BIO-ECONOMIC MODELLING TO SUPPORT GENETIC IMPROVEMENT OF DAIRY CATTLE IN KENYA

Wahinya, P.K.

KM11/1764/06

A thesis submitted to the Graduate School in Partial Fulfilment for the Requirements of the Master of Science Degree in Animal Production (Animal Breeding Option) of Egerton University.

EGERTON UNIVERSITY

APRIL, 2014

DECLARATION AND RECOMMENDATION

DECLARATION

This thesis is my original work and has not, wholly or in part, been presented for an award of a degree or diploma in any other University.

Signed: ___________________________

Peter Kiongo Wahinya (KM11/1764/06)

Date: _____________________________

RECOMMENDATION

This thesis has been approved for final submission with our approval as University supervisors.

Signed: ____________________________

Prof. Dr. A. K. Kahi

Date: ______________________________

Signed: _____________________________

Prof. Isaac S. Kosgey, PhD.

Date: _______________________________

COPYRIGHT

DEDICATION

This work is dedicated to my parents, Mr. John Wahinya and Mrs. Mary Wahinya, for their never ending support, my wife Irene, son Noel and siblings Faith, Ann and Julia for their prayers and encouragement. May the Almighty God bless you all.

ACKNOWLEDGEMENTS

I wish to express my sincere appreciations to institutions and individuals who made the realisation of this study. Special thanks go to Egerton University's Graduate School and the Department of Animal Sciences for offering me a chance to pursue postgraduate studies. The Department of Animal Sciences, for sharing their skills and enriching guidance to me throughout the study period. Appreciation goes to all my fellow postgraduate students for their encouragement and comradeship. I greatly thank RUFORUM for financial support towards the fee for my study to undertake this programme.

Much gratitude goes to my supervisors, Prof. Dr. Alexander.K. Kahi and Prof. Dr. Isaac.S. Kosgey for their mentorship, technical advice, professional supervision, inspiration and unlimited material support they provided in the course of this research work. Special thanks to Prof. Dr. A.K. Kahi for suggesting this interesting study and offering me work space, material and financial support. Your support made my research work exciting. Special gratitude is also extended to Prof. Bockline O. Bebe, Prof. H. Hirooka, Dr. Michael.G. Gicheha and Dr. Tobias.O. Okeno for their important contribution to this study. The Principal and staff at AHITI Ndomba who encouraged and supported me during the study period.

Special gratitude to my parents for their inspirational, moral and material support throughout my education. I also acknowledge my sisters, wife and son for their moral support and encouragement.

Thanks to God for everything.

ABSTRACT

A deterministic bio-economic model that incorporates risk for pasture-based dairy cattle production in the tropics was developed. Two production circumstances were considered: fixed pasture (FP) and fixed herd size (FH). In each circumstance, efficiencies (both economic and biological) and profit were calculated based on milk marketing on volume, and on volume and butter fat content. Additionally, a profit function was used to estimate risk-rated profit(s) where the intensity of the farmer's aversion to risk was measured using the Arrow-Pratt coefficient (λ). Arrow-Pratt coefficients of 0.0001 and 0.02 were assumed. Feeding cost was the highest followed by marketing, labour, health and reproduction costs, respectively. Under FH, the economic efficiency when milk marketing was based on volume was 3.825 and 4.378 when based on volume and butter fat content. The corresponding economic efficiencies were 3.736 and 4.277 under FP. The biological efficiencies were 0.143 and 0.148 for milk production, and 0.002 and 0.001 for live weight production under FH and FP, respectively. The profits derived when incorporating and when not incorporating risks were different. They also differed when (λ) was 0.02 and 0.0001. The changes in profit after incorporating risk indicate that farmers who were risk averse should be ready to accept lower returns to avoid the unexpected outcomes. This has a direct application in the dairy production systems in the tropics. Dairy cattle production is viable in the tropics for both large- and small-scale farmers. Future production circumstances still need to be considered in the estimation of economic and biological values for the traits of economic importance. Economic and biological values for milk yield (MY), milk butter fat (FY), daily gain (DG), weaning weight (WWT), mature live weight (MLW), calving interval (CI), pre-weaning survival rate (PreSR), post-weaning survival rate (PostSR), age at first calving (AFC) and productive life time (PLT) were estimated under FH and FP production circumstances assuming milk marketing based on volume, and volume and butter fat. The economic values for the traits ranged from -17.246 to 100.536, while the biological values ranged between -1.29 to 0.791. Economic values with higher Arrow-Pratt coefficient of absolute risk aversion (λ=0.02) were lower than those reported under λ=0.0001, indicating that the uncertainty of the future market is important and should be considered during the estimation of economic values. Genetic improvements targeting MY and growth traits would be recommended to production systems with unlimited feed supply for profit maximization. However, since dairy production systems in the tropics are characterised by feed scarcity,

fixing the herd size and concentrating on genetically improved animals would result in more profitability than increasing animal populations.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

AI	Artificial insemination
AFRC	Agricultural and Food Research Council
ARC	Agricultural Research Council
a.s.l	above sea level
BLUP	Best Linear Unbiased Prediction
CAIS	Central Artificial Insemination Station
ECF	East Coast Fever
FAO	Food and Agricultural Organization (of the United Nations)
GDP	Gross domestic product
KARI	Kenya Agricultural Research Institute
KCC Ltd.	Kenya Co-operative Creameries Limited

CHAPTER ONE

GENERAL INTRODUCTION

1.1. Background to the study

In the developing countries of the tropics, the demand for animal products has been increasing due to high human population growth, increasing urbanization and rising incomes, giving the consumers better purchasing power and change in food preference (Delgado *et al*., 1999; Omore *et al*., 1999; Thorpe *et al*., 2000). The consumption of both meat and milk is still set to increase (Bebe *et al*., 2002). The fact that the consumption per capita still surpasses the nutritional optimum due to inefficiency in production in developing countries (FAO, 1991; Delgado *et al*., 1999; FAO, 2006) makes production efficiency of dairy cattle, especially at the smallholder level, the biggest challenge to satisfy the demand for dairy products (Bondoc *et al*., 1989). To counter the increasing demand, the rate of production has also increased, but through increased animal populations and not through improved productivity (Nicholson *et al*., 2001; Mwai *et al*., 2005; Wambugu et al., 2011). To solve this problem, the performance per cow can be increased through genetic improvement.

Currently, only about 18% of the increased per capita milk availability in Kenya can be attributed to increased cow productivity compared to approximately 10% and 61% due to increased cow number and proportion of milking cows, respectively, as observed by Bebe *et al*. (2002). In that study, farmers ranked poor animal performance as a major constraint to improving productivity. In the tropics, local selection programmes, breed substitution and crossbreeding have been used as breeding strategies to genetically improve dairy cattle. Other selection programmes like progeny testing take long, but have a cumulative improvement over time (Mpofu *et al*., 1993). In the developed countries, selection and introduction of new genes have been used to improve productivity of dairy cattle. Such strategies have been tried in developing countries, but the success rate is usually low mainly due to genotype by environment interactions, social and economic factors (Bondoc *et al*., 1989; Ojango and Pollot., 2001; Kahi *et al*., 2004; Mulder and Bijma., 2005; Mulder *et al*., 2006).

Genetic improvement of dairy cattle in developing countries in the tropics is mainly based on use of imported germplasm. This breeding strategy may not be the best due to genotype by environment interaction as well as presence of different breeding goals (Ojango and Pollot, 2001). Although importation of germplasm results in higher genetic response than the use of local genes (Mpofu *et al*., 1993), Okeno *et al*. (2010) showed that there are no significant differences in the traits in the breeding goal, and that the genetic gain achieved through semen importation mainly depends on the level of genetic correlation between the importing and exporting populations. It is, therefore, important to suggest or come up with possibilities of implementing local genetic improvement programmes for dairy cattle that can satisfy production under tropical conditions where these animals thrive (Kahi and Nitter, 2004; Kosgey *et al.,* 2006).

Kenya has about 85% of the dairy cattle population in the Eastern Africa region, which is approximately 70% of the population in both Eastern and Southern Africa (Thorpe *et al*., 2000). This makes the country a good focal point for genetic improvement of dairy cattle in the tropics where sustainable production systems are lacking or are not effective (Kahi *et al*., 2004; Philipsson *et al.,* 2011). To increase food production, a sustainable breeding programme is important to utilise the genetic diversity that is available in the tropics. Many breeding programmes have achieved positive results after decades of selection in the temperate regions, and lessons can be learnt. Breeding objectives form one of the foundations of any successful breeding programme (Ponzoni and Newman, 1989). To develop breeding objectives, bio-economic models are used to derive economic values or biological values. Either deterministic or stochastic models can be used to model a production system. The breeding objective traits are used in a breeding programme to carry out selection for genetic improvement. The economic and biological values of the breeding objective traits can then be used to estimate genetic progress. The economic values are estimated using economic units while the biological values are estimated using energy units. The economic values are later discounted to account for time difference when the traits are expressed using the gene flow method (Groen *et al.,* 1997*)*. The implication of these results can then be evaluated in breeding programme by working out genetic gain of various selection indices(Rendel and Robertson, 1996).

1.2. Statement of the problem

In the developing countries, consumption of animal products per capita is not yet met due to inefficient production despite the increased production. This is due to the increase in human population, increased urbanization and rising incomes, leading to change in consumer taste and preference. The increasing demand is being met through an increase in the animal population rather than through productivity increases. Due to decreasing land sizes and scarcity of pasture this strategy is unsustainable. Genetic improvement is a possible option to improve productivity per cow but requires local genetic improvement programmes for dairy cattle on traits of economic importance. To ensure effective genetic improvement programs in Kenya, there is need for sustainable systems that account for the needs and aspirations of the target group, and these systems are either lacking or are not effective to improve the actual production circumstances in the country.

1.3. Overall objective of the study

The overall objective was to contribute to increased dairy production by designing sustainable and effective systems to support genetic improvement of dairy cattle in Kenya. To achieve this, the specific objectives were to:

(i) Develop a bio-economic model that takes into account dairy production circumstances in the country.

(ii) Estimate biological and economic values of production and functional traits for dairy cattle using the developed bio-economic model.

(iii) Derive selection indexes and examine the effects of using different biological and economic values on genetic responses.

1.4. Research questions

To tackle the specific objectives, the following questions were answered:

(i) Which bio-economic model was appropriate for the dairy production circumstances in Kenya?

(ii) What were the biological and economic value estimates of production and functional traits for dairy cattle in Kenya?

(iii) What were the selection indices for selection of dairy cattle and the effects of using different biological and economic values on genetic responses?

