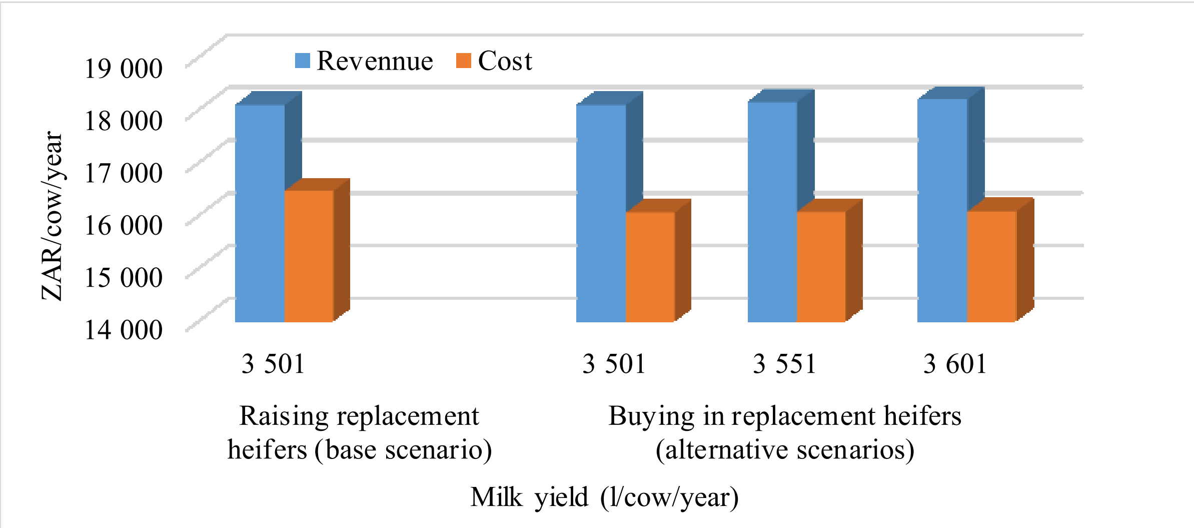

Figure 5.8.1: The effects of raising and buying in herd replacement heifers with different milk yield (l) levels on production costs and revenue per cow per year

Figure 5.8.2 presents the sensitivity of gross margins of replacement heifer sourcing options to variation in milk and feed prices. An increase in milk price from R4.10/l to R 5/l leads to an exponential increase in gross margins. On the other hand, an escalation in the price of feed results in a steady negative impact on gross margins. The response is, however, much more pronounced for the on-farm rearing option and, at the feed price of R4.48/kg DM, raising replacement heifers becomes more profitable than buying in.

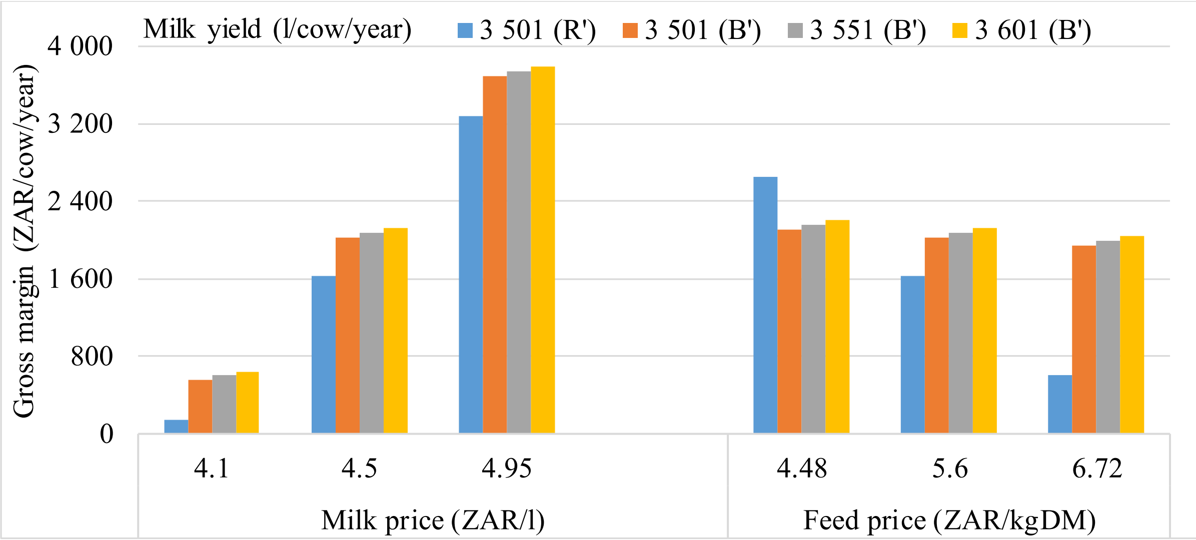

Figure 5.8.2: Sensitivity of gross margins of raising, and buying in, herd replacement heifers with different milk yield (l) levels to milk and feed prices.

5.4. Discussion

One of the best ways to encourage farmers to adopt sound herd production strategies is through a demonstration of their economic benefits (Salmon *et al.*, 2018). Hence, the main aim of this study was to identify herd management strategies that will maximize profit for the smallholder dairy production system in South Africa. Such strategies should minimize production costs and/or maximize revenue per unit of product value (Visscher *et al.*, 1994; Giordano *et al.*, 2011).

Preceding work on the current study (Abin *et al.,* 2018), identified poor cow performance as a major constraint to productivity of the smallholder dairy production system. The current results build on this research by investigating the impact of the different indicators of cow performance on herd profitability. Income from dairy farming is mainly determined by the yields of milk and its components, and its quality such as fat, and protein percentage as well as somatic cell count (Kahi & Nitter, 2004; Wolfova *et al.*, 2007; Banga *et al.*, 2014). Fitness traits, such as reproductive performance and survivability also influence dairy herd profitability, through their effects on income and production costs (Giordano *et al.*, 2011; Do *et al.*, 2013; Krpálková *et al.*, 2017). In addition to cow performance, it was also pertinent to determine the impact that different herd management practices, such as herd size, and feeding methods, would have on herd profitability.

5.4.1. Milk yield

Milk yield, and quality are the major determinants of revenue in dairy farming (Miglior *et al.*, 2017; Britt *et al.*, 2018). In the smallholder production system, milk is mainly sold in the informal market (Opoola *et al.*, 2019), with the price based on volume rather than compositional or hygienic quality. Hence, the current study focused on milk volume as one of the major indicators of cow performance. An increase in milk yield resulted in a lower increase in production costs relative to revenue from the additional milk. The increase in production costs reflects the cost of extra feed required to produce the additional milk. These findings agreed with Rodriguez *et al.* (2012), and VandeHaar *et al.* (2016), who attributed this trend to a non-linear increase in energy requirements that is associated with marginal increases in milk yield. There was a linear increase in revenue with an increase in milk yield, which explains the corresponding exponential increase in gross margin. Similar trends have been reported in other studies, especially when the milk price was based on volume (Kahi & Nitter, 2004; Khan, 2009; Kariuki *et al.*, 2019).

Low milk yield was identified as a constraint to SH herd profitability. The lowest gross margins (break-even point) were obtained when milk yield per cow was 3 319 litres per year. Thus, there is a large room to improve SH herd profitability by increasing milk yield. Sensitivity analysis showed that significant improvement in SH herd profitability can be achieved by increasing the price of milk or by using cheaper feeds. A higher milk price can be realized by selling to more lucrative markets or adding value to the milk. Research to investigate the use of cheaper, and nutritious feeds may also contribute towards improved profitability of SH dairy herds.

5.4.2. Live weight

There is a strong justification for the inclusion of live weight as a breeding objective for dairy cattle (Visscher *et al*., 1994; Kahi & Nitter, 2004; Banga *et al*., 2014). This is mainly due to its effect on maintenance costs. The marginal increase in revenue associated with an increase in cow mature live weight was due to the additional income from culled animals. There is, however, a substantial escalation in maintenance costs associated with increase in cow live weight, which outweighed the corresponding gains in revenue. Thus, herd gross margins decreased as cows' live weight increased. This concurred with other previous studies (Groen, 1989; Banga *et al.,* 2014; Wahinya *et al.,* 2015), and was a result of higher feed costs associated with the rise in energy requirements for maintenance. Spelman & Garrick (1997) and Lopez-

Villalobos *et al.* (2000) also reported that smaller cows were more profitable under a pasture-based feeding system.

The breakeven point for cow live weight was 500 kg, indicating that it would not be economically viable to farm with cows exceeding this weight under the smallholder dairy production system. Feeding levels in the smallholder production system are generally low, and consequently, the higher maintenance requirements associated with larger cows result in little energy being available for milk production, and other physiological needs.

5.4.3. Reproductive performance

Reproductive performance is one of the major determinants of dairy herd profitability (Esslemont & Peeler, 1993; Giordano *et al.*, 2011). Age at first calving (AFC), and calving interval (CI) are commonly used indicators of cow reproductive performance. These two traits are influenced by, among other factors, the management, and feeding of heifers and cows (Ribeiro *et al.*, 2008; Crowe *et al.*, 2018). Given the available data, the model used in the current study was only able to account for the economic effects of AFC, and CI on maintenance requirements (nutrient energy).

5.4.3.1. Age at first calving

Increasing AFC from 29 months (base situation) by 30 days resulted in a 13.7% reduction in gross margins. This negative economic effect of increasing AFC has been reported previously, and may be attributed to increased costs of rearing heifers (Kahi & Nitter, 2004; Meyer *et al.*, 2004; SeyedSharifi *et al.*, 2013). Reducing AFC below the current average (i.e. 29 months) would be a good management option towards the improvement of SH dairy herd profitability. A considerable increase in gross margins of R446.70/cow/year (27.5%) would be realized by reducing AFC by 60 days. A reduction in AFC to 27 months or less was also found to have a large economic impact by Pirlo *et al.* (2000) and Krpálková *et al.* (2014) as it would allow for optimal savings in heifer rearing costs. An added advantage of lower AFC, though not accounted for in the current model, is an increase in the number of productive days in a cow's lifetime (Ettema & Santos, 2004; Zavadilová & Štípková, 2013 Wathes *et al.*, 2014).

Reducing AFC is a complex, and challenging task. From a breeding perspective, it depends on the breeders' decisions, and age at first service, which are in part influenced by genetics (De Jong, 1998; Makgahlela *et al.*, 2008; Cooke *et al.*, 2013), and nutrition (Heinrichs *et al.*, 1993; Tozer & Heinrichs, 2001; Penev *et al.*, 2014). Due to the available additive genetic variation in age at puberty (Makgahlela *et al.*, 2008; Ghiasi *et al.*, 2011; Kelleher et al., 2016), selection could be used along with proper nutrition to achieve early calving in heifers. Proper nutrition is essential as it will improve body condition, and enhance growth and development of the reproductive system (Penev *et al.*, 2014).

5.4.3.2. Calving interval

Increasing calving interval was associated with a decrease in gross margins, which is in agreement with several other studies (Veerkamp *et al.*, 2002; Inchaisri *et al.*, 2011; Do *et al.*, 2013; Krpálková *et al.*, 2017). These results reflected a confounding economic effect of longer calving interval on herd profitability. An increase in CI, irrespective of herd production level, increase cows' maintenance cost, as explained by Banga *et al.* (2014).

Sensitivity analysis, however, indicated that the profitability of shorter CI was eroded by a drop in the milk price or increase in the price of feed. For example, if the price of milk is reduced to R4.10/l, herd profitability would only be realized with a calving interval equal to or less than 420 days. Factors such as high milk price, and lower feed cost may relatively dilute the effects of different levels of CI, and improve herd profitability.

The widely recommended CI for profit maximization is 365 days (Esslemont *et al.*, 2001; Evans *et al.*, 2006; Ribeiro *et al.*, 2012). Thus, there is much room for improving CI in smallholder dairy herds in South Africa, from the current average of 420 days. This can be achieved through improved feeding, and breeding management, particularly during the transition period, to ensure early re-conception of cows. Poor feeding, on the other hand, leads to a deterioration in the cow's body condition, a delay in normal ovarian cyclicity, and an inhibition of follicular growth, and maturity (Butler, 2001; Llewellyn *et al.,* 2007; Berry *et al.*, 2016).

5.4.4. Replacement rate

Generally, replacement is intended to compensate for both voluntary, and involuntary culling, in order to maintain the herd size at a steady state or introduce improved genetics in the herd. A comprehensive analysis of reasons for replacement of cows under the smallholder production system was difficult due to a lack of appropriate data. Hence, in the present study, replacement was assumed to compensate for losses owing to both voluntary, and involuntary culling, so as to maintain herd size at a steady state.

Replacement rate is an indicator of cow longevity. A change in replacement rate (i.e. increased or decreased longevity) influences profitability through its effects on herd structure, and milk yield. Low culling rates are a reflection of high cow longevity, which positively impacts on herd profitability. Increased cow longevity was previously associated with higher profit in the high-input dairy cattle production system in South Africa (Banga *et al.*, 2013). The positive economic impact of increased longevity is mainly due to: i) an increase in average herd milk yield as a result of a larger proportion of higher producing older cows, ii) lower cost of energy requirements for growth due to a reduction in the proportion of younger cows, and iii) lower heifer rearing costs prompted by the reduced number of replacements needed to maintain the herd in a steady state (Kahi & Nitter, 2004; Banga *et al*., 2013; Liang & Cabrera, 2015).

High culling rates (i.e. lower longevity) reduced revenue through an increased proportion of younger cows within the herd. The revenue lost due to high culling is generally not compensated for by the gains from the sale of cull cows. Thus, high replacement rate is a risk to smallholder dairy herd profitability. This risk is particularly high when the milk price is low and/or the feed price is high, as demonstrated by the sensitivity analysis. Smallholder dairy farmers should, therefore, adopt management strategies to minimize replacement (i.e. prolong cow longevity). A sound approach is to use cows that are better adapted to the relatively harsh smallholder production system.

5.4.5. Herd size

Capital investment costs were not included in this analysis, and the focus was on comparing different herd sizes, given a constant set of fixed costs (e.g. labour, mortgage/rent, equipment maintenance, electricity and transport), and with feed costs as the main variable cost. Larger herd size was associated with higher profitability per cow, primarily due to the dilution of fixed costs with increasing herd size. This result supported economies of scale for the improvement of smallholder dairy herd profitability, which was in agreement with some previous studies (Von Keyserlingk *et al.*, 2013; Krpálková *et al.*, 2016), and consistent with the current trend within the dairy industry (Thornton, 2010; Lacto data, 2019). Increasing cow numbers would, however, not be an easy strategy to improve SH dairy herd profitability, as it would require considerable capital outlay; thus, it should be considered with caution. It may also cause land degradation, since smallholder dairy farming relies mainly on natural pastures (Thornton, 2010). Increasing revenue through improved cow performance is, therefore, a more appealing option to improve herd profitability for smallholder dairy farmers.

5.4.6. Feeding systems

Generally, dairy cattle farmers rely on different feed sources to formulate their feeding systems, which directly influence cows' performance, and eventually herd profitability. Under the natural pasture-based system, farmers often have to provide additional feed as a supplement to improve milk production (Roche *et al.*, 2006). It was, therefore, necessary to evaluate the effects of different supplementary feeds on the pasture-based smallholder system. The results provide information that may assist SH farmers to adopt feeding strategies that will improve the biological, and financial performance of their herds. Four different feeding systems were simulated to determine their comparative effects on herd profitability. The substitution rule was applied to the base situation, to form alternative feeding systems, for simplicity, and ease of adoption.

The feeding system based on pasture only (P) had the lowest total production costs, and revenue; however it was unprofitable, with gross margins of -R871.00/cow/year. The highest production costs were incurred when pasture was supplemented with concentrate only (PC). In terms of profitability, PC had the highest gross margins (R1 712.20), followed by PSC (R1 626.60), then PS (R754.80). Similar economic effects of different feeding systems were also observed in earlier research by Tozer *et al.* (2003), Aguilar-Pérez *et al.* (2009), and Ashfield *et al*. (2014).

The different feeding systems varied in nutritional (ME) content; hence they elicited variable levels of milk production. Dietary energy is an essential factor affecting the dairy cow's metabolic ability for maintenance, growth, pregnancy, and milk production (ARC, 1980; AFRC, 1993; Macdonald *et al.*, 2017) as used in the current model. The dietary energy consumed by a dairy cow is inherently directed to fulfill maintenance requirements prior to milk production, and other physiological activities (Bauman *et al.*, 1980; Lucy, 2000). Consequently, the production potential of dairy cows cannot be fully expressed in a situation with a limited supply of energy, such as the P system. The negative gross margin for the P system is therefore a reflection of its poor feed quality that resulted in exceptionally low milk yield.

Milk production increased with supplementation of pasture with silage only (PS), silage plus concentrate (PSC), and concentrate only (PC), due to increased availability of metabolisable energy for milk production. Cows on the PC system produced 2.8% more milk than those on the PSC system. Conversely, milk yield under the PSC system was 42.4%, and 16.8% higher than on the P, and PS systems, respectively. The value of the additional milk produced more than compensated the cost of supplementation; hence the increase in gross margins. Pasture plus concentrate (PC), and PSC feeding systems was economically more resilient as shown by sensitivity analysis. Supplementation of natural pasture with silage (PS) may be the only supplementation option for farmers who cannot afford concentrates. This system resulted in lower production costs but lower gross margins compared to PSC, and PC.

5.4.7. Breeding methods:

Dairy farmers may use either a natural service bull or artificial insemination (AI) to maintain their production process. Despite the benefits of AI, its adoption remains low among smallholder dairy farmers in developing countries. For example, in a study carried out in Zambia, it was reported that, depending on the province, only between 22% and 35.1% of smallholder farmers used AI (Kawambwa *et al.*, 2014). The presumed high cost of AI was cited as one of the reasons behind its low adoption (Mwanga *et al.,* 2019). The current study therefore aimed to compare the impact of using natural service bulls vs. AI on smallholder herd profitability. This knowledge may contribute in guiding smallholder farmers to decide on an appropriate breeding practice that would increase their herd profitability.

In the current study, a herd using artificial insemination attained higher annual gross margins (R1 999/cow/year) than NS (R1 627/cow/year), when the insemination rate was 2 inseminations per conception ,which represents a 22.9 % economic advantage. Similar economic advantages of AI over NS service were reported by Valergakis *et al*. (2007), and Lima *et al*. (2010). The high cost of acquiring, and feeding a breeding bull was identified as one the major constraint when using natural service (Ribeiro *et al.*, 2012).

However, an increase in the number of AI services per conception could shift the economic advantage towards NS, as observed in the current study. A higher number of inseminations per conception increased the production costs, and resulted in a downward trend in gross margins from R1 627/cow/year in the base herd (NS) to R649/cow/year for a herd with an average of 4 AI services per conception. The high costs associated with the need for many AI inseminations per conception, often forces smallholder farmers to opt for natural service (Murage & Ilatsia, 2011; Ojango *et al.*, 2017). It can therefore be suggested that the introduction of services such as training of smallholder farmers on AI and subsidization of AI semen, would be necessary to capitalize on the benefits of AI.

5.4.8. Source of replacement heifers:

Selecting the source of replacement heifers is a strategic management decision that influences herd profitability. Buying-in replacement heifers resulted in a cost saving of about 2.5% compared to raising them. The main reason for this difference was the high feeding costs associated with raising calves, which could range between at 48.5 to 64% of the heifer's rearing costs (Gabler *et al.*, 2000; Boulton *et al.*, 2015). When the feed price decreased from R5.60 to R4.50 per kgDM, raising replacement heifers became more profitable than buying in replacement heifers. Practically, this is difficult to achieve as cheaper and good quality feed is not often readily available to smallholder farmers (Bebe 2003; Ojango *et al.*, 2017).

The evaluation of herd replacement strategies also considered the genetic quality of replacement heifers, in terms of milk production potential. This is because heifers' milk yield has a direct impact on herd profitability through its effect on first lactation milk yield, and herd lifetime productivity (Le Cozler *et al.*, 2008; Heinrichs *et al.*, 2013; Liang & Cabrera, 2015). As expected, the advantage of herd replacements was bigger if bought-in heifers were of higher genetic quality than those raised on farm. Good quality heifers, however, tend to be more expensive, which presents a challenge to SH farmers.

5.5. Conclusion and recommendations

The aim of this study was to evaluate alternative herd production models for the improvement of SH dairy herd profitability in South Africa, using a normative, and deterministic herd model. Models were based on the current production environment within the smallholder dairy cattle production system in South Africa. The results of this research may, however, also be of use in decision making in other smallholder dairy production systems in Sub-Saharan Africa. The current study has revealed that profitability of SH dairy herds can significantly be influenced by cow performance, and management practices. In general, the models were found to be sensitive to the prices of milk, and feed. This was expected, since milk is the major contributor to income, and feed is the main variable cost. Thus, besides aiming for sound cow performance, and optimal management practices, SH farmers need to explore markets with higher milk prices as well as source cheaper feeds. Based on the model developed in the current study, it can be concluded that low milk yield (volume), large cow body size, late AFC, longer CI, and high replacement rate have a negative impact on SH dairy herd profitability. The best models for improvement of SH dairy herd profitability, based on a combination of factors considered in the current study, may be summarized as follows:

- Farmers need to improve individual animal performance through higher milk yields in order to increase herd profitability.
- Farmers need to farm with small or medium sized dairy cows to minimize cow maintenance costs.
- Smallholder dairy farmers should properly manage heifer rearing to decrease AFC, as well as manage milking cows to reduce CI. Monitoring body condition score to ensure that cows maintain satisfactory BCS during, and after pregnancy, is crucial.
- Farmers should attempt to reduce replacement rate by increasing cows' longevity. They should decrease the percentage of first-lactation cows to increase herd average milk production.
- Smallholder dairy farmers could increase their herd profitability through expansion of herd size. Despite the likely benefits of larger herd size, the huge initial capital cost would be an obstacle for smallholder famers. The impediments may include the capital cost for the purchase of more cows, extra land, and infrastructure such as milking facilities. A possible option for applying such a strategy would be through an amalgamation of different SH dairy herds under cooperatives or societies. This will enhance the opportunity to pool resources from individual farmers.
- Supplementation of pasture is an important driver in improving SH dairy herd profitability.
- Smallholder farmers can minimize costs by using AI, especially if they can achieve a high conception rate per service. Subsidization of an AI program is therefore necessary to aid SH dairy farmers to benefit from AI.
- Buying in replacement heifers is a good strategy for SH farmers to decrease production costs and optimize herd profitability.
- From a practical standpoint, it is unlikely that any single strategy will aid SH dairy farmers to fully realize the potential of their herds. It is therefore recommended that the different strategies be adopted in combination.

References

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. 50, 1479-1484.

AFRC (Agricultural &Food Research Council), 1993. Energy and protein requirements of ruminants. An advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients. CAB INTERNATIONAL, Wallingford, UK.

Aguilar-Pérez, C., Ku-Vera, JC, Centurion-Castro, F., Garnsworthy, P.C., 2009. Energy balance, reproduction and milk production in grazing crossbred cows in the tropics with and without cereal supplementation. Livest. Sci. 122, 227-233.

ARC (Agricultural Research Council), 1980. The nutrient requirements of grazing livestock. Commonwealth Agricultural Bureau, London.

Armengol, R. & Fraile, L., 2018. Descriptive study for culling and mortality in five high-producing Spanish dairy cattle farms (2006-2016). Acta Vet Scand.60, 2-11.

Ashfield, A., Wallace, M., Prendiville, R. & Crosson, P., 2014. Bioeconomic modelling of male Holstein-Friesian dairy calf-to-beef production systems on Irish farms. Ir. J. Agric. Food Res. 53, 133-147.

Bach, A., Terré, M. & Vidal, M., 2020. Symposium review: Decomposing efficiency of milk production and maximizing profit. J. Dairy Sci. 103, 5709-5725.

Banga, C.B., 2009. The development of breeding objectives for Holstein and Jersey cattle in South Africa. (Ph.D. thesis, University of the Free State, Bloemfontein, South Africa).

Banga, C., Neser, F. & Garrick, D., 2013. Derivation of Economic Values of Longevity for Inclusion in the Breeding Objectives for South African Dairy Cattle. International Conference on Agriculture and Biotechnology IPCBEE, IACSIT Press, Singapore DOI: 10.7763/IPCBEE. 2013. 60, 63-79.

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

Bauman, D.E. & Currie, W.B., 1980. Partitioning of nutrients during pregnancy and lactation: a review of mechanisms involving homeostasis and homeorhesis. J. Dairy Sci. 63, 1514-1529.

Bebe, B.O., 2003. Herd dynamics of smallholder dairy in the Kenya highlands. (PhD Thesis, Wageningen Agric. University, Wageningen, The Netherlands).