CHAPTER TWO

LITERATURE REVIEW

2.1. Dairy production in Kenya

The dairy industry accounts for about 14% of the agricultural GDP and 3.5% of the total GDP (KNBS 2010; Behnke and Muthami 2011; Wambugu *et al.,* 2011). This sub-sector has been undergoing phenomenal changes since the introduction of exotic cattle breeds in the 1920's (Omiti and Muma, 2000). Among the major changes is the shift from large-scale production to smallholder crop-livestock mixed farming after the country's independence when the white settlers sold their farms to individual Africans and the government. The introduction of free or cheap and efficient livestock services and the abolishment of the contract and quota system of dairy marketing in 1996 are among the major changes. Milk marketing was liberalized in 1992, which ended the monopoly of KCC Ltd (Omiti and Muma, 2000; Thorpe *et al*., 2000), while veterinary and AI services were commercialized during that period.

2.1.1. Dairy cattle population in Kenya

Kenya has an estimated dairy cattle population of 3.8 million (Muriuki, 2011; Wambugu *et al.,* 2011) of which approximately 80% is owned by smallholder farmers (Bebe *et al*., 2002). Figure 1 below shows the number of cattle in what used to be provinces in Kenya, the total cattle population is approximately 17,467,774. The bulk population is found in the former Rift Valley and North Eastern provinces while Nairobi has a small population of about 25,536 and 29,010 exotic and indigenous cattle respectively.

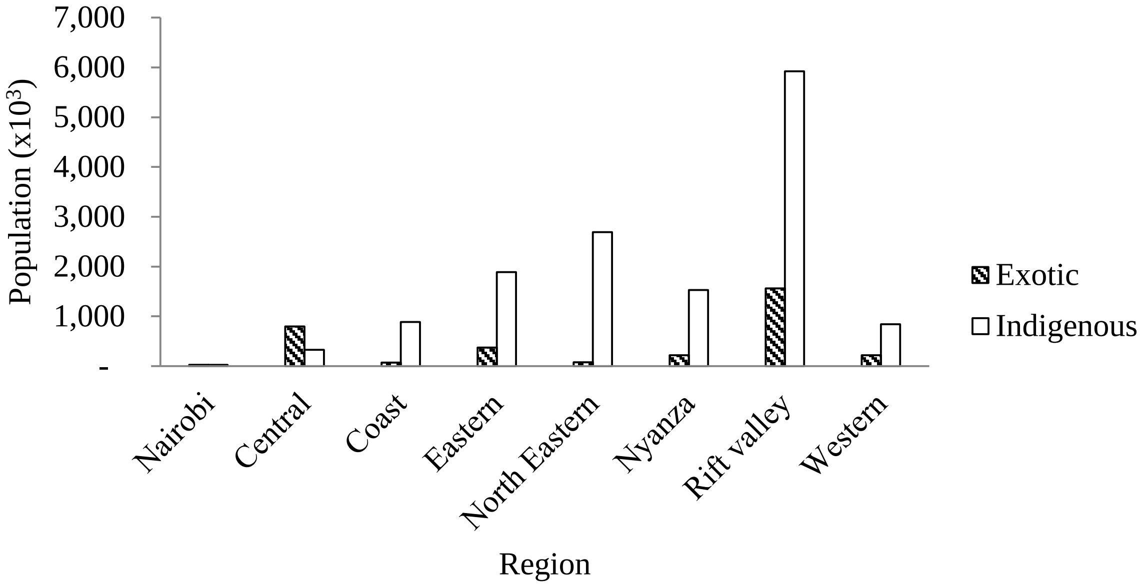

Figure 1: Livestock population data in Kenya (Accessed from http://www.knbs.or.ke/censuslivestock.php on 20th February, 2011)

2.1.2. Milk production in Kenya

Figure 2 presents milk production trends in Kenya which has been on an upward linear trend. The production generally increased from 2000 to 2011 by 108% with reduction only in 2005 and 2008. This decrease could be attributed to a drought in the years while the increase in production could be due to improved animal husbandry practices and veterinary care, better quality feeds, adoption of more intensive grazing systems and improved animals (Wambugu *et al.*, 2011). According to this study the highest level of productivity was achieved in the Central Highlands followed by the High Potential Maize Zone and was lowest in the Western Lowlands. This is due to larger herd sizes, intensity of grazing system and improved animals in the higher potential areas. Out of the increase, about 10% can be attributed to increased cattle population, 18% to increased cow productivity and 61% to a higher proportion of milking cows (Bebe *et al.*, 2002). This shows that approximately 71% of the increase is attributable to increased population of dairy cattle. The MLD (2010) eight years later after Bebe *et al.* (2002) reported an increase of 260%, 43.6%, 71.4%, 71.9 and 25% in dairy farms, dairy population, milk production, per capita milk and productivity, respectively.

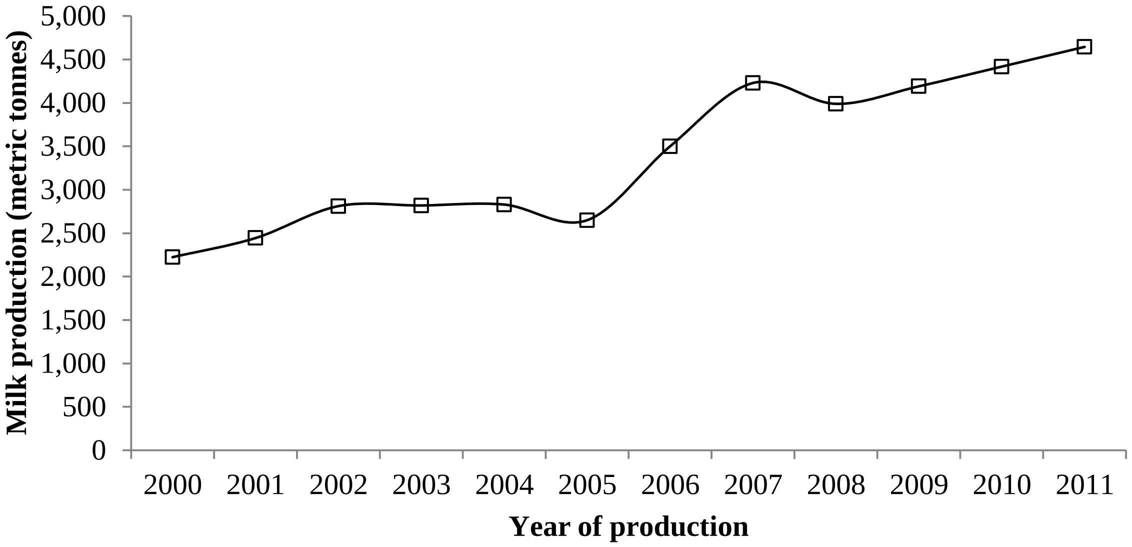

Figure 2: Cow milk production trend in Kenya from 2000 to 2011. (Accessed from http://www.kdb.co.ke/index.php?option=com_content&view=article&id=211&Itemid=275 20th June 2013).

2.1.3. Dairy marketing in Kenya

The per capita milk consumption in Kenya has been estimated at 145 litres and the consumption is expected to increase due to increased income of most households and urbanization (Bebe *et al*., 2002; KDB, 2012). Currently, most of the milk produced and marketed in Kenya is produced by the smallholder farmers (Bebe *et al*., 2002; KDB, 2012). These farmers are mainly located in peri-urban and urban centres, implying an easy and readily available market. Out of the milk produced, about 88% is marketed raw compared to 12% that is processed. Milk sold locally fetches higher prices for the farmers, while the dairy cooperatives have an important role to market and organize milk collection and delivery (Reynolds *et al*., 1996). Milk from the pastoralist and agro-pastoralist systems in the country is not considered, unlike in Uganda and Tanzania, due to the high cost involved in collection and transportation (Reynolds *et al*., 1996). Figure 3, show a general trend of change in milk intake through the formal sector; the linear trend shows a decline of milk intake in the informal sector. The highest drop is in the years 2002 and 2008, which can be explained by the political influence during the years when general elections were conducted. Despite this, there is generally a high demand for milk and milk products.

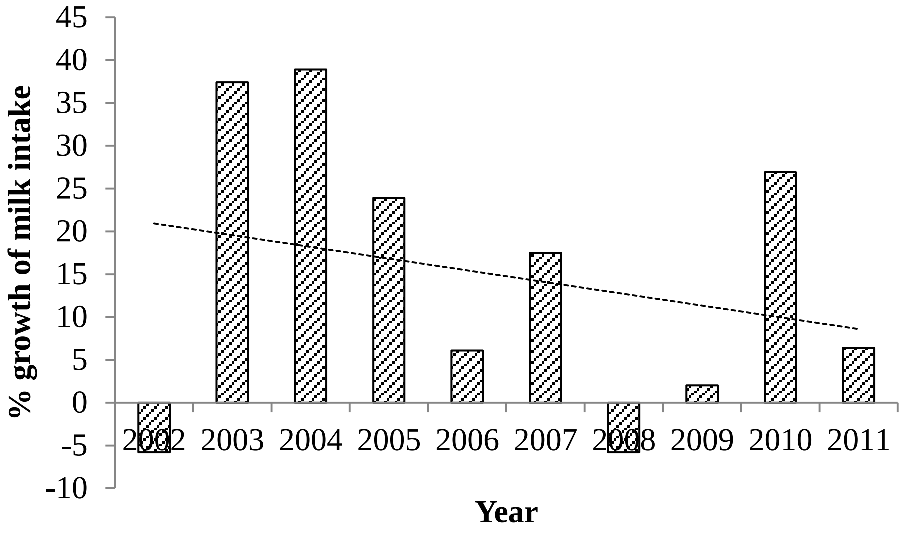

Figure 3: Milk intake in the formal sector (Source: MLD, 2010)

Figure 4 shows how milk marketing is done in Kenya, including all the key actors in the value chain from production, transportation, bulking/chilling, processing, and marketing to the consumer level.