Berry, D.P., Friggens, N.C., Lucy, M. & Roche, J.R., 2016. Milk production and fertility in cattle. Annual review of anim. biosci, 4, 269-290.

Boulton, A.C., Rushton, J. & Wathes, D.C., 2015. A Study of Dairy Heifer Rearing Practices from Birth to Weaning and Their Associated Costs on UK Dairy Farms. Open J. Anim. Sci. 5, 185-197.

Britt, J.H., Cushman, R.A., Dechow, C.D., Dobson, H., Humblot, P., Hutjens, M.F., Jones, G.A., Ruegg, P.S., Sheldon, I.M. & Stevenson, J.S., 2018. Invited review: Learning from the future-A vision for dairy farms and cows in 2067. J. Dairy Sci. 101, 3722-3741.

Butler, W.R., 2001 Nutritional effects on resumption of ovarian cyclicity and conception rate in post-partum dairy cows. Anim. Sci. Occas. Publ. 26, 133-145.

Cooke, J. S., Cheng, Z., Bourne, N. E. & Wathes, D. C., 2013. Association between growth rates, age at first calving and subsequent fertility, milk production and survival in Holstein-Friesian heifers. Open J. Anim. Sci. 3, 1-12.

Crowe, M.A., Hostens, M. & Opsomer, G., 2018. Reproductive management in dairy cows-the future. Irish Vet. J. 71, 2-13.

De Jong, G., 1998. Index for daughters' fertility in the Netherlands. Interbull Bull., 18: 102-105.

Dekkers, J.C.M., 1991. Estimation of economic values for dairy cattle breeding goals: Bias due to sub-optimal management policies. Livest. Prod. Sci. 29, 131-149.

Diakité, Z.R., Corson, M.S., Brunschwig, G., Baumont, R. & Mosnier, C., 2019. Profit stability of mixed dairy and beef production systems of the mountain area of southern Auvergne (France) in the face of price variations: Bioeconomic simulation. Agric. Syst.171, 126-134.

Dillon, J.L. 1992. The Farm as a Purposeful System, Miscellaneous Publication No. 10, Department of Agricultural Economics and Business Management, University of New England, Australia.

Do, C., Wasana N., Cho, K., Choi, Y., Choi, T., Park, B. & Lee, D., 2013. The effect of age at first calving and calving interval on productive life and lifetime profit in Korean Holstein. Asian-Australas. J. Anim. Sci., 26, 1511-1517.

Esslemont, R.J. & Peeler, E.J., 1993. The scope for raising margins in dairy herds by improving fertility and health. British Veterinary Journal 149, 537-547.

Esslemont, R.J., Kossaibati, M.A. & Allcock, J., 2001. Economics of fertility in dairy cows. In: Fertility in the High Producing Dairy Cow, BSAS Occasional Publication No. 26, pp. 21-29.

Ettema J, & Santos, J.E.P., 2004. Impact of age at calving on lactation, reproduction, health, and income in firstparity Holsteins on commercial farms. J. Dairy Sci. 87, 2730-2742.

Evans, R.D., Wallace, M., Shalloo, L., Garrick, D.J., & Dillon, P., 2006. Financial implications of recent declines in reproduction and survival of Holstein-Friesian cows in spring-calving Irish dairy herds. Agric. Syst. 89, 165-183.

Gabler, M.T., Tozer, P.R., & Heinrichs, A.J., 2000. Development of a cost analysis spreadsheet for calculating the costs to raise a replacement dairy heifer. J. Dairy Sci. 83, 1104-1109.

Ghiasi, H., Pakdel, A., Nejati-Javaremi, A., Mehrabani-Yeganeh, H., Honarvar, M., Gonzalez-Ricio, O., Carabano, M.J. & Alenda, R., 2011. Genetic variance components for female fertility in Iranian Holstein cows. Livest. Sci. 139, 277-80.

Giordano, J. O., Fricke, P.M., Wiltbank, M.C. & Cabrera, V. E., 2011. An economic decision-making support system for selection of reproductive management programs on dairy farms. J. Dairy Sci. 94, 6216-6232.

Goddard, M.E. & Grainger, C., 2004. A review of the effects of dairy breed on feed conversion efficiency-An opportunity lost. Science Access, 1, 77-80.

Groen, A.F., 1989. Cattle breeding goals and production circumstances. (Fokdoel in de rundveefokkerij en produktie-omstandigheden), (Ph.D. Thesis, Department of Farm Management and Department of Animal Breeding, Wageningen Agricultural University, Wageningen, The Netherlands).

Heinrichs, A.J. & Vazquez-Anon, M., 1993. Changes in first lactation dairy herd improvement records. J. Dairy Sci. 76, 671-675.

Heinrichs, A.J. Jones, C.M., Gray, S.M., Heinrichs, P.A., Cornelisse, S.A. & Goodling, R.C., 2013. Identifying efficient dairy heifer producers using production costs and data envelopment analysis. J. Dairy Sci. 96, 7355-7362.

Inchaisri, C., Jorritsma, R., Vos, P.L.A.M., Van Der Weijden, G.C. & Hogeveen, H., 2011. Analysis of the economically optimal voluntary waiting period for first insemination. J. Dairy Sci. 94, 3811-3823.

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.

Kariuki, C.M., van Arendonkc, J.A.M., Kahid, A.K. & Komena, H., 2019. Deterministic simulations to determine the impacts of economic and noneconomic breeding objectives on sustainable intensification of developing smallholder dairy farms. Livest. Sci. 226, 7-12.

Kawambwa, P., Hendriksen, G., Zandonda, E. & Wanga, L., 2014. Business Viability assessment study of small holder dairy farming in Zambia. Wageningen, Alterra Wageningen UR (University & Research centre).

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.

Khan, M.K.I., 2009. Development of models for the genetic improvement of dairy cattle under cooperative dairying conditions in Bangladesh: (a thesis presented in partial fulfillment of the requirements for the degree of Doctor of Philosophy in animal Breeding and Genetics at Massey University, Palmerston North, New Zealand).

Kristensen, E., Østergaard, S., Krogh, M.A. & Enevoldsen, C., 2008. Technical indicators of financial performance in the dairy herd. J. Dairy Sci. 91, 620-631.

Krpálková, L. Cabrera, V. E., Kvapilík, J., Burdych, J. & Crump, P., 2014. Associations between age at first calving, rearing average daily weight gain, herd milk yield and dairy herd production, reproduction, and profitability. J. Dairy Sci. 97, 6573-6582.

Krpálková, L., Cabrera, V.E., Kvapilík, J. & Burdych, J., 2016. Dairy farm profit according to the herd size, milk yield, and number of cows per worker. Agric.Econ-Czech, 62, 225-234.

Krpálková, L., Syrůček, J., Kvapilík, J. & Burdych, J., 2017. Analysis of milk production, age at first calving, calving interval and economic parameters in dairy cattle management. Mljekarstvo. 67, 58-70.

Lacto data, 2019 Statistics: A Milk SA publication compiled by the milk producers' organization. 22, 1-32. www.milksa.co.za.

Le Cozler, Y., Lollivier, V., Lacasse, P. & Disenhaus, C., 2008. Rearing strategy and optimizing first-calving targets in dairy heifers: a review. Anim., 2, 1393-1404.

Liang, D. & Cabrera, V.E., 2015. Optimizing productivity, herd structure, environmental performance, and profitability of dairy cattle herds. J. Dairy Sci. 98, 2812-2823.

Llewellyn, S., Fitzpatrick, R., Kenny, D.A., Murphy, J.J., Scaramuzzi, R.J. & Wathes, D.C., 2007. Effect of negative energy balance on the insulin-like growth factor system in pre-recruitment ovarian follicles of postpartum dairy cows. Reprod. 133, 627-639.

Lima, F.S., De Vries, A., Risco, C.A., Santos, J.E.P., & Thatcher, W.W., 2010. Economic comparison of natural service and timed artificial insemination breeding programs in dairy cattle. J. Dairy Sci. 93, 4404-4413.

Lopez-Villalobos, N., Garrick, D.J., Holmes, C.W., Blair, H.T., & Spelman, R.J., 2000. Effects of Selection and Crossbreeding Strategies on Industry Profit in the New Zealand Dairy Industry. J. Dairy Sci. 83,164-172.

Lucy, M.C., 2000. Regulation of ovarian follicular growth by somatotropin and insulin-like growth factors in cattle. J. Dairy Sci. 83, 1635-1647.

Macdonald,K.A., Penno,J.W., Lancaster, J.A.S., Bryant, A.M., Kidd, J.M. & Roche, J.R., 2017. Production and economic responses to intensification of pasture-based dairy production systems. J. Dairy Sci. 100, 6602-6619.

Makgahlela, M.L., Banga, C.B., Norris, D., Dzama, K. & Ngambi, J.W., 2008. Genetic analysis of age at first calving and calving interval in South African Holstein cattle. Asian Journal of Animal and Veterinary Advances, 3, 197-205.

Masuku, B.B. & Belete, A., 2014. Economic Efficiency of Smallholder Dairy Farmers in Swaziland: An Application of the Profit Function. J. Agric. Stud. 2, 132-146.

Mbuthia, J.M., Rewe, T.O. & Kahi, A.K., 2015. Breeding objectives for pigs in Kenya. II: economic values incorporating risks in different smallholder production systems. Trop. Anim. Health Prod. 47, 361-367.

Meyer, M.J, Everett, R.W. & van Amburgh, M.E., 2004. Reduced age at first calving: effects on lifetime production, longevity, and profitability. In: 'Dairy Day 2004'. Ed: Srevenson, J.S., Kansas State University: Tempe, AZ. pp. 42-52.

Miglior, F., Fleming, A., Malchiodi, F., Brito, L.F, Martin, P. & Baes, C.F., 2017. A 100-Year Review: Identification and genetic selection of economically important traits in dairy cattle. J. Dairy Sci. 100, 10251-10271.

Muntswu, E.A., Chitura, T., Abin, S.A. & Banga, C.B. 2017. Characterization of emerging and smallholder dairy production systems in South Africa. In: Proc. of the 50th Annual Congress of the SA Society for Animl Science, Port Elizabeth, 18-21 September 2017.

Murage, A.W. & Ilatsia, E. D., 2011. Factors that determine use of breeding services by smallholder dairy farmers in Central Kenya, Trop Anim Health Prod. 43, 199-207.

Mwanga, G., F.D.N. Mujibi, Z.O. Yonah, and M.G.G. Chagud. 2019. Multi-country investigation of factors influencing breeding decisions by smallholder dairy farmers in sub-Saharan Africa. Trop. Anim. Health Prod. 51, 395-409.

Ojango, J.M.K., Mrode, R., Okeyo, A.M., Rege, J.E.O., Chagunda, M.G.G. & Kugonza, D.R. 2017. Improving smallholder dairy farming in Africa. In: Achieving sustainable production of milk. Safety, quality and sustainability. Ed: Belzen, N. van, Cambridge, UK: Burleigh Dodds Science Publishing Limited. 2, 371-396.

Opoola, O., Mrode, R., Banos, G, Ojango, J., Banga, C., Simm, G. & Chagunda, M.G.G., 2019. Current situations of animal data recording, dairy improvement infrastructure, human capacity and strategic issues affecting dairy production in sub-Saharan Africa. Trop. Anim. Health Prod. 51, 1699-1705.

Penev, T., Vasilev, N., Stankov, K., Mitev, J. & Kirov, V., 2014. Impact of heifer's age at first breeding and first calving on some parameters of economic effectiveness at dairy cattle farms. Int. J. Curr. Microbiol. App. Sci, 3, 772-778.

Pirlo, G., Miglior, F. & Speroni. M., 2000. Effect of age at first calving on production traits and on difference between milk yield returns and rearing costs in Italian Holsteins. J. Dairy Sci. 83, 603-608.

Ribeiro, A.C., McAllister, A.J., & de Queiroz, S.A., 2008. Profitability measures of dairy cows. Revista Brasileira De Zootecnia-Brazilian J. Anim. Sci. 37, 1607-1616.

Ribeiro, E.S., Galvão, K.N., Thatcher, W.W., & Santos, J.E.P., 2012. Economic aspects of applying reproductive technologies to dairy herds. Anim Reprod. 9, 370-387.

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

Rodriguez, L.A., Bethard, G., Tomlinson, D., & McGilliard, M., 2012. Impact of milk yield, herd size, and feed efficiency on economic change between and within California dairies from 2006 through 2010. J. Anim. Sci. 90(E-Suppl.1). (Abstr.).

Salmon, G., Teufel, N., Baltenweck, I., van Wijk, M., Claessens, L. & Marshall, K., 2018. Trade-offs in livestock development at farm level: Different actors with different objectives. Glob. Food Sec. 17, 103-112.

Sánchez, Z., Galina, C.S., Vargas, B., Romero, J.J. & Estrada, S., 2020. The Use of Computer Records: A Tool to Increase Productivity in Dairy Herds. Anim. 10, 2-16.

SeyedSharifi1, R, Shadparvar, A.A. & Zadeh, N.G.H., 2013. Estimation of economic values for some traits in dairy herds of Iran using computer simulation. Tech. J. Engin. & App. Sci. 3, 2036-2041.

Seyedsharifi, R., Ghadimi, M., Hedayat Evrigh, N., Seifdavati, J., Boustan, A. & Abdi Benamar, H., 2018. Economic evaluation in traditional and industrial livestock with different levels of milk production in Ardebil province with emphasis on risk criteria. Kafkas Univ Vet Fak Derg, 24, 681-689.

Spelman, R.J. & Garrick, D.J. 1997. Effect of live weight and differing economic values on responses to selection for milk fat, protein, volume, and live weight. J. Dairy Sci. 80:2557-2562.

Thornton, P.K., 2010. Livestock production: recent trends, future prospects. Review. Phil. Trans. R. Soc. B. 365, 2853-2867.

Tozer, P.R. & Heinrichs, A.J., 2001. What affects the costs of raising replacement dairy heifers: A multiple- component analysis. J. Dairy Sci. 84, 1836-1844.

Tozer, P.R., Bargo, F. & Muller, L.D., 2003. Economic Analyses of Feeding Systems Combining Pasture and Total Mixed Ration. J. Dairy Sci. 86, 808-818.

Valergakis, G. E., Arsenos, G. & Banos, G., 2007. Comparison of artificial insemination and natural service cost effectiveness in dairy cattle. Anim. 1, 293-300.

VandeHaar, M.J., Armentano, L.E., Weigel, K., Spurlock, D.M., Tempelman, R.J. & Veerkamp, R., 2016. Harnessing the genetics of the modern dairy cow to continue improvements in feed efficiency1. J. Dairy Sci. 99, 4941-4954.

Veerkamp, R.F., Dillon, P., Kelly, E., Cromie, A.R. & Groen, A.F., 2002. Dairy cattle breeding objectives combining yield, survival and calving interval for pasture-based systems in Ireland under different milk quota scenarios. Livest. Prod. Sci. 76, 137-151.

Visscher, P.M., Bowman, P.J. & Goddard, M.E., 1994. Breeding objectives for pasture based dairy production systems. Livest. Prod. Sci. 40, 123-137.

Von Keyserlingk, M.A., Martin, N.P., Kebreab, E., Knowlton, K.F., Grant, R.J., Stephenson, M., Sniffen, C.J., Harner III, J.P., Wright, A.D. & Smith S.I., 2013. Invited review: Sustainability of the US dairy industry. J. Dairy Sci. 96, 5405-5425.

Wahinya, P.K., Okeno, T.O., Kosgey, I.S., & Kahi, A.K. 2015. Economic and Biological Values for Pasture-Based Dairy Cattle Production Systems and their Application in Genetic Improvement in the Tropics. J. Anim. Pro. Adv. 5, 664-675.

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

Wolfová, M., Wolf, J., Kvapilík, J. & Kica, J., 2007. Selection for profit in cattle: I: Economic weights for purebred dairy cattle in the Czech Republic. J. Dairy Sci. 90, 2442-2445.

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.

CHAPTER VI

Critical review and Recommendations

6.1. Introduction

Cow productivity, and herd profitability are major factors determining the ability of a dairy farm to contribute to food security and socio-economic development. Improvement of cow productivity, and herd profitability depends on the implementation of appropriate production strategies (Oltenacu & Algers, 2005; Doole, 2014; Getaneh *et al.*, 2017). Many of the commonly accepted strategies, and interventions may, however, not be suitable for certain production systems, such as smallholder farming. There is a general lack of information required to support decision making for achieving maximum herd profitability in the South African smallholder dairy production system.

Due to the dynamic, and complex nature of livestock production systems, researchers have used a variety of tools to measure livestock productivity, and guide improvement policies. Benchmarking, and bio-economic simulation modelling are some of these decision supporting tools (Jalvingh, 1993; Banga, 2009; Goni *et al.*, 2015).

The aim of this thesis was to evaluate alternative management options for the improvement of the smallholder dairy cattle production system, using benchmarking, and simulation modelling. Three research objectives (Chapters III to V) were formulated, to achieve the main aim of this thesis. Firstly, benchmarking was conducted to determine cow productive performance in the South African smallholder dairy production system, relative to the high-input commercial production system. Secondly, a bio-economic model was developed to mimic, and understand the impact of current management practices, and cow performance on the economic performance of smallholder dairy herds. Finally, alternative production strategies were evaluated for their impact on smallholder dairy herd profitability. The practical implications of the results generated, and how they can be utilized to develop the smallholder dairy production system, will be discussed in this chapter.

6.2. Benchmarking of dairy cows' performance in low-input smallholder and high-input production systems in South Africa

Benchmarking at a farm level entails developing an understanding of the performance, and profitability of the herd operation, through comparison with an appropriate standard within the industry. Farmers can thus assess their herd's performance, detect performance gaps, and adopt the best practices for improvement of the enterprise. In South Africa, the primary dairy industry is dualistic in nature, ranging from a low-input low-output smallholder production system (SH) to a high-input highly productive (H) commercial production system. The H system acted as an appropriate standard to which the SH system could be compared to determine its production potential. This exercise also served to identify opportunities, or focus areas, for developing the commercial SH dairy production system.

Productive and reproductive performance:

Both productive, and reproductive performance were inferior for dairy cows in the SH production system compared to those in the H system. Cows in the smallholder system produced significantly less milk, and milk components than those in the high-input system. The poor productive performance of dairy cows in the SH dairy cattle production system was also clearly manifested in low-peaking, and flat lactation curves. Additionally, lactation length (LL), which is an indicator of lactation persistency (Fadlelmoula *et al.*, 2007), was significantly shorter in the SH dairy system compared to the high-input system. These results indicate an inadequacy in the productivity, and consequently constrained profitability in the SH system. Although several factors, including climate, and disease, may influence dairy cattle production performance (Liu *et al.*, 2019), inadequate nutrition was clearly the major reason causing low milk production in the studied SH system.

Dairy cows are genetically subjected to a greater risk of negative energy balance (NEB) particularly during the transitional period, around the third trimester, and early lactation period (Opsomer, 2015). The extent of the negative energy balance (NEB), and its effects on milk production depends on the quantity, and quality of feed offered to the dairy cows (Delaby *et al.*, 2009, Remppis *et al.*, 2011, Urdl *et al.*, 2015). Restricted nutrient energy supply during this transitional period aggravates body tissue mobilization for cow maintenance, and milk production (Alphonsus & Essien, 2012; Maltz *et al.*, 2013). This is manifested by an extreme decline in body condition, low peaking, and poorly persisting lactation curves (Němečková *et al.*, 2015; Ferland *et al.*, 2018).

The poor reproductive performance of the smallholder dairy cows in the current study was demonstrated by late AFC, and longer CI. Generally, poor reproductive performance implies economic losses (Haworth *et al*, 2008; Giordano *et al.*, 2011). Late age at first calving and longer CI reduce lifetime productivity (milk yield and the number of calves born for replacement and sale), and increase production costs through an increase in rearing and breeding costs (Ribeiro *et al.*, 2012; Do *et al.*, 2013; Penev *et al.*, 2014).

The observed late AFC could mainly be attributed to poor feeding, particularly of energy, within the SH system. Underfeeding leads to energy deficiency for growth, which in turn reduces growth rate, delays age at puberty and increases age at calving in heifers (Bhatti *et al.*, 2007; Curtis *et al.*, 2018). Nutrient energy deficiency has also been recognized as one of the major factors affecting reproductive performance in dairy cows (Drackley & Cardoso 2014; Humer *et al.*, 2018). Insufficient nutrient energy for maintenance, milk production, and growth reduces nutrient load for reproduction, which leads to postpartum reproductive problems (Rodney *et al.*, 2018). It impairs folliculogenesis, uterine involution, and ovulation, causing silent heat, and prolongs the interval from calving to conception (Llewellyn *et al.*, 2007; Walsh *et al.*, 2011; Crowe *et al.*, 2018).

Somatic cell count:

Although milk somatic cell count is one of the most important indicators for monitoring udder health and milk quality (Mostert, 2007; Cinar *et al.*, 2015), its value is often overlooked in smallholder systems. This may be due to ignorance regarding its importance, as well as the absence of an economic incentive attached to this trait under the SH production systems. The level of somatic cell count in milk signifies the status of mammary health, with a higher level above 200,000 cells/ml indicating an immune response against intra-mammary inflammation or infections (Schukken *et al.*, 2003; IDF, 2013).

The estimated mean SCC for SH herds was higher than the recommended threshold, and also higher than that recorded in the high-input system. High SCC levels demonstrate stressful conditions related to poor management practices within the SH system. For instance, excessive environmental heat or cold, dirty barns and improper milking practices predispose cows to inflammation or mammary infections (DeLong *et al.*, 2017; Alhussien & Dang, 2018; Dalen *et al.*, 2019; Bach *et al.*, 2020). Therefore, higher levels of SCC suggest increased risk of udder damage among SH dairy cows. Damaged udders reduce milk production (Forsbäck, 2010; Li *et al.*, 2014; Sabistino *et al.*, 2020), predispose cows to involuntary culling, and finally, increase replacement costs (Sewalem *et al.*, 2006; Hadrich *et al.*, 2018). High SCC may also reduce the farm gate price for those SH farmers who may need to access mainstream formal market. This is probably because of its negative effect on milk shelf life and flavor (Li *et al.*, 2014; Murphy *et al.*, 2016). Thus, SCC is an important management tool that can be used to detect udder subclinical infection, avoid production losses and increase herd profitability (DeLong *et al.*, 2017; Dalen *et al.*, 2019).

This study has contributed towards identifying the opportunities for improving SH dairy cattle farming. These opportunities include improving milk production, age at first calving (AFC) and calving interval (CI). Improvement of these performance measures could be realized through improved feeding/supplementation (Crowe *et al.*, 2018). Improved feeding management will increase milk production, enhance growth and reproductive development in heifers for early breeding, before 16 months of age (Heinrichs *et al.*, 2013), and reduce the length of the re-conception period in cows to less than 85 days postpartum (Kaewlamun *et al.*, 2011). Improvement of milk composition quality, as well as somatic cell count, is also necessary although these are currently not considered in the milk payment system for smallholder producers. Improving these will open up opportunities for the SH farmers to improve their milk price by selling directly to processors who require good milk composition and hygienic milk.

6.3. Development of a herd simulation model for the smallholder dairy cattle production system

The aim of this part of the study was to develop a bio-economic simulation model of a typical smallholder (SH) dairy herd in South Africa, in order to evaluate alternative management interventions to improve SH dairy herd profitability. A positive, and normative smallholder herd model was developed by adapting a herd model that was previously developed for evaluation of the high-input commercial dairy production system in South Africa. The basic approaches for development of a model were applied (Dent & Anderson, 1971, Reinmuth & Dabbert, 2017), and these include the identification of:

- Major sub-systems
- Important components, and relationships within each sub-system
- Association between sub-systems
- Important environmental variables and
- Control points (e.g. management)

Several herd sub-models were identified and incorporated into the main model, as described in Chapter 4. The utility of a dairy herd model lies in its ability to simulate animals' nutrient requirements for maintenance, growth, pregnancy, and lactation/milk production. Nutrient requirements were estimated based on the principle of metabolizable energy requirements of dairy cows (AFRC, 1993). The model further integrated herd dynamics (e.g. herd structure), production costs associated with feeding, and other management aspects, and revenue from the sale of outputs, using a profit function. The inclusion of a profit function allowed the economic efficiency of each simulated production scenario to be evaluated. The model for an average smallholder herd in South Africa (current scenario) produced gross margins of R 1 626.60 per cow per year. The developed model generated baseline information on the relationships between the biological, and economic components of a typical SH dairy herd.

This type of herd model is suitable for research designed for supporting planning, and decision-making. The base model serves as a standard for comparison of individual herds, and a starting point for simulation of alternative production options. The biological, and management sub-models offer the possibility of investigating the impact of alternative production options on herd profitability. In order to achieve this, alternative production options were investigated by varying cow performance indicators and certain management practices on herd profitability.