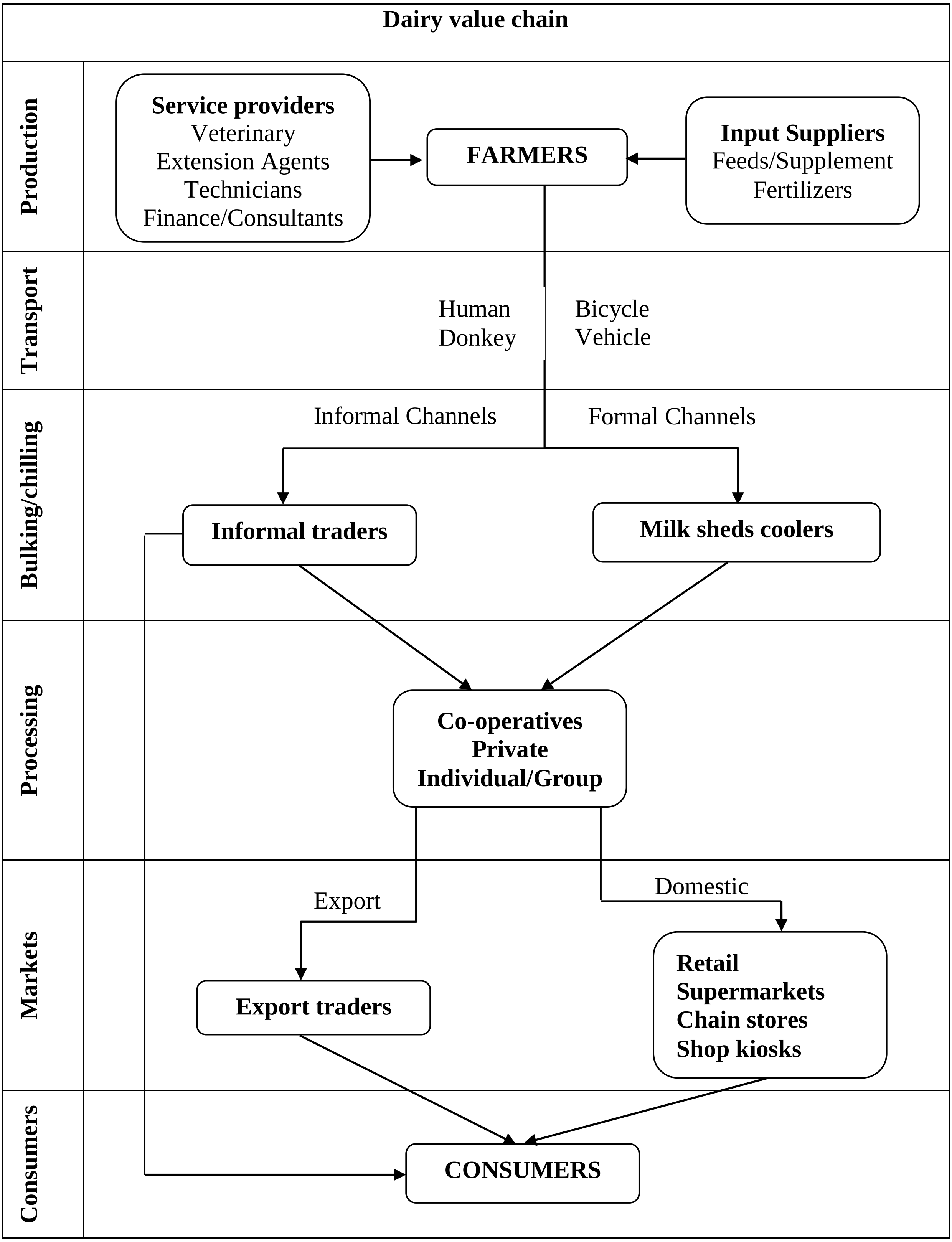

Figure 4: Flow of the actors in the dairy value chain in Kenya. (Source: MLD, 2010)

2.1.4. Dairy cattle production systems

Most of the smallholder farmers are found in the highlands (>1000m a.s.l) due to the favourable agro-ecology in these areas for dairy and crop production, and the high human population density that create a better market for livestock products. Small holder farmers mainly practice mixed farming where the dairy enterprise interacts with food and cash crops. The main dairy production systems in the country are zero, semi-zero and free-grazing. Zero-grazing dominates in the highlands where landholdings are declining, and it is mostly a way of intensifying dairying (Bebe *et al*., 2003b). The average land size is 2.4, 1.8 and 0.9 hectares for the free, semi-zero and zero grazing systems respectively keeping on average, correspondingly 2.2, 1.7, and 1.3 dairy cows. These production systems could be of medium - large scale.

2.1.5. Dairy cattle breeds

The most preferred dairy cattle breed is the Holstein Friesian followed by the Ayrshire. Other dairy breeds like the Jersey and Guernsey, and the dual-purpose breeds like the Sahiwal, Brown Swiss, Red Poll, Small East African Zebu, Zebu and Boran (for the pastoralists) are also reared (Gachuiri *et al.*, 2012). Bebe *et al*. (2003a) quantified the breed preference for high milk production as 78%, 59%, 47% and 22% for Friesian, Aryshire, Guernsey, Jersey and the indigenous breeds, respectively.

2.1.6. Constraints to the dairy industry in Kenya

Feeds - feed resource is a limiting factor in terms of both quantity and quality, particularly due to small land holdings attributed to increasing human and cattle populations. Consequently, most smallholder farmers have problems in maintaining sufficient replacement stock. The feed industry has a weak regulatory framework which encourages malpractices (MLD, 2010). Concentrate feeds are often expensive for the small-scale farmers. This is largely due to the cost of raw materials the bulk of which is imported from the neighbouring countries. The quality of the raw material also contributes to the poor quality of the animal feeds manufactured in the country. In most small-scale farms the supply of water and its quality is also a challenge to livestock productivity.

Herd health - high mortalities, especially of heifers, attributed to disease incidences are the major constraint to dairy production in Kenya. The main diseases that lead to mortalities are ECF, anaplasmosis and helminthosis (Thorpe *et al*., 2000; Bebe *et al*., 2003b). The collapse of the epidemiology, surveillance and economics units in the Ministry of Livestock development in 2006 led to a weak response to disease challenges of public health and those that affect productivity. Despite the liberal supply of veterinary supplies, most small-scale farmers have limited access to these services because of the cost involved especially of acaricide treatment and ECF (MLD, 2010). As a result of this farmers buy drugs and administer on their own treatments, subsequently misusing and abusing drugs.

Livestock breeding - Most farmers experience low reproductive rates due to lack of bulls, inefficient delivery of AI services and poor access to veterinary services because of poor infrastructure and difficulty in oestrus detection (Thorpe *et al.*, 2000; Bebe *et al.*, 2003b). Table 1 shows the various government institutions that offer breeding services. Some of these institutions that are mandated with the roles indicated are ineffective, mostly due to poor coordination and therefore not benefitting the farmers (MLD, 2010). Most small-scale farmers obtain their replacement stock from large scale farms as culls due to the high cost of breeding and raising young stock. A reliable national database is also lacking because only a few farmers participated in livestock recording. This translates to very few dairy animals being registered, officially recorded and genetically evaluated to give any credible results for the overall herd improvement.

Table 1: The services of breeding institutions in Kenya

Institutions	**Roles**
Kenya Livestock Breeders Organisation (KLBO)	1. KSB-Registration of all breeds of domestic livestock 2. Maintains an upgrading programme
Livestock Records Centre (LRC)	1. Runs National Dairy cattle breeding programme with two schemes: contract mating and progeny testing. 2. Estimation of breeding values
Kenya Animal Genetic Resource Centre (KAGRC)	1. Semen production, distribution and maintains AI bulls 2. Bull Purchasing Committee
Kenya National Artificial Insemination Service (KNAIS)	1. Distributes AI services to dairy farmers across the country
Dairy Recording Services of Kenya (DRSK)	1. Keeps and processes official milk records, butter fat and produce lactation certificates.
Breed Societies	1. Safeguards the purity of various breeds. 2. Set standards for the Herd Book Registers to promote the interest of specific breeders

Extension and financial services - in Kenya, extension services are offered by the government, NGO's, co-operatives and private companies (MLD, 2010). The private companies package their extension services to suit sale of their products. The major constraints according to a study by the National Agriculture and Livestock Extension

Programme (NALEP) are low adoption of innovations, lack of credits, ignorance, handout mentality and unreliable weather. Lack of capital and rigid formalities to obtain credit facilities as well as high interest rates are challenges to farmers.

Marketing - transportation and poor or lack of infrastructure is the major marketing constraints. To sustain an effective improvement programme, infrastructure is important, which is either partially or completely lacking in the developing countries, resulting to poor communication, inefficient recording systems, poor data collection or processing procedure, and unstandardised methods of evaluation (Bondoc *et al*., 1989).

2.2. Principles of breed improvement

2.2.1. Development of a breeding objective

The breeding objective (aggregate genotype or breeding goal) is defined in terms of traits of known genetic and phenotypic relationships (Tess *et al*., 1983b). It is expressed by profit or production efficiency, where economic values derived for each trait express the direction of the desired improvement (Hirooka *et al*., 1998). It comprises traits that are to be improved genetically because they influence returns and costs to the producer (Kahi and Nitter, 2004). In any genetic improvement programme, a well-defined breeding objective should be considered first and should represent the overall objectives of the target groups who directly benefit or use the genetically improved animals.

Breeding objectives can be defined either in terms of biological or economic efficiency. The biological efficiency uses metabolizable energy (ME), while economic efficiency uses cost as a measure (Tess *et al*., 1983b). The ratio of input to output (efficiency) has been recommended to be the best measure of the two. In any livestock improvement programme, profit, return on investment or cost per unit production should be the main goal (Dickerson, 1970; Harris, 1970). Smith *et al*. (1986) concluded that economic efficiency is a more appropriate basis for estimating economic values.

Steps of developing breeding objectives

Definition of breeding objectives follows the following steps (Ponzoni and Newman, 1989; Hirooka *et al*., 1998): (1) specification of the breeding, production and marketing systems; (2) identification of sources of income and expense in the system; (3) determination of the biological traits that influence income and expense in the system, and (4) derivation of appropriate economic values of each trait utilized in the breeding objective.

Specification of the breeding, production and marketing systems - specification of the breeding system involves describing the role of the breed to be used in a breeding programme (Ponzoni and Newman, 1989). In Kenya, the most preferred breeds are Friesian, Aryshire, Jersey and the Guernsey (Bebe *et al.,* 2002; Gachuiri *et al.,* 2012). The role of the breed is to determine the sample of the genes present in the production system (Kluyts *et al*., 2003). While specification of production and marketing system involves determining the feeding scheme of the animals, the age composition of the herd, the replacement policy and age of animals at marketing and slaughter (Ponzoni and Newman, 1989). Understanding the herd composition aids the identification of age of animals and the numeric distribution of the herd, the number of replacements required each year, the number of animals of all classes available for market every year. These details are also important to estimate the economic value since traits are expressed with different frequency and at different times (Kluyts *et al*., 2003).

Identification of sources of income and expense - this enables identification of the sources of revenue and expenditure, which enable the formulation of the profit equation. In a dairy enterprise, revenue is obtain from sale of milk, cull heifers and cows, and bull calves while expenses are from feed intake, husbandry, marketing and health which are variable and fixed costs (Kahi *et al*., 2004).

Determination of biological traits influencing revenues and costs - during this phase, the profit equation is expressed as a function of biological traits that impact on income, expense or both (Ponzoni and Newman, 1989). The traits commonly included in the breeding objective of dairy cattle are; production (milk yield and butter fat yield), reproductive traits (age at first calving and calving interval), growth traits (pre-weaning, post-weaning and mature live weight), survival (pre-weaning and post-weaning survival rates) and longevity (productive life time). Table 2 shows the mean performances of traits that have been included in the breeding objective in Kenya. These performances can be used to estimate genetic and phenotypic improvement trends (Shook, 2006).