6.4. The effects of alternative herd production options on smallholder dairy herd profitability

An important goal of system analysis is to improve the output across one or more individual farms of a given class (Woodward *et al.*, 2008). The benchmarking study and simulation model development were conducted to identify potential areas of improvement, in order to achieve impact on SH dairy herd profitability. Changes in these areas were simulated in the model, so as to evaluate alternative production strategies for the improvement of SH dairy herd profitability in South Africa. Alternative production options investigated included varying milk yield per cow, cow live weight, heifer's age at first calving, calving interval, herd size, replacement rate, feeding systems, source of replacement heifers, and breeding method. The gross margins obtained for each production option were assessed for their sensitivity to the prices of milk, and feed. Fluctuations in input and output prices are unpredictable exogenous production events that inevitably influence dairy herd profitability (Groen, 1989; Kahi & Nitter, 2004; Arriola, 2016); hence, the need to assess their impact on the various production options.

Milk yield and quality:

Low milk yield has been identified as one of the main reasons why dairy herds do not make a meaningful contribution to the socio-economic livelihoods of smallholder farmers in Sub-Saharan Africa (Ojango *et al.*, 2017). In the present study, farming was not viable if the milk yield dropped below 3 300 l/ cow/year; however, milk yield above 3687.40 l/cow/year was sufficient to offset up to a 48% increase in feeding costs. This underscores the importance of achieving high levels of milk yield, as a means of ensuring SH dairy herd profitability. High milk yield in dairy cattle could be achieved through proper feeding management, and stringent health measures such as control of somatic cell count in milk. Proper feeding, particularly during the pre-calving period, is a prerequisite for cows to maintain optimum body condition, and have sufficient body reserves to enable them to partition more nutrients to the mammary gland for milk production (Crookenden *et al.*, 2017; Ferland *et al.*, 2018; Bach *et al.*, 2020). Controlling SCC alleviates the potential economic losses associated with high SCC levels, due to their effect on milk yield, and quality (Gonçalves *et al.*, 2016; Hadrich *et al.*, 2018; Sabistino *et al.*, 2020).

Cows' mature live weight:

Cow mature live weight had a remarkable influence on SH dairy herd profitability. Heavier cows were associated with lower profitability, which is attributable to higher feeding costs to meet the increase in maintenance requirements. This points to the unsuitability of heavy cows for the SH pasture-based production system. Natural pasture-based feeding systems, which are predominant in the smallholder system, are typically low in nutritive value. Heavy cows, which have high maintenance requirements, are therefore likely to receive limited nutrients to support milk production in such a production environment. Such cows are also likely to suffer excessive losses in body condition during early lactation, which negatively impacts on milk production as well as performance, including an increased risk of reproductive complications (Němečková *et al.*, 2015; Ferland *et al.*, 2018; Humer *et al.*, 2018). Hence, smaller cows (less than 450 kg) are appealing for the SH production system, as they will improve both biological, and economic efficiency. Smaller framed cows required less energy for maintenance, and therefore, less cost, and more nutrient energy will be available for other physiological activities.

Age at first calving and calving interval

An increase in AFC or CI resulted in a reduction in profitability, due to an increase in production costs. The expected economic benefits from earlier AFC include a reduction in rearing costs (decreasing both monetary & managerial loads), earlier income from milk production, and the delivery of a calf for replacement or sale (Do *et al.*, 2013). Early AFC, below the current average of 29 months, should be a target for SH dairy farmers.

Dairy herd profitability was affected by calving interval, which is in agreement with several other studies (Dono *et al.*, 2013; Krpálková *et al.*, 2016b). Increasing calving interval led to higher maintenance costs, resulting in a reduction in herd profitability. This underscores the importance of sound reproductive performance in dairy production. Management practices should focus on keeping CI close 365 days (one year) for optimum economic performance. A major factor requiring attention is nutritional management, as insufficient nutrient energy supply is one of the most important factors related to poor reproductive performance. Insufficient energy intake during late gestation increases the length of postpartum anestrous, increases the incidence of silent heats, reduces subsequent pregnancy rate, and increases days dry (Humer *et al.*, 2018; Rodney *et al.*, 2018). Extremely long dry periods (e.g. beyond 85 days) are associated with high production costs due to an increase in maintenance costs, multiple inseminations, and treatments for reproductive failure (Chebel *et al.*, 2018).

Herd size

Results of the current study indicate that larger herd size is desirable, as it results in higher profitability. This concurs with the views advocating larger herd size for the sake of efficiency (Rodriguez *et al.*, 2012; Krpálková *et al.*, 2016a). However, the possibility for increasing herd size may be hindered by a shortage of agricultural land, water, grazing areas (Thornton, 2010), and the cost of upgrading infrastructure such as milking facilities. Thus, adopting alternative strategies such as increasing milk yield, while maintaining the current herd size, could be a more practical approach for smallholder farmers.

Replacement rate

Replacement rate, in this study, was equal to culling rate, in order to maintain a fixed herd size. As replacement rate (RR) increased, the annual herd gross margins decreased. High replacement rate is usually caused by high rates of involuntary culling, which mainly result from poor biological, and management efficiency (Ansari-Lari *et al.*, 2012; Shalloo *et al.*, 2014 De Vries & Marcondes, 2020). Common causes of involuntary culling are disease, infertility, leg and udder problems, and/or death (Ansari-Lari *et al.*, 2012; Armengol & Fraile, 2018; De Vries & Marcondes, 2020).

Involuntary culling can be reduced through improved management or genetics. Low replacement rate, which implies increased cow longevity, improves lifetime cow performance, and increases the opportunity for voluntary culling, such as culling of older cows with low producing ability. Smallholder dairy farmers can improve longevity by using animal genotypes that are more adapted to their typically harsh environmental conditions.

Feeding strategies

In order to become competitive, SH dairy farmers need to be informed regarding different feeding strategies, and their impact on animal performance, and herd profitability. Provision of supplementary feeds to increase milk production, and profitability is a common practice among pasture-based commercial dairy farmers.

The pasture-based feeding system, supplemented with 2kg DM of concentrate, produced the highest gross margins (GM), despite incurring the highest production costs. High GM attained for this feeding system was due to the higher level of energy supplied, which led to increased milk yield, with the greater revenue exceeding the increase in feed costs. This demonstrates the need to feed cows to achieve their production potential, in order to improve profitability, although this has cost implications. Those farmers who cannot afford concentrates can opt for silage, as a less expensive feed supplement.

Breeding methods

Selection of a suitable breeding method is critical for reproductive management in dairy farming. Artificial insemination (AI) is widely used in dairy herds worldwide, due to its numerous benefits such as increased rate of genetic gain, eradicating venereal diseases, more accurate dry-off dates, reduced incidence of dystocia, and increased safety of farm employees (Norman *et al.*, 2003; Vishwanath, 2003; Overton, 2005). Despite these benefits, SH dairy farmers mostly use natural service bulls, due to their perceived ease of management, and lower cost (Overton, 2005; Mwanga *et al.*, 2019). Besides some disadvantages relative to AI, maintaining service sires may pose management challenges such as low libido, risk to personnel, and more importantly, impaired herd genetic progress (Ribeiro *et al.*, 2012).

In this study, AI was generally the more profitable breeding strategy, due to its lower cost. However, an increased number of AI services per conception (>3 services/conception) led to an escalation in costs, leading to AI becoming more expensive than NS. Thus, AI will become more attractive, and economically justifiable for SH dairy farmers only if it is conducted efficiently, and achieves high conception rates. Wide adoption of AI by SH farmers could be achieved through subsidization of either the semen or insemination service. Efficient application of AI could be realized through training of the SH farmers, and provision of effective means to detect heat, such as heat patches. The success of AI also depends to a large extent on the nutritional management of the dairy herd. Poor nutritional management impairs reproductive performance, which is manifested in low AI conception rates (Humer *et al.*, 2018; Rodney *et al.*, 2018).

Heifer replacement method

The source, and quality of replacement heifers are important considerations in a dairy operation, as they influence overall herd productivity. Farmers can raise their own replacements or buy them in from external sources. These two heifer replacement options, and their impact on SH dairy herd profitability, were investigated in the current study.

Buying in replacement heifers was more profitable than rearing them on-farm. Rearing heifers on farm appeared to be a more expensive option for SH farmers, due to high feeding costs. The economic advantage of buying in replacements is greater when the genetic merit of the bought-in replacement heifers is superior to that of their predecessors. This advantage is, however, dependent on the heifers being fed properly, and calving in good body condition in order to realize their genetic potential (Le Cozler *et al.*, 2008; Hawkins, 2019). Availability of cheaper high quality heifers is therefore essential to improve SH dairy herd productivity, and profitability. In a situation where feed is not expensive, rearing high quality replacement heifers, bred through AI, would be a reasonable option. However, rearing replacement heifers is also demanding in terms of requirements for good management skills, and appropriate infrastructure (Boulton *et al.*, 2015; Hawkins, 2019), which are not always available on smallholder farms.

6.5. General conclusion

The results generated in this study contribute baseline knowledge that can assist in improving the smallholder dairy production system in South Africa, and sub-Saharan Africa in general. Benchmarking of the current performance of the smallholder dairy production system, against the commercial system, provided knowledge of the areas that require focus, and attention for the improvement of smallholder dairy herd profitability. A variety of scenarios within different models were simulated, to account for the wide range of production, and management environments that are found in Africa, and the profitability of each scenario was assessed. The results obtained can serve to support sound smallholder dairy herd management, as well as assist farmers to make informed decisions. This is of vital importance to the development of smallholder dairy farming in Sub-Saharan Africa, and will enable the smallholder dairy sector to contribute effectively to food security, job opportunities, and livelihoods. The recommended management options for improving SH dairy herd profitability are discussed in the following section.

6.6. General recommendations

Results emphasized the importance of improving SH cow productivity by increasing milk yield per cow per year above the current 3687.4 l, as well as reducing AFC below 29 months, and CI below 420 days. These interventions will increase SH herd profitability. Early AFC has the added advantage of reducing generation intervals, thus expediting genetic gain. These improvements could be achieved by using genetically superior animals, and adopting proper feeding management practices. Proper feeding is crucial for high producing cows, in order to satisfy their maintenance requirements, and ensure that sufficient nutrients are available for achieving their potential for milk production. It is also essential to feed heifers properly, so as to ensure their optimal growth, for early breeding in order to achieve young age at first calving. Sound nutritional management also serves to enhance cow body condition, which is necessary for improving productive, and reproductive performance.

The current feeding system for SH dairy herds could be improved by adopting appropriate supplementation programmes. Supplementation of natural pasture with concentrate, silage, or a combination of both, will increase nutrient energy supply, which will improve milk yield, and reproductive performance. Although pasture supplementation is expensive, the resultant improvement in cow performance would more than compensate the additional costs.

It is recommended that smallholder dairy farmers use breeds that can provide a balance between low production costs, and high milk yield (i.e. breeds that are adapted to the harsh smallholder production environment). Cows of small or medium body weight (below 500 kg mature live weight) are preferable, as they will minimize maintenance costs.

Smallholder farmers should embrace sound udder health management practices such as teat cleaning, and disinfection of the whole udder, in order to achieve good udder health. This will enhance herd profit through minimization of milk loss, and production costs.

Larger herd size will improve smallholder dairy herd profitability; however, this is difficult as it entails high capital investment. Smallholder farmers should focus on improving cow longevity, in order to reduce replacement rate. This will improve herd profitability by minimizing replacement costs, and increasing overall herd milk production. Alleviating the major causes of involuntary culling such as udder infection, and poor reproductive performance provides an opportunity to improve cows' longevity.

Provided that it is conducted efficiently, artificial insemination is more profitable, and therefore, preferred over natural service. In terms of sourcing herd replacements, it is advisable for smallholder farmers to buy-in replacement heifers, instead of raising their own. Besides being more cost-effective, buying in heifers provides an opportunity to improve herd genetics by ensuring that the replacement heifers are of superior genetic quality.

Overall, it is recommended that these strategies should be adopted in combination, in order to achieve maximum benefits. Continued animal performance recording (e.g. firstly basic recording of animal identity, and reproduction records, but also traits such as calving ease, and stillbirths, mastitis incidence, number of inseminations, veterinary costs etc.) will be vital for the regular, and accurate evaluation of herds' performance, and profitability.

Although this falls outside the scope of this study, it is recommended that the results of this study be utilized to build policy frameworks for developing the smallholder dairy sector, by stakeholders such governments, and non-governmental organizations. These could include supporting programmes such as AI, heifer replacement, and supply of production inputs (e.g. feed supplements, and veterinary services). Such policy frameworks would enable SH farmers to cope with the high transaction costs associated with purchasing of extra land, infrastructure, and supplementary feeding.

While the results generated in this thesis provide valuable information, further studies are needed. Such studies could include, for example, simulating additional scenarios such as one where the price of milk is based on volume as well as composition, and hygienic quality. Such analyses would be valuable to smallholder farmers who may wish to sell their milk on the formal market.

6.7. References

AFRC (Agricultural & Food Research Council), 1993. Energy and protein requirements of ruminants. An advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients. CAB International, Wallingford, UK.

Alhussien, M.N. & Dang, A.K., 2018. Milk somatic cells, factors influencing their release, future prospects, and practical utility in dairy animals: An overview, Vet. World, 11, 562-577.

Alphonsus, C. & Essien, I.C., 2012. The relationship estimates amongst milk yield and milk composition characteristics of Bunaji and Friesian × Bunaji cows. Afr. J. Biotechnol. 11, 8790-8793.

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. 3, 233-237.

Armengol, R. & Fraile, L., 2018. Descriptive study for culling and mortality in five high-producing Spanish dairy cattle farms (2006–2016). Acta Vet Scand.60, 2-11.

Arriola, J.C., 2016. Exploring opportunities for on-farm innovations in smallholder dairy systems of Michoacán, Mexico. (PhD thesis, Wageningen University, Wageningen, The Netherland).

Bach, A., Terré, M. & Vidal, M., 2020. Symposium review: Decomposing efficiency of milk production and maximizing profit. J. Dairy Sci. 103, 5709-5725.

Banga, C.B., 2009. The development of breeding objectives for Holstein and Jersey cattle in South Africa. (Ph.D. thesis, University of the Free State, Bloemfontein, South Africa).

Bhatti, S.A., Sarwar, M., Khan, M.S. & Hussain, S.M.I., 2007. Reducing the age at first calving through nutritional manipulations in dairy buffaloes and cows: A review. Pakistan Vet. J., 27, 42-47.

Boulton, A.C., Rushton, J. & Wathes, D.C., 2015. A Study of Dairy Heifer Rearing Practices from Birth to Weaning and Their Associated Costs on UK Dairy Farms. Open J. Anim. Sci. 5, 185-197.

Chebel, R. C., Mendonça, L.G.D. & Baruselli, P.S., 2018. Association between body condition score change during the dry period and postpartum health and performance. J. Dairy Sci. 101, 4595-4614.

Cinar, M., Serbester, U., Ceyhan, A. & Gorgulu, M., 2015. Effect of Somatic Cell Count on Milk Yield and Composition of First and Second Lactation Dairy Cows.

Crookenden, M.A., Walker, C.G., Heiser, A., Murray, A., Dukkipati, V.S.R., Kay, J.K., Meier, S., Moyes, K.M., Mitchell, M.D., Loor, J.J. & Roche, J. R., 2017. Effects of precalving body condition and prepartum feeding level on gene expression in circulating neutrophils. J. Dairy Sci. 100, 2310-2322.

Crowe, M.A., Hostens, M. & Opsomer, G., 2018. Reproductive management in dairy cows-the future. Irish Vet. J. 71, 2-13.

Curtis, G., Argo, C.M., Jones, D. & Grove-White, D., 2018. The impact of early life nutrition and housing on growth and reproduction in dairy cattle. PLoS ONE 13(2): e0191687. https://doi.org/10.1371/journal.pone.0191687.

Dalen, G., Rachah, A., Nørstebø, H., Schukken, Y.H. & Reksen, O., 2019. Dynamics of somatic cell count patterns as a proxy for transmission of mastitis pathogens. J. Dairy Sci. 102, 11349-11358.

Delaby, L., Faverdin, P., Michel, G., Disenhaus, C. & Peyraud, J.L., 2009. Effect of different feeding strategies on lactation performance of Holstein and Normande dairy cows. Animal, 3, 891-905.

DeLong, K.L., Lambert, D.M., Schexnayder, S., Krawczel, P., Fly, M., Garkovich, L. & Oliver, S., 2017. Farm business and operator variables associated with bulk tank somatic cell count from dairy herds in the southeastern United States. J. Dairy Sci. 100, 9298-9310.

Dent, J.B. & Anderson, J.R., 1971. Systems Analysis in Agricultural Management. John Wiley, Sydney.

De Vries, A. & Marcondes, M.I., 2020. Review: Overview of factors affecting productive lifespan of dairy cows. Anim. 14, s155-s164.

Do, C., Wasana, N., Cho, K., Choi, Y., Choi, T., Park, B. & Lee, D., 2013. The effect of age at first calving and calving interval on productive life and lifetime profit in Korean Holsteins. Asian Austral. J. Anim. Sci. 26, 1511-1517.

Doole, G.J., 2014. Economic feasibility of supplementary feeding on dairy farms in the Waikato region of New Zealand, New Zealand Journal of Agricultural Research, 57, 90-99.

Dono, G., Giraldo, L. & Nazzaro, E., 2013. Contribution of the calving interval to dairy farm profitability: results of a cluster analysis of FADN data for a major milk production area in southern Italy. Spanish J. Agric. Res. 11,857-868.

Drackley, J.K. & Cardoso, F.C., 2014. Prepartum and postpartum nutritional management to optimize fertility in high-yielding dairy cows in confined TMR systems. Anim. 8, 5-14.

Fadlelmoula, A.A., Yousif, I.A. & Abu Nikhaila, A.M., 2007. Lactation Curve and Persistency of Crossbred Dairy Cows in the Sudan. J. Appl. Sci. Res. 3, 1127-1133.

Ferland, M.C., Guesthier, M.A., Cue, R.I, Lacroix, R., Burgos, S.A., Lefebvre, D. & Wade, K.M., 2018. Effect of feeding system and grain source on lactation characteristics and milk components in dairy cattle. J. Dairy Sci. 101, 8572-8585.

Forsbäck, L., 2010. Bovine udder quarter milk in relation to somatic cell count. Focus on milk composition and processing properties. (PhD Dissertation, Swedish University of Agricultural Sciences, Uppsala).

Getaneh, A.M., Mekonnena, S.A. & Hogeveena, H., 2017. Stochastic bio-economic modeling of mastitis in Ethiopian dairy farms. Prevent. Vet. Med. 138, 94-103.

Giordano, J.O., Fricke, P.M., Wiltbank, M.C. & Cabrera, V.E., 2011. An economic decision-making support system for selection of reproductive management programs on dairy farms. J. Dairy Sci. 94, 6216-6232.

Gonçalves, J.L., Tomazi, T., Barreiro, J.R., Beuron, D.C., Arcari, M.A., Lee, S.H.I., Martins, C.M.D.M.R., Junior, J.P.A. & dos Santos, M.V., 2016. Effects of bovine subclinical mastitis caused by Corynebacterium spp. on somatic cell count, milk yield and composition by comparing contralateral quarters. Vet. J. 209, 87-92.

Goni, S., Muller, C.J.C., Dube, B. & Dzama, K., 2015. Reproductive performance of Jersey and Fleckvieh x Jersey heifers and cows maintained on a pasture-based feeding system. S. Afr. J. Anim. Sci. 45, 381- 385

Groen, A.F., 1989. Cattle breeding goals and production circumstances. (Fokdoel in de rundveefokkerij en produktie-omstandigheden), (Ph.D. Thesis, Department of Farm Management and Department of Animal Breeding, Wageningen Agricultural University, Wageningen, The Netherlands).

Hadrich, J.C., C. Wolf, C.A., Lombard, J. & Dolak, T.M., 2018. Estimating milk yield and value losses from increased somatic cell count on US dairy farms. J. Dairy Sci. 101, 3588-3596.

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. The Vet. Record 162, 643-647.

Hawkins, A.C., 2019. Evaluating costs associated with management decisions of replacement dairy heifers and their impact on the total rearing investment. Theses and Dissertations. Anim. Food Sci. 109. https://uknowledge.uky.edu/animalsci_etds/109.

Heinrichs, A.J., Jones, C.M., Gray, S.M., Heinrichs, P.A., Cornelisse, S.A. & Goodling, R.C., 2013. Identifying efficient dairy heifer producers using production costs and data envelopment analysis. J. Dairy Sci., 96. 7355-7362.

Humer, E., Petri, R.M., Aschenbach, J.R., Bradford, B.J., Penner, G.B., Tafaj, M., Südekum, K.H. & Zebeli, Q., 2018. Invited review: Practical feeding management recommendations to mitigate the risk of subacute ruminal acidosis in dairy cattle. J. Dairy Sci. 101, 872-888.

International Dairy Federation. 2013. Guidelines for the use and interpretation of bovine milk somatic cell counts (SCC) in the dairy industry. Bulletin of the International Dairy Federation. 466/2013. IDF, Brussels, Belgium.

Jalvingh, A.W., 1993. Dynamic livestock modelling for on farm decision support. (PhD thesis. Department of Farm Management and Department of Animal Breeding, Wageningen Agricultural University, Wageningen).

Kaewlamun, W., Chayaratanasin, R., Virakul, P., Ponter, A.A., Humblot, P., Suadsong, S., Tummaruk, P. & Techakumphu, M. 2011. Differences of Periods of Calving on Days Open of Dairy Cows in Different Regions and Months of Thailand. Thai J Vet Med. 41, 315-320.

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.

Krpálková, L., Cabrera, V.E., Kvapilík, J. & Burdych, J., 2016a. Dairy farm profit according to the herd size, milk yield, and number of cows per worker. Agric.Econ-Czech, 62, 225-234.

Krpalkova, L, Cabrera, V.E, Kvapilik, J. & Burdych, J., 2016b. Associations of reproduction and health with the performance and profit of dairy cows. Agric. Econ. 62, 385-394.

Le Cozler, Y., Lollivier, V., Lacasse, P. & Disenhaus, C., 2008. Rearing strategy and optimizing first-calving targets in dairy heifers: a review. Anim., 2, 1393-1404.

Li, N., Richoux, R., Boutinaud, M., Martin, P. & Gagnaire, V., 2014. Role of somatic cells on dairy processes and products: a review. Dairy Sci. & Technol. 94, 517-538.

Llewellyn, S., Fitzpatrick, R., Kenny, D.A., Murphy, J.J., Scaramuzzi, R.J. & Wathes, D.C., 2007. Effect of negative energy balance on the insulin-like growth factor system in pre-recruitment ovarian follicles of postpartum dairy cows. Reprod. 133, 627-639.

Liu, J., Li, L., Chen, X., Lu, Y. & Wang, D., 2019. Effects of heat stress on body temperature, milk production, and reproduction in dairy cows: a novel idea for monitoring and evaluation of heat stress-A review. Asian-Australas J. Anim. Sci. 32, 1332-1339.

Maltz, E., Barbosa, L.F., Bueno, P., Scagion, L., Kaniyamattam, K., Greco, L.F., De Vries, A. & Santos, J.E.P., 2013. Effect of feeding according to energy balance on performance, nutrient excretion, and feeding behavior of early lactation dairy cows. J. Dairy Sci. 96, 5249-5266.

Mostert, B.E. 2007. The suitability of test-day models for genetic evaluation of dairy cattle in South Africa (Doctoral dissertation, University of Pretoria Pretoria).

Murphy, S.C., Martin, N.H., Barbano, D.M. & Wiedmann, M., 2016. Influence of raw milk quality on processed dairy products: How do raw milk quality test results relate to product quality and yield? J. Dairy Sci. 99, 10128-10149.

Mwanga, G., F.D.N. Mujibi, Z.O. Yonah, and M.G.G. Chagud. 2019. Multi-country investigation of factors influencing breeding decisions by smallholder dairy farmers in sub-Saharan Africa. Trop. Anim. Health Prod. 51, 395-409.

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.

Norman, H.D., Powell, R.L., Wright, J.R. & Sattler, C.G., 2003. Timeliness and Effectiveness of Progeny Testing Through Artificial Insemination. J. Dairy Sci. 86, 1513-1525.

Ojango, J.M.K., Mrode, R., Okeyo, A.M., Rege, J.E.O., Chagunda, M.G.G. & Kugonza, D.R. 2017. Improving smallholder dairy farming in Africa. In: Achieving sustainable production of milk. Safety, quality and sustainability. Ed: Belzen, N. van, Cambridge, UK: Burleigh Dodds Science Publishing Limited. 2, 371-396.