Table 2: The mean performances of traits in the breeding objective of dairy cattle in Kenya

Breed	Traits[a]							
	CI	LL	FY	MLW	AFC	MY	Country	Source
Holstein-Friesian						10,447	Israel	Weller (1989)
”	412		121		35	3,577	Kenya	Rege (1991)
	372	300			24	5,830	Zimbabwe	Mpofu *et al*. (1993)
”		294			32		”	Makuza and McDaniel (1996)
”			253			7,204	South Africa	NDPT (1998)
”		363			25	5,117	The Sudan	Ageeb and Hayes (2000)
”	390		202		28	6,000	Costa Rica	Vargas (2000)
”	406	300		-	28	5,056	Kenya	Ojango and Pollot (2001)
”	460				36	2,953	”	Muasya (2005)
Ayrshire	455	253			38	2,573	”	Kahi *et al*. (2004)
”	460				37	2,856	”	Muasya (2005)
”	487			-	39		”	Amimo *et al*. (2006)
Guernsey	466				33	2,353	”	Muasya (2005)
”	486	269			36	2,189	”	Kahi *et al*. (2004)
Jersey	445				34	2,334	”	Muasya (2005)
”		408			31	1,788	”	Njubi *et al* (1992)
”	430	242			34	1,872	”	Kahi *et al*. (2004)
”	412				30	2,112	”	Musani and Mayer (1997)
”	390				40	4,000	Costa Rica	Vargas (2000)
Friesian-Sahiwal cross	388	320		485	-	3,922	Kenya	Kahi *et al*. (2000)
Sahiwal	468	282			45	1,368	”	Ilatsia *et al*. (2007)
”	422	307			34	3,158	”	Muhuyi and Lokwaleput (1998)
”				338			”	Ilatsia *et al*. (2011)

[a]MY-milk yield at 305 days; CI-calving interval (days); LL-lactation length (days); FY-fat yield (kg); MW-Mature weight; AFC-age at first calving (months).

Derivation of economic and biological values - an economic value of a trait expresses the value of a unit change in that trait, while keeping all the other traits in the breeding goal constant (Bekman and van Arendonk, 1993) or it can be the value in monetary units of one unit of a trait (Falconer and Mackay, 1996). Economic values are important in selection index theory where the aggregate genotype is defined as a linear function of traits to be improved and each trait is multiplied by its economic weight (Smith *et al.*, 1986; Bekman and van Arendonk, 1993). Economic values can be derived from the profit function in two major ways: (1) by accounting for a unit change in returns (marginal returns) and of costs (marginal costs) that result from improvement of a trait, which is the marginal profit or partial budgeting of the function with respect to the trait of interest and (2) by partial differentiation of the function with respect to the trait of interest.

The two methods of deriving economic values are applied using either the normative approach (data simulation or bio-economic modelling) or positive approach which analyzes field data. Bio-economic simulation models can be used to examine changes in the profit or production efficiency due to genetic change and to derive economic values. Simulation modelling is important in offering more detailed and mechanistic understanding of the relationship between breeding and production (du Plessis and Roux, 1998). A model is an equation or a set of equations that represent the behaviour of a system, while a multi-equation encompassing both biological and economic parameters is a bio-economic model (Groen *et al.*, 1997). The biological value of a trait is the change in biological efficiency due to a unit change in genetic merit of a trait of interest, all other traits being constant. It is also estimated using bio-economic models. Incorporating risk in breeding goals influences the cost–benefit analysis of breeding programs and hence affect selection (Kulak *et al.*, 2003).

Incorporation risk into the bio-economic model

Future products and input prices are uncertain (Hirooka and Sasaki, 1998). The product prices influence the contribution of improvement of animal traits to economic efficiency of production (Groen, 1989). Failure to account for risk results to overestimation of the value of selection which could result to suboptimal genetic gains when error is larger than 50% (Vandepitte and Hazel, 1977; Amer and Hofer, 1994).). The traditional profit model assumes perfect knowledge of all relevant parameters while a risk rated profit model like the one described by Kulak *et al.* (2003) accounts for the producers risk attitude and variance of market prices.

Discounted economic values

Animal breeding aims at changing the genetic merit of animals in future generations to ensure they produce the desired products more efficiently under future economic, natural and social circumstances. Cumulative discounted expressions explain the future expression of genetic superiority due to selection, while economic values represent the current expression of genetic superiority. The product between the economic value and the cumulative discounted expression is the discounted economic value (Groen *et al.*, 1997).

The cumulative discounted expressions (CDE) of traits are calculated using the Gflow Computer Programme (Brascamp, 1978). The CDE can be calculated using year or generation approach. The generation approach overestimates CDE and, therefore, the year approach is recommended (Hill, 1974). The discounted gene flow method is used at discounting rates of 0%, 5% and 10% and considering all generations with trait expression. In the programme, CDE are estimated as follows:

$$\mathrm{CDE}_{lT} = \sum_{t=0}^{T} hm_{lt} \left(\frac{1}{1+r} \right)^{l} \qquad \text{(Equation 1)}$$

where T is the time horizon, l the selection path, h the incidence vector that specifies frequencies of the contribution of each age-class to phenotypic expression of a trait, m_{lt} a vector which specifies the relative contribution of the initial set of genes in a particular selection pathway l to the genes of animals in this age-class at time t, and r the interest rate at the base year (t = 0). The numbers of rows of h and m vectors are equal to the number of age-classes and sexes within the tiers considered in the gene flow.

2.2.3. Genetic and phenotypic parameters

It is important that traits in the breeding objective be heritable, have a variation and their phenotypic and genetic correlations with the traits in the selection criteria be known (Rewe *et al.*, 2006). Table 6 presents the heritability, genetic and phenotypic correlations of traits in the breeding objective from various studies. These estimates vary depending on the population's gene frequency, previous selection, environment and the dynamics of the population from which the data were collected. It is important to note that genetic and phenotypic parameters for survival traits are rare. Production traits (MY, FY, MLW) are more heritable than the functional traits (AFC, CI, LL, PreWDG, PreSR, PostSR and PLT) and more correlated. Production and functional traits are more correlated to their related production and functional traits. For example, MY and FY are both highly genetically and phenotypically correlated between themselves and to LL. The low heritability values for reproductive and survival traits suggest that they are more influenced by the environment.

2.2.4. Prediction of genetic gain

Genetic gain is the mean breeding value of the selected parents, predicted from the regression of breeding values on index values or the change in performance seen in a new generation after mating the selected parents. It is derived as shown in equation 1 below:

$$\Delta G = i r_{IA} \sigma_A \qquad \text{(Equation 2)}$$

where r_{IA} is the accuracy of selection and is the correlation between the index values and breeding value, which is maximized in the construction of an index, i the selection intensity and σ_A the square root of the genetic variation for the trait being selected (Rendel and Robertson, 1950; Falconer and Mackay, 1996).

Selection criteria

Trait measurements are required to carry out any genetic evaluation because the true genetic value is not known and at times not measurable (Falconer and Mackey, 1996). Selection criteria are the measurements used to estimate an animal's genetic value. Sometimes the traits to be improved may be immeasurable and, consequently, other measurable traits that are highly correlated to these traits are chosen as criteria to select for the immeasurable traits (Hazel, 1943). Mature live weight can be evaluated using BWT, ADG and WWT as the criteria of selection, while to select for reproductive performance, AFC, CI and the conception rate (CR) can be used (Gutierrez *et al*., 2002). In this study, survival was evaluated using mortality rates. The more the traits in the criteria, the higher the accuracy of estimation (Pirchner, 1983).

Selection index

Selection index is a linear function of phenotypic observations of traits measured on an individual and it is the best linear prediction of an individual's breeding value (Hazel, 1943; Smith *et al*., 1986). It takes the form of a multiple regression of the breeding value on all the sources of information (Falconer and Mackay, 1996). It is like a yardstick for measuring the net merit of breeding animals with an aim of attaining maximum genetic progress. To achieve optimum results for selection, all the information available about each individual's breeding value combined into an index of merit should be used. This involves use of matrix methods, especially with more than two sources of information. It defines the breeding goal in terms of an aggregate genotype selected for through a correlated information index. A selection index that considers genetic and economic gains is more valuable in a breeding programme (Hazel, 1943). Selection index is estimated as

$$b=P^{-1}Gv \qquad \text{(Equation 3)}$$

where b is a vector of index weights, P the phenotypic variance-covariance matrix of the traits in the selection criteria, G the genetic variance-covariance matrix between the traits in the selection criteria and those in the breeding objective and *v* a vector of the economic values of traits in the breeding goal.

Table 3: Heritability, genetic correlations (above diagonal) and phenotypic correlations (below diagonal) of traits in the breeding objective in Kenya

Parameter[b]	Traits[a]										
	AFC	MY	FY	CI	WWT	PreWDG	PostWDG	MLW	PreSR	PostSR	PLT
σ_p	114.00	1620.00	41.30	79.00	15.60	19.00	743.00	54.14	30.00	30.00	864.90
h^2	0.38	0.26	0.10	0.06	0.34	0.29	0.32	0.30	0.09	0.09	0.11
R		0.34		0.06							
AFC (days)		0.20	-0.10	-0.21		-0.25	-0.25	0.15			
MY (kg)	-0.21		0.75	0.17		0.10	0.11	0.23			
FY (kg)	0.05	0.75		0.08		0.10	0.11	0.12			
CI (days)	-0.21	0.17	0.08			0.00	0.00	-0.53			0.10
WWT (kg)				0.84		0.95	0.88				
PreWDG (kg)	-0.25	0.10	0.10	0.10	0.95		-0.25	0.40	0.06	0.03	0.10
PostWDG (kg)	-0.25	0.11	0.11	0.10	0.88	0.49		0.47	0.03	0.06	0.10
MLW (kg)	0.15	0.23	0.12	-0.53		0.40	0.47		0.01		0.27
PreSR (%)	0.00	0.00	0.00	0.00	0.04	0.06	0.03	0.00			
PostSR(%)	0.00	0.00	0.00	0.00		0.03	0.06	0.00	0.01		
PLT (days)	-0.13	0.00	0.00	0.10		0.10	0.10	0.27	0.00	0.00	

[a] AFC, age at first calving (days); MY, milk yield (kg); FY, fat yield (kg); CI, calving interval (days); LL, lactation length (days); PreWDG, pre-weaning daily gain (g/day); PostWDG, post-weaning daily gain (to 18 months) (g/day); MLW, mature live weight (kg); PreSR, pre-weaning survival rate (%); PostSR, post-weaning survival rate (%); PLT, productive life time (days). MY period – 305 days

[b] σ_p, phenotypic standard deviation; h^2, heritability.

R – repeatability.

Source: Rege (1991), Ojango and Pollot (2001) and Kahi *et al*. (2004).

5.5.3. Genetic evaluation

Genetic evaluation refers to the calculation and dissemination of genetic predictions for individual traits (Bourdon, 1998). Accurate prediction of the breeding values is of great value to genetic improvement since a few selected animals may produce a major influence on the genetic merit of the population. This requires estimation of variance components of the random effects. Selection criterion can be based on the best linear unbiased prediction (BLUP) of additive genetic effects, while to estimate the variance components of the fixed linear models of animal breeding, the restricted maximum likelihood (REML) method can be used. This has been made possible by the increased development of efficient computing algorithms and computing power (Hofer, 1998; Bourdon, 1998) using general programmes such as SAS, Genstat or R and the more specialised like ASREML (Gilmour *et al.,* 2006), VCE (Groeneveld *et al.,* 2010), DMU (Madsen and Jensen, 2006), DFREML (Meyer, 1988) and WOMBAT (Meyer, 2007). BLUP uses pedigree information, individual performance as well as genetic and phenotypic parameters. Selection is sometimes based solely on the individual performance records, and, therefore mass or individual phenotypic selection but BLUP is more accurate theoretically (Belonsky and Kennedy, 1988).

Best Linear Unbiased Prediction (BLUP)

Selection index method gives biased estimates because it does not correct for possible systematic environmental effects on the phenotypes like season, herd, age and year. To achieve increased accuracy in the prediction of unbiased breeding values, BLUP estimates are developed. BLUP is a statistical estimate derived from a mixed model procedure that accounts for possible systematic environmental effects on the phenotype and includes weighted information from relatives (Henderson, 1973). Mixed model procedures in BLUP include animal relationship matrix that enables the estimation of breeding values of all animals in the herd. It also enables sorting of animals in genetic groups to account for differences in expected value in the base population, especially when it is not possible to go back to the unselected base population. More accurate method have been devised to use genomics selection which uses genomic breeding values (Haye *et al*., 2009).

Genomic BLUP

Genome selection is the state of the art for genetic improvement of animal production. It was first coined by Haley and Visscher (1998). The use of high density marker map across the entire genome as a method of predicting total genetic value was initiated by Meuwissen *et* *al*. (2001). Marker-assisted selection provides completely heritable traits that can be measured at any age in both sex and that are potentially correlated with traits of economic value (Haley and Visscher, 1998). This is made possible by the large number of single nucleotide polymorphisms (SNP) discovered by genome sequencing and new methods to efficiently genotype a large number of SNP (Goddard and Haye, 2007).

Genome-wide selection has an advantages over procedures like progeny testing in dairy cattle because it reduces the operational costs and generation interval (Schaeffer, 2006). The efficiency of genome-assisted index selection is however highly affected by various genetic factors, which are mostly beyond the control of the breeders (Togashi *et al*., 2011). Togashi *et al*. (2011) carried out a comparison between estimated breeding values based on genome wide markers (GEBV) as compared with traditional BLUP for a number of alternatives, including low heritability, number of generations of training, marker density, initial distributions and effective population size. Their results showed that the more the generations of data in which both genotypes and phenotypes were collected, termed training generations (TG), the better the accuracy and persistency of accuracy based on GEBV. It also excelled for traits of low heritability regardless of initial equilibrium conditions, as opposed to traditional marker-assisted selection, which is not useful for traits of low heritability. The effective population size was found critical for populations starting in Hardy-Weinberg equilibrium but not for populations started from mutation-drift equilibrium. In their evaluation Togashi *et al*. (2011)concluded that GEBV can exceed the accuracy of BLUP provided enough TG are included.

2.2.5. Dairy cattle breeding structure for dissemination of superior genetics

Animal breeders seek to improve the performance of the next generation of animals using the selected superior parents. This requires development of organized selection and mating systems so as to optimize response to selection (Lewis and Simm, 2000). In most developing countries, the livestock industry is unstructured and constrained. This is contrary to the livestock industries in the developed countries where there are national selection programmes that facilitate recording systems and reproductive technologies (Bondoc and Smith, 1993). An unstructured industry consists of a number of independent closed herds, each with its own breeding objective and rate of genetic progress through local selection programmes, breed substitution and crossbreeding (Cunningham, 1980). A structured industry is organized into a nucleus where selection and mating decisions are made, a multiplication tier and a commercial population.

A nucleus scheme takes the form of a pyramid in terms of animal numbers and migration of germplasm and can have different number of tiers and migration policies (Roden, 1994). The nucleus can either be run as open, closed or sire reference scheme. The nucleus occupies the peak of the pyramid while below it is the multipliers and the commercial herds that source the genetic materials in form of live animals, semen or embryos from the nucleus (Bondoc and Smith, 1993). The use of reproductive technologies like AI makes the multipliers less important in the dairy industry because genes flow from the nucleus to the commercial population directly (Garrick, 1993).

The successful implementation of a breeding scheme in smallholder and pastoral production circumstances is largely dependent on adequate interaction between the nucleus and farmers' flocks, in a technical as well as socio-economic sense (Kosgey *et al*., 2006). The nucleus should be set up with the breeding objectives of the farmer in mind because the nucleus-breeding objectives impact on the whole scheme. The main challenge in genetic improvement programmes in developing countries in the tropics is how to effectively organize breeding schemes involving farmers at the village level, how to record such flocks and to monitor progress (Osinowo and Abubakar, 1988). To involve farmers, it is advisable to back the breeding programme with an effective extension service for maximum effect (Kosgey *et al*., 2006).

Open nucleus scheme

In an open nucleus scheme, animals are allowed to move from the nucleus herd to the lower tiers and *vice-versa*. The nucleus can either be dispersed or centralized. Figure 6 shows a two-tier open nucleus scheme where there is movement (shown with arrows) of genetic material from the nucleus to the participating herds and *vice-versa*. In this scheme, a large number of base females must be recorded, of which a very small proportion is used as nucleus replacements. This allows recording in the base herd but the cost of recording prohibits the collection of detailed information on all base females. To avoid the cost, Mueller (1984) proposed preliminary selection on measurements that are cheap to obtain, followed by a second selection on more expensive criteria obtained for only a small fraction of base females. This can result to extra genetic gain, which might compensate for the additional costs. Sires could be selected in stages where progeny test results could be used in the second stage, because it may be impracticable to retain all of them until full information is collected.

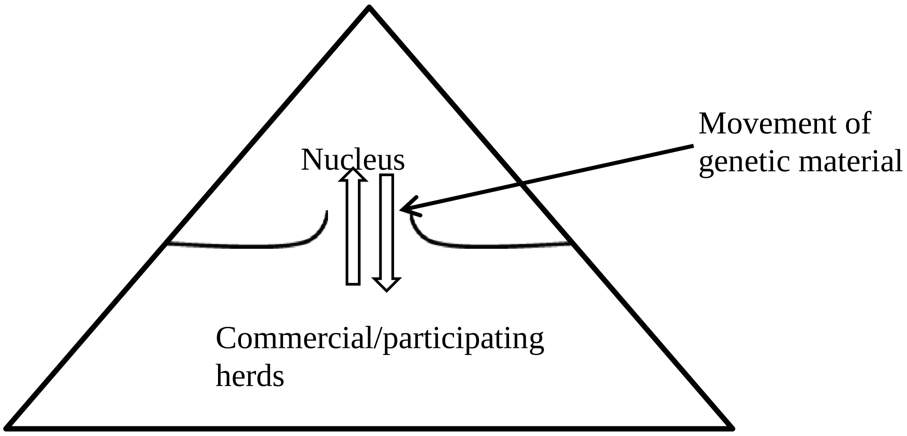

Figure 5: Illustration of a two-tier open nucleus breeding scheme

The movement of animals from the lower tiers to the nucleus is recommended because, Mendelian sampling can generate superior offspring to the average of the parents in the commercial population (Garrick, 1993). It is also beneficial when selecting for lowly heritable traits since a lower response per generation would reduce the genetic lag between the nucleus and the commercial population (James, 1977). In this scheme, it is only females of high merit, and not males, from lower tiers are allowed to migrate up for breeding in the nucleus.

Closed nucleus scheme

In a closed nucleus, selection is only done within the nucleus, i.e., there is no importation of genes from the lower tiers. Male replacement stock for the nucleus herds are selected only within the nucleus and no importation is done from the commercial population, resulting in a one-way flow of genes. Figure 7 below shows a two-tier closed nucleus scheme where there is only one direction of movement (shown with arrows) of genetic material from the nucleus to the participating herds. The scheme requires that elaborate infrastructure be in place due to the required high level of organization and expertise, and use of reproductive technologies (Cunningham, 1999). It has the advantage of blocking unimproved genetic material from the commercial herds into the nucleus where superior genetic material is bred. The genetically superior males and females not selected for replacement in the nucleus are used to genetically improve animals in the lower tiers (James, 1977). In some circumstances, the nucleus can be opened to allow the genetically superior cows into the nucleus after considerable genetic improvement in the commercial herd (Garrick, 1993).

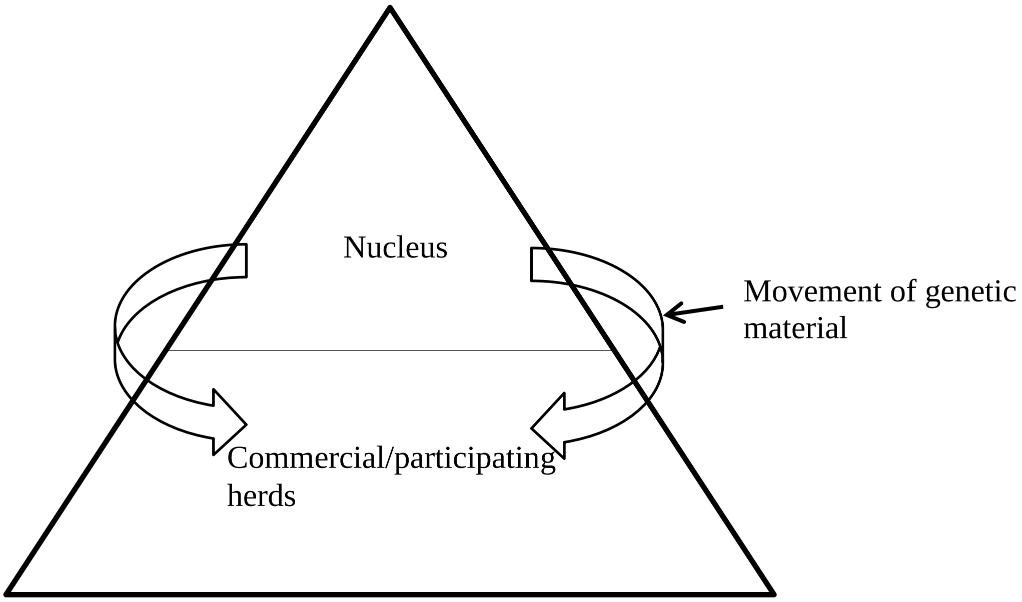

Figure 6: Illustration of a two-tier closed nucleus breeding scheme

A sire reference scheme

A sire reference scheme (SRS) involves the use of common sires by a group of farmers in different environments. This provides a link between herds, especially in dispersed nucleus schemes, where there are dispersed nuclei and, consequently, increased accuracy of calculating estimates like genetic gains (Smith, 1988; Bondoc and Smith, 1993; Garrick, 1993). Figure 8 below illustrates how (SRS) operates. A SRS offer advantages to participating breeders, non-participating breeders and crossbred calf producers purchasing bulls from SRS because: (a) across flock estimated breeding values in SRS are more accurate due to more effective separation of genetic and non-genetic effects and fuller use of information from relatives; (b) BLUP estimated breeding values can be compared across flocks that participate in SRS which increases the pool of animals available for selection, allowing more intense selection of outstanding animals and therefore faster rates of genetic progress; (c) BLUP estimated breeding values from SRS can be compared across years enabling breeders and commercial producers to ensure that the animals they select were better than those used in previous years (Simm and Wray, 1991).