Oltenacu, P.A., & Algers, B., 2005. Selection for increased production and the welfare of dairy cows: Are new breeding goals needed? Ambio 34:311-315.

Opsomer, G., 2015. Interaction between metabolic challenges and productivity in high yielding dairy cows. Jap. J. Vet. Res. 63, S1-S14.

Overton, M.W., 2005. Cost comparison of natural service sires and artificial insemination for dairy cattle reproductive management. Theriogen. 64, 589-602.

Penev, T., Vasilev, N., Stankov, K., Mitev, J. & Kirov, V., 2014. Impact of heifers age at first breeding and first calving on some parameters of economic effectiveness at dairy cattle farms. Int. J. Curr. Microbio. App. Sci. 3, 772-778.

Reinmuth, E. & Dabbert, S., 2017. Toward more efficient model development for farming systems research–An integrative review. Comput. Electron. Agric. 138, 29-38.

Remppis, S., Steingass, H., Gruber, L. & Schenkel, H., 2011. Effects of energy intake on performance, mobilization and retention of body tissue, and metabolic parameters in dairy cows with special regard to effects of pre-partum nutrition on lactation-A Review. Asian Austral. J. Anim. Sci. 24, 540-572.

Ribeiro1, E.S., Galvão, K.N., Thatcher, W.W. & Santos, J.E.P., 2012. Economic aspects of applying reproductive technologies to dairy herds. Anim Reprod. 9, 370-387.

Rodney, R.M., Celi, P., Scott, W., Breinhild, K., Santos, J.E.P. & Lean, I.J., 2018. Effects of nutrition on the fertility of lactating dairy cattle. J. Dairy Sci. 101, 5115-5133.

Rodriguez, L.A., Bethard, G., Tomlinson, D. & McGilliard, M., 2012. Impact of milk yield, herd size, and feed efficiency on economic change between and within California dairies from 2006 through 2010. J. Anim. Sci. 90(E-Suppl.1). (Abstr.).

Sebastino, K.B., Uribe, H. & González, H.H., 2020. Effect of test year, parity number and days in milk on somatic cell count in dairy cows of Los Ríos region in Chile. Austral. J. Vet. Sci. 52, 1-7.

Schukken, Y.H., Wilson, D.J., Welcome, F., Garrison-Tikofsky, L. & Gonzalez, R.N., 2003. Monitoring udder health and milk quality using somatic cell counts. Vet. Res. 34, 579-596

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

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

Thornton, P.K., 2010. Livestock production: recent trends, future prospects. Review. Phil. Trans. R. Soc. B. 365, 2853-2867.

Urdl, M., Gruber, L., Obritzhauser, W. & Schauer, A. 2015. Metabolic parameters and their relationship to energy balance in multiparous Simmental, Brown Swiss and Holstein cows in the periparturient period as influenced by energy supply pre-and post-calving. Journal of Animal Physiology and Animal Nutrition, 99, 174-189.

Vishwanah, R., 2003. Artificial insemination: the state of the art. Theriogen. 59, 571-584.

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.

Woodward, S.J.R., Romera, A.J., Beskow, W.B. & Lovatt, S.J., 2008. Better simulation modelling to support farming systems innovation: Review and synthesis, New Zealand J. Agric. Res, 51, 235-252.

Appendix A.1. Age structure, survival, and production per age group for the simulated average smallholder dairy cattle herd of 20 cows in South Africa

	Age group (parity)	Age (months)	Number	Survival	Number culled	Milk yield (kg/cow/year)	Milk yield (l/cow/year)	Fat yield (kg/cow/year)	Protein yield (kg/cow/year)	Live weight (kg)
	1	29	5.0	0.8	1.0	3606	3501	180	160	413
	2	43	4.0	1.0	0.0	3814	3703	188	163	439
	3	57	4.0	0.8	1.0	4046	3928	192	168	447
	4	71	3.0	0.7	1.0	3970	3854	194	171	449
	5	84	2.0	0.5	1.0	3781	3671	190	169	450
	6	97	1.0	1.0	0.0	3613	3507	185	165	450
	7	110	1.0	0.0	1.0	3404	3305	182	162	450
Average	**3.0**	**56.7**			**5.0**	**3798**	**3687.4**	**187.7**	**165.1**	**442**

Appendix B.1. Summary result for the analysis of the milk yield (l/cow/year) production model

MODEL	**AVERAGE HERD MILK YIELD (L/COW/YEAR)**					**3 134.3**	**3318.7**	**3503.1**	**3 687.4**	**3871.8**	**4056.2**	**4240.5**
SOURCE OF PRODUCTION COST												
Item						Cost (ZAR/cow)						
Animal's health						570.0	570.0	570.0	570.0	570.0	570.0	570.0
Breeding bull						1 272.2	1 272.2	1 272.2	1 272.2	1 272.2	1 272.2	1 272.2
Feeding (R/head)						12 406.1	12 556.6	12 707.0	12 857.5	13 008.0	13 158.4	13 308.9
Labor cost						1 146.0	1 146.0	1 146.0	1 146.0	1 146.0	1 146.0	1 146.0
Electricity						91.0	91.0	91.0	91.0	91.0	91.0	91.0
Recording and other logistics						235.0	235.0	235.0	235.0	235.0	235.0	235.0
Transport						289.0	289.0	289.0	289.0	289.0	289.0	289.0
Total cost						**16 009.3**	**16 159.8**	**16 310.2**	**16 460.7**	**16 611.2**	**16 761.6**	**16 912.1**
SOURCE OF INCOME												
Beef sales:												
Class	No. sold	Carcass wt (kg)	Price	Price / unit	Income (ZAR/herd)	Income (ZAR/cow)						
Cull cows	5	216.40	22.5	kg	4 869.0	1 217.3	1 217.3	1 217.3	1 217.3	1 217.3	1 217.3	1 217.3
yearlings	0.28	164.45	28	kg	4 604.5	64.5	64.5	64.5	64.5	64.5	64.5	64.5
Bull calves	8.32		510	Individual	4 243.2	212.2	212.2	212.2	212.2	212.2	212.2	212.2
Sub-total						1 493.9	1 493.9	1 493.9	1 493.9	1 493.9	1 493.9	1 493.9
Milk sale:												
Average herd milk yield (l/cow/year)						3 134.3	3318.7	3503.1	3 687.4	3871.8	4056.2	4240.5
Milk price (ZAR)/l						4.5						
						Income (ZAR/cow)						
Sub-total						14 104.4	14 934.1	15 763.7	16 593.4	17 423.1	18 252.8	19 082.4
Total income						**15 598.3**	**16 428.0**	**17 257.6**	**18 087.3**	**18 917.0**	**19 746.6**	**20 576.3**
GROSS MARGIN (ZAR/COW/YEAR)						**- 411.0**	**268.2**	**947.4**	**1 626.6**	**2 305.8**	**2 985.0**	**3 664.2**

Appendix B.2. Summary result for the analysis of the live weight (kg) production model

MODEL	**MATURE COW LIVE WIGHT (KG)**					**382.5**	**405.0**	**427.5**	**450.0**	**472.5**	**495.0**	**517.5**
SOURCE OF PRODUCTION COST												
Item						Cost (ZAR/cow)						
Animal's health						570.0	570.0	570.0	570.0	570.0	570.0	570.0
Breeding bull						1 272.2	1 272.2	1 272.2	1 272.2	1 272.2	1 272.2	1 272.2
Feeding (R/head)						10 530.1	11 306.0	12 080.1	12 857.5	13 625.5	14 398.2	15 171.7
Labor cost						1 146.0	1 146.0	1 146.0	1 146.0	1 146.0	1 146.0	1 146.0
Electricity						91.0	91.0	91.0	91.0	91.0	91.0	91.0
Recording and other logistics						235.0	235.0	235.0	235.0	235.0	235.0	235.0
Transport						289.0	289.0	289.0	289.0	289.0	289.0	289.0
Total cost						**14 133.3**	**14 909.2**	**15 683.3**	**16 460.7**	**17 228.7**	**18 001.4**	**18 774.9**
SOURCE OF INCOME												
Beef sales:												
Class	No. sold	Carcass Wt (kg)	Price (ZAR)	Price / unit	Income (ZAR/herd)	Income (ZAR/cow)						
Cull cows	5	183.9	22.5	R/kg	4138.3	1 034.6	1 095.5	1 156.4	1 217.3	1 278.1	1 339.0	1 399.9
yearlings	0.28	139.5	28.0	R/kg	3907.2	54.7	58.0	61.2	64.5	67.7	70.9	74.2
Bull calves	8.32		510.0	Individual	4243.2	212.2	212.2	212.2	212.2	212.2	212.2	212.2
Sub-total						1 301.4	1 365.6	1 429.7	1 493.9	1 558.0	1 622.1	1 686.2
Milk sale:												
Average milk yield (l/cow/year)						3 687.4	3 687.4	3 687.4	3 687.4	3 687.4	3 687.4	3 687.4
Milk price (ZAR)/l						4.5						
						Income (ZAR/cow)						
Sub-total						16 593.4	16 593.4	16 593.4	16 593.4	16 593.4	16 593.4	16 593.4
Total income						**17 894.8**	**17 959.0**	**18 023.1**	**18 087.3**	**18 151.4**	**18 215.5**	**18 279.6**
GROSS MARGIN (ZAR/COW/YEAR)						**3 761.6**	**3 049.7**	**2 339.8**	**1 626.6**	**922.7**	**214.1**	**- 495.3**

Appendix B.3. Summary result for the analysis of the age at first calving (months) model

MODEL	**AGE AT FIRST CALVING (MONTHS)**					**27**	**28**	**29**	**30**	**31**
SOURCE OF PRODUCTION COST										
Item						Cost (ZAR/cow)				
Animal's health						570.0	570.0	570.0	570.0	570.0
Breeding bull						1 272.2	1 272.2	1 272.2	1 272.2	1 272.2
Feeding (R/head)						12 407.0	12 632.5	12 857.5	13 082.1	13 306.2
Labor cost						1 146.0	1 146.0	1 146.0	1 146.0	1 146.0
Electricity						91.0	91.0	91.0	91.0	91.0
Recording and other logistics						235.0	235.0	235.0	235.0	235.0
Transport						289.0	289.0	289.0	289.0	289.0
Total cost						**16 010.2**	**16 235.7**	**16 460.7**	**16 685.3**	**16 909.4**
SOURCE OF INCOME										
Beef sales:										
Class	No. sold	Carcass Wt (kg)	Price (ZAR)	Price/unit	Income (ZAR/herd)	Income (ZAR/cow)				
Cull cows	5	216.4	22.5	R/kg	4 869.0	1 217.3	1 217.3	1 217.3	1 217.3	1 217.3
yearlings	0.28	154.8	28	R/kg	4 333.6	60.7	62.6	64.5	66.2	67.8
Bull calves	8.32		510	Individual	4 243.2	212.2	212.2	212.2	212.2	212.2
Sub-total						1 490.1	1 492.1	1 493.9	1 495.6	1 497.2
Milk sale:										
Average milk yield (l/cow/year)						3 687.4	3 687.4	3 687.4	3 687.4	3 687.4
Milk price (ZAR)/l						4.5				
						Income (ZAR/cow)				
Sub-total						16 593.4	16 593.4	16 593.4	16 593.4	16 593.4
Total income						**18 083.5**	**18 085.5**	**18 087.3**	**18 089.0**	**18 090.6**
GROSS MARGIN (ZAR/COW/YEAR)						**2 073.3**	**1 849.8**	**1 626.6**	**1 403.7**	**1 181.1**

Appendix B.4. Summary result for the analysis of the calving interval (days) model