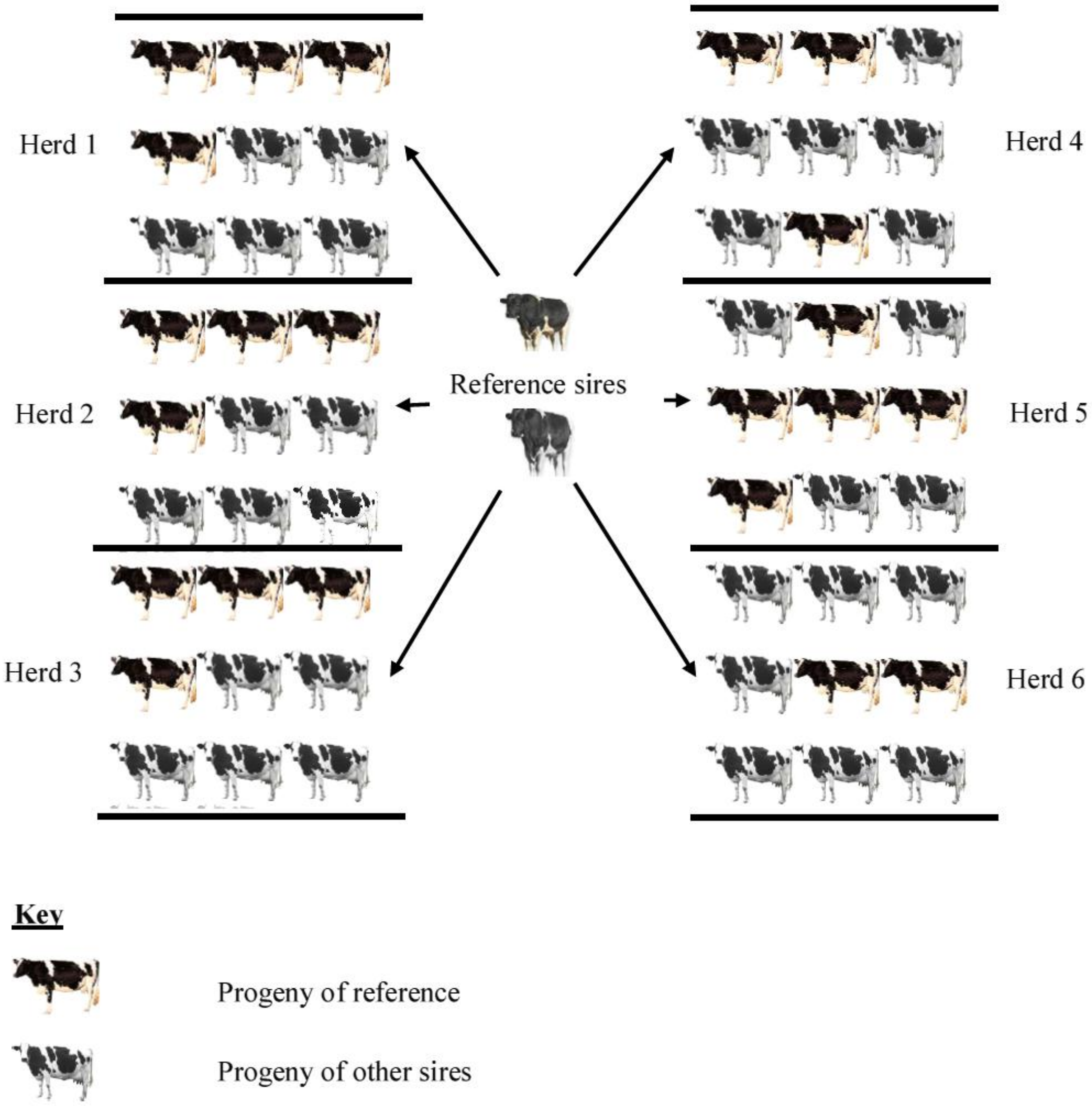

Figure 7: An illustration of a sire referencing scheme

2.3. Systems analysis

All production systems are complex. For example, dairy cattle production consists of various genetic, nutritional, management and economic factors, and their interrelationships (Hirooka *et al*., 1998). The use of mathematical models to study the behaviour of a production system is called systems analysis. In systems analysis, all major inputs and outputs, and relationships of the various components in the system are put into consideration (Joandet and Cartwright, 1975; Cartwright, 1979; Hirooka *et al*., 1998). Bio-economic models are used to simulate real life and, therefore, determine the effect of genetic change on production efficiency (Tess *et al*., 1983a). Systems analysis involves the following sequence of steps: (1) specification of the problem and defining the goals; (2) setting boundaries of the system and level of modelling; (3) formulation of the system model in terms of its components and the functional relationships of the components; (4) specification of the detailed model in quantitative form; (5) programming for computer operation; (6) validation of the model against experimental data and other real world knowledge; (7) simulation or experimentation of outcomes under different sets of conditions; and (9) analysis of results (Cartwright, 1979).

There are various ways of carrying out systems analysis, i.e., use of linear or non-linear, static or dynamic and stochastic or deterministic models. Models can be used to optimize an objective function, determine the effect of changes of a specific variable onto the final output, and provide insight about the relationship among components in a system, and also to simulate experiments (Dickerson, 1970; Joandet and Cartwright, 1975). One model can be used to examine more than one system as long as the assumptions are not violated (Hirooka *et al*., 1998).

CHAPTER THREE

A BIO-ECONOMIC SIMULATION MODEL INCORPORATING RISKS FOR PASTURE-BASED DAIRY PRODUCTION SYSTEMS IN THE TROPICS

3.1. Introduction

In any genetic improvement programme, well defined breeding objectives should be considered first since they represent the overall objectives of the target producers and consumers. The breeding objective, aggregate genotype or breeding goal comprises the breeding values and economic values of traits to be improved genetically due to their contribution to returns and costs of a production system. Economic values are assigned so that selection emphasis is proportional to the economic importance of each of the traits in the breeding objective *(*Amer *et al*., 2001). The development of breeding objectives involves description of the breeding, production and marketing systems, establishment of the biological traits that influence income and expense and derivation of economic values of the breeding objective traits (Ponzoni and Newman, 1989; Hirooka *et al*., 1998). Breeding objectives for a dairy cattle production system in Kenya have been developed by Kahi and Nitter (2004). In that study, economic values were estimated using a bio-economic model that only simulated revenues and costs for the traits of interest due to scarcity of economic information.

Bio-economic models allow simulation of production systems considering a large number of factors and their interrelationships simultaneously (Cartwright, 1979). The model used by Kahi and Nitter (2004) did not include all the important relationships in a production system. In that study, the approach also assumed the risk attitude of the producers and the market price variation (Kulak *et al*., 2003). The later study showed that when developing breeding objectives, it is important to take into account the fact that knowledge is imperfect and economic circumstances are dynamic with time because the future prices of products are uncertain. During the definition of breeding objectives, therefore, producers' risk preferences should be included because it influences the cost-benefit of a breeding programme and the selection decisions (Kulak *et al*., 2003; Pruzzo *et al*., 2003). The variance of profit and producers risk attitude are used to define risk, where the variance of profit is derived from the input and output prices, while a coefficient value is used to account for risk aversion when calculating profit (Kulak *et al*., 2003).

Incorporation of producers risk is important in the definition of breeding objectives, especially in the tropics that are characterized by unstable production circumstances. In this Chapter, an integrated bio-economic simulation model that incorporates risks and takes into account the dairy production circumstances in the tropics is developed.

3.2. Materials and method

3.2.1. Description of the production system

A pasture-based dairy production system was assumed. In Kenya, Friesian, Aryshire, Jersey and Guernsey are the *Bos taurus* breeds mostly reared (Bebe *et al*., 2003b). These breeds have a dual-purpose role. The predominant grass species is *Panicum infesticum.* The roughage is fed to the animals throughout the year at a ratio of 33% silage and 67% natural pasture (Kahi and Nitter, 2004). The cows are grazed on natural pasture and supplemented with silage. It is assumed that the dry season did not have an effect on the productivity of the animals since the animals are supplied with all their nutritional requirements. This is achieved by ensuring that pasture is available through preservation as silage, pasture management and feeding the cows on concentrates during the high energy demand period of lactation. The lactating animals are fed on concentrates during the lactation period at a constant rate of 3 kg per day. All the standard management practices like drenching, spraying, prophylactic treatment, vaccination and others are undertaken and 100% AI is assumed. Marketing of animals for slaughter is based on live weight at a fixed price, while marketing of milk is based on milk volume. However, a future scenario where marketing of milk will be based on its composition (specifically the butter fat content) is also assumed.

3.2.2. Model description

Development of breeding objectives involves the development of a bio-economic simulation model, determination of the animal traits, nutritional, management and economic variables that affect income and expense then deriving economic values (Ponzoni and Newman, 1989). In this study, a deterministic bio-economic model is developed for a pasture-based dairy production system and it accounts for risks in the derivation of profits during the whole life cycle of a cow. Inputs and outputs of the cow are considered from the entry point to a breeding herd as a replacement to culling (voluntarily or involuntarily) after a number of reproductive cycles. All male calves are considered to be sold at a fixed price within the first week after birth, mainly to avoid the cost of rearing. Energy intake is assumed to be sufficient to meet all energy requirements and environmental factors like temperature and rainfall did not have any effects on inputs or outputs.

Two production circumstances were considered in this study: fixed herd (FH) and fixed pasture input (FP). Under FP, the number of animals in the simulation model are determined by a fixed pasture that is available and excess animals are culled, while under FH, a fixed herd size is assumed and the energy requirements of these animals is assumed to be met. Feed (roughages and concentrates) is the main limiting factor of dairy production. Roughages are the principle source of feed for most dairy farms and an obvious constraint is farm size (i.e., hectares of land available for their cultivation). Climatic factors also influence the availability of roughages. A restricted farm size limits the number of animals able to be maintained on it, while feed is scarce during the dry season. For concentrates, the constraint is the financial resources at the disposal of the farmer for its purchase. The availability of financial resources is directly determined by the profitability of the herd. Consequently, breeding objectives need to be developed taking into account the constraints or limitations prevailing in the area where the breeding programme is to be set. Table 4 shows the assumed values of the input variables. These variables were obtained from previous studies on dairy cattle in the tropics (Osei *et al*., 1991; Rege, 1991; Hirooka *et al*., 1998; Ojango and Pollot, 2001; Ageeb and Hayes, 2004; Kahi and Nitter, 2004; KNBS, 2010) and, therefore, reflect the typical dairy productions circumstances in the tropics. The variables are grouped into animal traits, management, economic and nutritional variables.

Table 4: Assumed values of biological input variables in the models

Variables	Units	Symbols	Value
Animal traits			
Milk yield per cow per parity	Kg	MY	4,557.00
Milk fat yield	g/kg	FY	0.0323
Mature live weight	Kg	MLW	435.00
Pre-weaning daily gain	g/day	PreWDG	313.00
Post-weaning daily gain	g/day	PostWDG	506.00
Birth weight	Kg	BWT	30.42
Weaning weight	Kg	WWT	69
Gestation period	Days	Gest	278.34
Woods parameters		B	0.121
		C	-0.025
Cow mortality		Cmort	0.02
Calf pre-weaning mortality		Calfmort	0.09
Nutritional variables			
Metabolizability		Q	0.6*
Dry matter content of concentrates	%	DMconc	89
Dry matter content in pastures (*Panicum infesticum*)	%	DMpast	20
Energy content in concentrates	MJ of NE_L/kg DM	ECconc	7.19
Energy content in pastures	MJ of NE_L/kg DM	ECpast	5.65
Management variables			
Period from birth to weaning	Days	PBW	126
Period from weaning to 18 months	Days	PW18	414
Period from 18 months to first calving	Days	P18FC	476
Maximum reproductive cycles		Cmax	6
Oestrus detection rate		Edr	0.75
Age at first mating	Days	AFM	741
Maximum inseminations	Days	Imax	3
Period from calving to 1st estrus cycle	Days	E	85.8
Single conception rate		SCR	0.6
Economic variables			
Price of calf	Kes	Pmilk	1,000.00
Price per live weight kg	Kes	Plvwt	56.18
Price of milk per kg	Kes	Pmilk	20.00
Price butter fat per kg	Kes	Pfat	92.35
Cost of concentrates/MJ	Kes	Cconc	1.62
Cost of pasture/MJ	Kes	Cpast	0.10
Cost of silage/MJ	Kes	Csilage	0.64
Health cost for; a heifer/day	Kes	Chealthh	0.48
a cow/day	Kes	Chealthc	4.48
Reproductive cost for; a heifer	Kes	Creprh	0.69
a cow	Kes	Creprc	0.81
Cost of labour/head/day	Kes	Clabour	4.63
Cost of labour for a cow/day	Kes	Clabourc	4.63
Milk marketing cost/kg	Kes	Cmilkm	1.12
Live weight marketing cost/kg	Kes	Clvwtm	2.81
Male calf marketing cost	Kes	Cmalecm	45.00
Fixed cost/head/day	Kes	Cfixed	1.12
Inflation rate	%		3.09

DM – Dry Matter; NE – Net Energy; MJ – Mega Joules; g – grams; kg – kilograms; Kes = Kenya Shillings

3.2.3. Herd dynamics

This includes the factors that influence the herd size, which are mainly culling, either voluntary or involuntary. Voluntary culling was considered as the removal of an animal from a herd due to fitness, while involuntary culling was based on poor performance, death or reproductive failures. Figure 9 is an illustration of the animal events and flows. Old cows were assumed to be slaughtered when they are approximately eight years old while heifers are to be kept for eighteen months when culling and replacement is done just before mating. A closed herd system was assumed, where the culled cows were replaced by own heifers. The first reproductive cycle for the replacement heifers was defined as an interval from replacement to weaning, and the subsequent reproductive cycles as the interval from weaning to next weaning. The growing period was included in the first reproductive cycle. Mortalities were accounted for by using a fixed mortality rates for the cows and calves in the model (Table 4). The cows that died (CD) in different stages of the reproductive cycle, i.e., before mating (CD_1) and weaning (CD_2) are shown in Figure 9. The calves that died within 24 hours after birth (DC_{24}), pre-weaning (DC_{PRW}) and post-weaning (DC_{PSW}) were also accounted for in the model.

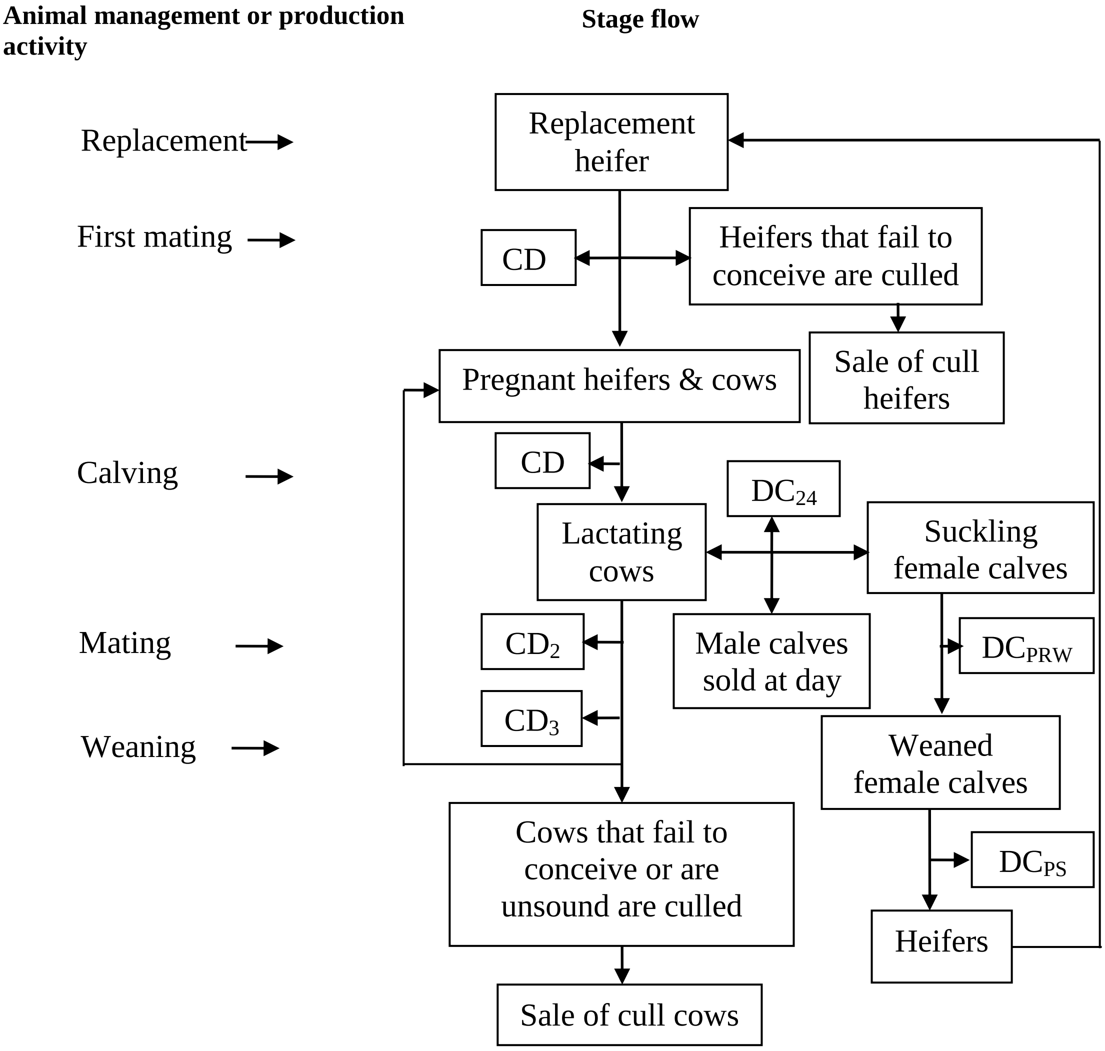

Figure 8: Schematic diagram of dairy cattle herd dynamics

(CD_0 – heifers dead during the growing period, CD_1 – cows dead from previous mating to weaning, CD_2 – cows dead between calving to the next mating, CD_3 – dead cows from mating to weaning, DC_{24} – calves that died within 24 hours after birth, DC_{PRW} – dead calves pre-weaning and DC_{PSW} – dead calves post-weaning).

3.2.4. Herd replacement

In a closed herd, replacement is done with own heifers and, therefore, the number of replacement heifers (RH) was computed as depicted in equation 4 below:

$$RH = r\left(NLC \times 0.5\right) \qquad \text{(Equation 4)}$$

where r is the replacement rate and was calculated as indicated in equation 5 below;

$$r = NFRH \div \sum_{n=1}^{N}\left(NLC \times 0.5\right) \qquad \text{(Equation 5)}$$

where NFRH is the proportion of first replacement heifers, which was assumed to be 1.0. The proportion of non-replacement heifers (NRH) was, consequently, calculated as shown in equation 6 below;

$$\mathrm{NRH} = \mathrm{NLC} \times 0.5 \times (1 - \mathrm{r}) \qquad \text{(Equation 6)}$$

where NLC was the proportion of live calves at weaning predicted as indicated in equation 7 below;

$$\mathrm{NLC} = \left(1 - \left(\mathrm{Calfmort} + 0.09 \times \mathrm{pcd_n}\right)\right) \times \mathrm{PCCD} \qquad \text{(Equation 7)}$$

This was considering a 9% mortality of calves at birth due to dystocia and assuming that there were no perinatal calf deaths, a 1:1 sex ratio, and that the mortality rate of both male and female calves (Calfmort) was equal. The proportion of cows that calved down (PCCD) was computed as indicated in equation 8 below:

$$\mathrm{PCCD} = 1 - \mathrm{ProDCows_1 n} - 0.1 \times \mathrm{pcd_1} \qquad \text{(Equation 8)}$$

In equation 14 above, 0.1 was used to account for 10% mortality of cows at calving due to dystocia (Hirooka *et al*., 1998; Tomlinson *et al*., 2009).