MODEL	CALVING INTERVAL (DAYS)					360	390	420	450	480
SOURCE OF PRODUCTION COST										
Item						Cost (ZAR/cow)				
Animal's health						570.0	570.0	570.0	570.0	570.0
Breeding bull						1 272.2	1 272.2	1 272.2	1 272.2	1 272.2
Feeding (R/head)						12 312.2	12 528.9	12 857.5	13 186.1	13 402.7
Labor cost						1 146.0	1 146.0	1 146.0	1 146.0	1 146.0
Electricity						91.0	91.0	91.0	91.0	91.0
Recording and other logistics						235.0	235.0	235.0	235.0	235.0
Transport						289.0	289.0	289.0	289.0	289.0
Total cost						15 915.4	16 132.1	16 460.7	16 789.3	17 005.9
SOURCE OF INCOME										
Beef sales:										
Class	No. sold	Carcass Wt (kg)	Price (ZAR)	Price / unit	Income (ZAR/herd)	Income ((ZAR)/cow)				
Cull cows	5	216.0	22.5	R/kg	4 861.1	1 215.3	1 216.3	1 217.3	1 218.2	1 219.0
yearlings	0.28	164.4	28	R/kg	4 604.5	64.5	64.5	64.5	64.5	64.5
Bull calves	8.32		510	Individual	4 243.2	212.2	212.2	212.2	212.2	212.2
Sub-total						1 491.9	1 492.9	1 493.9	1 494.8	1 495.6
Milk sale:										
Average milk yield (l/cow/year)						3 687.4	3 687.4	3 687.4	3 687.4	3 687.4
Milk price (ZAR)/l						4.5				
						Income (ZAR/cow)				
Sub-total						16 593.4	16 593.4	16 593.4	16 593.4	16 593.4
Total income						18 085.3	18 086.3	18 087.3	18 088.2	18 089.1
GROSS MARGIN (ZAR/COW/YEAR)						**2 169.9**	**1 954.3**	**1 626.6**	**1 298.9**	**1 083.1**

Appendix B.5. Summary result for the analysis of the herd size (number of individual cows per herd) model

MODEL	**HERD SIZE**					**10**	**15**	**20**	**25**	**30**
SOURCE OF PRODUCTION										
Item						Cost (ZAR/cow)				
Animal's health						570.0	570.0	570.0	570.0	570.0
Breeding bull						1 272.2	1 272.2	1 272.2	1 272.2	1 272.2
Feeding (R/head)						12 584.3	12 766.4	12 857.5	12 912.1	12 948.6
Labor cost						1 146.0	1 146.0	1 146.0	1 146.0	1 146.0
Electricity						91.0	91.0	91.0	91.0	91.0
Recording and other logistics						235.0	235.0	235.0	235.0	235.0
Transport						289.0	289.0	289.0	289.0	289.0
Total cost						**16 187.5**	**16 369.6**	**16 460.7**	**16 515.3**	**16 551.8**
SOURCE OF INCOME										
Beef sales:										
Class	No. sold	Carcass Wt (kg)	Price (ZAR)	Price/unit	Income (ZAR/herd)	Income (ZAR/cow)				
Cull cows	2.5	216.4	22.5	R/kg	4 869.0	1 217.3	1 217.3	1 217.3	1 217.3	1 217.3
yearlings	-2.02	164.4	28.0	R/kg	4 604.5	- 930.1	- 267.1	64.5	263.4	396.0
Bull calves	3.12		510.0	Individual	1 591.2	159.1	194.5	212.2	222.8	229.8
Sub-total						446.3	1 144.7	1 493.9	1 703.4	1 843.1
Milk sale:										
Average milk yield (l/cow/year)						3 687.4	3 687.4	3 687.4	3 687.4	3 687.4
Milk price (ZAR)/l						4.5				
						Income (ZAR/cow)				
Sub-total						16 593.4	16 593.4	16 593.4	16 593.4	16 593.4
Total income						**17 039.7**	**17 738.1**	**18 087.3**	**18 296.8**	**18 436.5**
GROSS MARGIN (ZAR/COW/YEAR)						**852.2**	**1 368.5**	**1 626.6**	**1 781.5**	**1 884.7**

Appendix B.6. Summary result for the analysis of the replacement rate model

MODEL	REPLACEMENT RATE					**21.3%**	**22.5%**	**23.8%**	**25%**	**26.3%**	**27.5%**	**28.8%**
SOURCE OF PRODUCTION COST (ZAR)												
Item						Cost (ZAR/cow)						
Animal's health						570.0	570.0	570.0	570.0	570.0	570.0	570.0
Breeding bull						1 272.2	1 272.2	1 272.2	1 272.2	1 272.2	1 272.2	1 272.2
Feeding (R/head)						12 302.3	12 485.5	12 556.6	12 857.5	13 038.3	13 219.2	13 392.9
Labor cost						1 146.0	1 146.0	1 146.0	1 146.0	1 146.0	1 146.0	1 146.0
Electricity						91.0	91.0	91.0	91.0	91.0	91.0	91.0
Recording and other logistics						235.0	235.0	235.0	235.0	235.0	235.0	235.0
Transport						289.0	289.0	289.0	289.0	289.0	289.0	289.0
Total cost						**15 905.5**	**16 088.7**	**16 159.8**	**16 460.7**	**16 641.5**	**16 822.4**	**16 996.1**
SOURCE OF INCOME												
Beef sales:												
Class	No. sold	Carcass Wt (kg)	Price (ZAR)	Price/unit	Income (ZAR/herd)	Income (ZAR/cow)						
Cull cows	4.25	219.8	22.5	R/kg	4 945.1	1 050.8	1 105.8	1 160.5	1 217.3	1 272.0	1 326.8	1 379.9
yearlings	1.03	164.4	28	R/kg	4 604.5	237.1	179.6	122.0	64.5	6.9	- 50.6	- 108.2
Bull calves	8.32		510	Individual	4 243.2	212.2	212.2	212.2	212.2	212.2	212.2	212.2
Sub-total						1 500.1	1 497.5	1 494.7	1 493.9	1 491.1	1 488.3	1 483.8
Milk sale:												
Average milk yield (l/cow/year)						3 699.7	3 695.9	3 691.7	3 687.4	3 683.2	3 679.0	3 675.1
Milk price (ZAR)/l						4.5						
						Income (ZAR/cow)						
Sub-total						16 648.7	16 631.4	16 612.4	16 593.4	16 574.5	16 555.5	16 537.9
Total income						**18 148.8**	**18 128.9**	**18 107.2**	**18 087.3**	**18 065.6**	**18 043.8**	**18 021.8**
GROSS MARGIN (ZAR/COW/YEAR)						**2 243.3**	**2 040.2**	**1 947.4**	**1 626.6**	**1 424.0**	**1 221.4**	**1 025.7**

Appendix B.7. Summary result for the analysis of the feeding system (number of individual cows per herd) model

MODEL	**FEEDING SYSTEM**					**Pure-pasture**	**Pasture plus silage**	**Pasture plus concentrate**	**Pasture and concentrate plus silage**
SOURCE OF PRODUCTION COST									
Item						Cost (ZAR/cow)			
Animal's health						570.0	570.0	570.0	570.0
Breeding bull						1 272.2	1 272.2	1 272.2	1 272.2
Feeding (R/head)						8 319.5	10 941.6	13 236.6	12 857.5
Labor cost						1 146.0	1 146.0	1 146.0	1 146.0
Electricity						91.0	91.0	91.0	91.0
Recording and other logistics						235.0	235.0	235.0	235.0
Transport						289.0	289.0	289.0	289.0
Total cost						**11 922.7**	**14 544.8**	**16 839.8**	**16 460.7**
SOURCE OF INCOME									
Beef sales:									
Class	No. sold	Carcass Wt (kg)	Price (ZAR)	Price/unit	Income (ZAR/herd)	Income (ZAR/cow)			
Cull cows	5	216.4	22.50	R/kg	4 869.0	1 217.3	1 217.3	1 217.3	1 217.3
yearlings	0.28	164.4	28	R/kg	4 604.5	64.5	64.5	64.5	64.5
Bull calves	8.32		510	individual	4 243.2	212.2	212.2	212.2	212.2
Sub-total						1 493.9	1 493.9	1 493.9	1 493.9
Milk sale:									
Average milk yield (l/cow/year)						2 124.0	3 067.9	3 790.7	3 687.4
Milk price (ZAR)/l						4.5			
						Income (ZAR/cow)			
Sub-total						9 557.8	13 805.7	17 058.0	16 593.4
Total income						**11 051.7**	**15 299.6**	**18 551.9**	**18 087.3**
GROSS MARGIN (ZAR/COW/YEAR)						**- 871.0**	**754.8**	**1 712.2**	**1 626.6**

Appendix B.8. Summary result for the analysis of the model for breeding methods

MODEL	**BREEDING METHODS: natural services (NS) vs artificial insemination (AI)**					**Natural service**	**AI_1s**	**AI_2s**	**AI_3s**	**AI_4s**
SOURCE OF PRODUCTION COST										
Item						Cost (ZAR/cow)				
Animal's health						570.0	570.0	570.0	570.0	570.0
Breeding bull						1 272.2	450.0	900.0	1 350.0	1 800.0
Feeding (R/head)						12 857.5	12 857.5	12 857.5	12 857.5	12 857.5
Labor cost						1 146.0	1 146.0	1 146.0	1 146.0	1 146.0
Electricity						91.0	91.0	91.0	91.0	91.0
Recording and other logistics						235.0	235.0	235.0	235.0	235.0
Transport						289.0	289.0	289.0	289.0	289.0
Total cost						**16 460.7**	**15 638.5**	**16 088.5**	**16 538.5**	**16 988.5**
SOURCE OF INCOME										
Beef sales:										
Class	No. sold	Carcass Wt (kg)	Price (ZAR)	Price/unit	Income (ZAR/herd)	Income (ZAR/cow)				
Cull cows	5	216.4	22.5	R/kg	4 869.0	1 217.3	1 217.3	1 217.3	1 217.3	1 217.3
yearlings	0.28	164.4	28.0	R/kg	4 604.5	64.5	64.5	64.5	64.5	64.5
Bull calves	8.32		510.0	Individual	4 243.2	212.2	212.2	212.2	212.2	212.2
Sub-total						1 493.9	1 493.9	1 493.9	1 493.9	1 493.9
Milk sale:										
Average milk yield (l/cow/year)						2 124.0	3 067.9	3 790.7	3 687.4	3 687.4
Milk price (ZAR)/l						4.5				
						Income (ZAR/cow)				
Sub-total						16 593.4	16 593.4	16 593.4	16 593.4	16 593.4
Total income						**18 087.3**	**18 087.3**	**18 087.3**	**18 087.3**	**18 087.3**
GROSS MARGIN (ZAR/COW/YEAR)						**1 626.6**	**2 448.8**	**1 998.8**	**1 548.8**	**1 098.8**

Appendix B.9. Summary result for the analysis of the model for source of replacement heifers

MODEL	**SOURCE OF REPLACEMENT HEIFERS**					**Raised**			**buying-in**		
	AVERAGE FIRST LACTATION MILK YIELD (L/COW/YEAR)					**3 452.6**	**3 501.2**	**3 549.7**	**3 452.6**	**3 501.2**	**3 549.7**
SOURCE OF PRODUCTION COST											
Item						Cost (ZAR/cow)					
Animal's health						570.0	570.0	570.0	570.0	570.0	570.0
Breeding bull						1 272.2	1 272.2	1 272.2	1 272.2	1 272.2	1 272.2
Feeding (R/head)						12 847.6	12 857.5	12 867.4	12 440.5	12 450.4	12 460.3
Labor cost						1 146.0	1 146.0	1 146.0	1 146.0	1 146.0	1 146.0
Electricity						91.0	91.0	91.0	91.0	91.0	91.0
Recording and other logistics						235.0	235.0	235.0	235.0	235.0	235.0
Transport						289.0	289.0	289.0	289.0	289.0	289.0
Total cost						**16 450.8**	**16 460.7**	**16 470.6**	**16 043.7**	**16 053.6**	**16 063.5**
SOURCE OF INCOME											
Beef sales:											
Class	No. sold	Carcass Wt (kg)	Price (ZAR)	Price/unit	Income (ZAR/herd)	Income (ZAR/cow)					
Cull cows	5	216.402	22.5	R/kg	4 869.0	1 217.3	1 217.3	1 217.3	1 217.3	1 217.3	1 217.3
yearlings	0.28	164.4464	28	R/kg	4 604.5	64.5	64.5	64.5	64.5	64.5	64.5
Bull calves	8.32		510	Individual	4 243.2	212.2	212.2	212.2	212.2	212.2	212.2
Sub-total						1 493.9	1 493.9	1 493.9	1 493.9	1 493.9	1 493.9
Milk sale:											
Average herd milk yield (l/cow/year)						3 675.3	3 687.4	3 699.6	3 675.3	3 687.4	3 699.6
Milk price (ZAR)/l						4.5					
						Income (ZAR/cow)					
Sub-total						16 538.8	16 593.4	16 648.0	16 538.8	16 593.4	16 648.0
Total income						**18 032.7**	**18 087.3**	**18 141.9**	**18 032.7**	**18 087.3**	**18 141.9**
GROSS MARGIN (ZAR/COW/YEAR)						**1 581.9**	**1 626.6**	**1 671.3**	**1 989.0**	**2 033.7**	**2 078.4**