3.2.5. Cow reproductive rate

After replacement in the first reproductive cycle, the proportion of own heifers that failed to conceive (HFC) were calculated as shown in equation 9 below:

$$\mathrm{HFC} = \left(1 - \mathrm{ProDCow_0 1}\right) \times \left(1 - \mathrm{CR_n}\right)^{\mathrm{Imax}} \qquad \text{(Equation 9)}$$

where $\mathrm{CR_n}$ is the conception rate in the $\mathrm{n^{th}}$ reproductive cycle, $\mathrm{ProDCow_0 1}$ the proportion of cows that died and Imax the fixed maximum times of insemination before conception (Table 4). The $\mathrm{CR_n}$ was calculated as indicated in equations 10 below;

$$\mathrm{CR_{n=1}} = \mathrm{SCR} \times \mathrm{Edr}$$

$$\mathrm{CR_{n\geq 2}} = \left[\left(1 - \mathrm{pcd_{(n-1)}}\right) \times \mathrm{CR_n} + \left(\mathrm{pcd_{(n-1)}} \times 0.85 \times \mathrm{CR_n}\right)\right] \times \mathrm{Edr} \qquad \text{(Equation 10)}$$

where SCR is the single conception rate; Edr the estrous detection rate and $\mathrm{pcd_n}$ the proportion of cows experiencing dystocia in the $\mathrm{n^{th}}$ reproductive cycle, which was calculated as described by Hirooka *et al.* (1998) as shown in equation 11 below;

$$\mathrm{pcd_1} = 0.0564\mathrm{BW} - 0.2038 - 0.0032 \times \mathrm{CCW}$$

$$\mathrm{pcd_2} = 0.02154\mathrm{BW} - 0.7227$$

$$\mathrm{pcd_{n\geq 3}} = 0.00608\mathrm{BW} - 0.223 \qquad \text{(Equation 11)}$$

where CCW is the cow weight at calving and BW the calf birth weight (averaged across sexes). Single conception rate, oestrous cycle number and oestrous detection rate determine the length of the period between the first mating to conception (calving to conception), ConcI_n, in the various reproductive cycles and were predicted as depicted in equation 12 below:

$$\mathrm{ConcI}_n = 21 \times \mathrm{CR}_n \times \sum_{x=1}^{\mathrm{xmax}} (1-\mathrm{CR}_n)^{x-1} \times (x-1) + E_1 \qquad \text{(Equation 12)}$$

where x is number of estrous cycle and E_1 the interval from calving to the first oestrous, with an additional voluntary waiting period (Table 4). This assumed that the oestrous cycle was 21 days and that the conception rate of the cows experiencing dystocia was lower by a 15% proportion than for the cows without calving difficulties (Danny *et al.*, 1973; Hirooka *et al.*, 1998). Single conception rate and Edr were constant variables in all reproductive cycles and are indicated in Table 4. Dystocia had an effect on the conception rate in the subsequent reproductive cycles and was, therefore, considered in the second and subsequent reproductive cycles. Since x is the number of oestrous cycle, while E_1 (Table 4) is the interval from calving to the first oestrous with an additional voluntary waiting period, E_1 is, therefore, omitted in equation 12 above for the first reproductive cycle.

A reproductive cycle as defined earlier is the period from weaning to the next weaning and is predicted as indicated in equation 13 below;

$$\mathrm{LRCyc}_n = (\mathrm{AFM} - \mathrm{PBW}) + \mathrm{ConcI}_n + \mathrm{Gest} + \mathrm{PBW}$$

$$\mathrm{LRCyc}_{n\geq 2} = \mathrm{ConcI}_n + \mathrm{Gest} \qquad \text{(Equation 13)}$$

where LRCyc_n is the length of nth reproductive cycle, AFM the age at first mating, PBW the period from birth to weaning and Gest the gestation period in days. The lengths are calculated separately because the growing period is included in the first reproductive cycle and not in subsequent cycles.

3.2.6. Cow mortality rates and culled cows

The proportion of cows that died (ProDCows) in a given period was calculated as a factor of cow mortality rate per year and the length of each period. It was computed as shown in equation 14 below:

$$\mathrm{ProDCows}_y n = \text{period length} \times \mathrm{Cmort} \div 365 \qquad \text{(Equation 14)}$$

where period (y) length is either the growing period (0) or period from previous weaning to calving (1) or from calving to next mating (2) or from mating to weaning (3).

Since the HFC_1 is known, the proportion of pregnant cows (heifers) was estimated as $PPC = 1 - HFC_1$.

The unsound cows (UC) proportion was calculated as depicted in equation 15 below;

$$UC = 0.013 \times (n + 1) - 0.014 \qquad \text{(Equation 15)}$$

The unfit cows were culled before the next reproductive cycle and, consequently, the proportion of cows that did not conceive in the next reproductive cycle (CFC_{n+1}) was calculated as shown in equation 16 below;

$$CFC_{n+1} = PCCD \times (1 - CR_{n \geq 2}) \times imax \times (1 - ProDCows_2 n - UC) \qquad \text{(Equation 16)}$$

while the proportion of pregnant cows in the next reproductive cycle (PGC_{n+1}) was computed as indicated in equation 17 below;

$$PGC_{n+1} = 1 - HFC_{n+1} \qquad \text{(Equation 17)}$$

The proportion of cows culled CC_n at weaning (non-pregnant, unsound and once without live calves) was calculated as depicted in equation 18 below;

$$CC_n = UC \times (1 - ProDCows_3 n) + HFC_{n+1} \times (1 - ProDCows_3 n) \qquad \text{(Equation 18)}$$

The proportion of culled cows as at the last reproductive cycle allowable (N) was estimated as shown in equation 19 below:

$$PCC_N = (1 - ProDCows_2 N) \times (1 - ProDCows_3 N) \qquad \text{(Equation 19)}$$

while the proportion of live cows at the end of a reproductive cycle was derived as indicated in equation 20 below;

$$PLC = (1 - ProDCows_3 n) \times PGC_{n+1} \qquad \text{(Equation 20)}$$

3.2.7. Growth

A growth curve is a function used to estimate changes in body weight and other body measurements like energy intake among other processes that take place in the duration of an animal's life. Since growth curves are described in terms of weight or other body measurements in relation to age, birth, weaning and mature weights were used in the growth curve for breeding females (Hirooka *et al.*, 1998). In the growth curve of breeding females, the period from birth to weaning is assumed to be represented by a straight line, while from weaning to culling by the Brody curve (Brody, 1945). This is with the assumption that there is unrestricted feed intake and constant environmental conditions. Using birth weight (BW), weaning weight (WW) and mature weight (MW), the live weight (LW(T)) of a cow at any given time (T) can be predicted as depicted in equation 21 below;

$$\mathrm{LW}(\mathrm{T}) = \left[(\mathrm{WW}-\mathrm{BW}) \div \mathrm{PBW}\right] \times \mathrm{T} + \mathrm{BW} \qquad \text{when } \mathrm{T} \leq \mathrm{PBW}$$

$$\mathrm{LW}(\mathrm{T}) = \mathrm{MW} - (\mathrm{MW}-\mathrm{WW})\,\mathrm{EXP}^{-k(\mathrm{T}-\mathrm{PBW})} \qquad \text{when } \mathrm{T} > \mathrm{PBW} \quad \text{(Equation 21)}$$

where PBW is the period from birth to weaning in days, T the age of the animal in days and k a maturity index.

Using equation 21 above, it is possible to estimate the pre-weaning daily gain (PreWDG) and post-weaning daily gain (PostWDG) in kg/day, to get the value of k as shown in equations 22 below;

$$\mathrm{PreWDG} = (\mathrm{WW}-\mathrm{BW}) \div \mathrm{PBW}$$

$$\mathrm{PostWDG} = k\left(\mathrm{MW}-\mathrm{LW}(\mathrm{T})\right) \div \mathrm{PBW}$$

$$k = \left[(\mathrm{WW}-\mathrm{BW}) \div \mathrm{PBW}\right] \div (\mathrm{MW}-\mathrm{WW}) \qquad \text{(Equation 22)}$$

3.2.8. Dam weight during gestation

During gestation, the mass of the conceptus (MC) has to be added to the dam’s weight, and is calculated as from 141 days from the day of conception as predicted by ARC (1980) in equation 23 below;

$$\mathrm{MC} = (\mathrm{BW} \div 40) \times \left(10^{2.932-3.347\times\exp(-0.00406\times \mathrm{T_g})}\right) \qquad \text{(Equation 23)}$$

where $\mathrm{T_g}$ is the number of days from conception, which should be between 141 days and the total gestation period length, while $(\mathrm{BW} \div 40)$ is a correction term for calves with birth weights exceeding 40 kg.

3.2.7. Energy requirements

Energy intake per day was estimated as the total maintenance, growth, pregnancy and lactation requirements added together. The total ME requirement per animal was assumed to be met throughout the year. The total ME requirement in MJ was converted to amounts of natural pasture, silage and concentrate using proportions and then a cost of feed determined using the energy and dry matter contents of the pasture and concentrate (Table 4).

The maintenance requirements (MER) in MJ/day was predicted as indicated in equation 24 below;

$$\mathrm{MER} = \left(1.4 \times \mathrm{S} \times \mathrm{M} \times 0.28\mathrm{LW}(\mathrm{T})^{0.75} \times \mathrm{e}^{-0.03\mathrm{A}} + 0.0095 \times \mathrm{LW}(\mathrm{T})\right) \div \mathrm{k_m} + 0.1(\mathrm{MErG} + \mathrm{MErL})$$

$$\mathrm{MER} = \left(1.4 \times \mathrm{S} \times \mathrm{M} \times 0.28\mathrm{LW}(\mathrm{T})^{0.75} \times \mathrm{e}^{-0.03\mathrm{A}} + 0.0071 \times \mathrm{LW}(\mathrm{T})\right) \div \mathrm{k_m} + 0.1(\mathrm{MErG} + \mathrm{MErL})$$

(Equation 24)

where 1.4 is the breed difference correction factor, which is either 1.2 or 1.4 for *Bos indicus* and *Bos taurus,* respectively, S the sex difference correction factor, which is 1.0 for steers and heifers, m the correction factor suckled calves, which is $1.26 - 0.01\mathrm{A_w}$, where $\mathrm{A_w}$ is the age in weeks, A the correction factor for age in years, and it should be less than or equal to 6, $\mathrm{k_m}$ the efficiency of utilization of metabolizable energy (ME) for maintenance, which is calculated as $0.35\mathrm{q} + 0.503$, where q is the metabolizability of the diet (CSIRO, 1990; Hirooka *et al.*, 1998), and LW(T) is derived in equation 21, while $0.0095 \times \mathrm{LW}(\mathrm{T})$ and $0.0071 \times \mathrm{LW}(\mathrm{T})$ are the activity allowances for lactating and pregnant or non-lactating dairy cattle, respectively (AFRC, 1993).

From equation 24, the ME requirement for growth (MErG) in MJ/day is predicted by equation 25 below;

$$\mathrm{MErG} = \left(\frac{\left(4.1 + 0.0332\mathrm{LW}(\mathrm{T}) - 0.000009\mathrm{LW}(\mathrm{T})^2\right)}{\left(1 - 0.1475\mathrm{DG}(\mathrm{T})\right)} \right) \times \left(\frac{\mathrm{DG}(\mathrm{T})}{(0.78\mathrm{q} + 0.006)} \right) \text{(Equation 25)}$$

where LW(T) and DG(T) are live weight and daily gain at time T, respectively, as explained in equations 20 and 21. The constants (0.78q + 0.006) in equation 25 above represent the efficiency of utilization of dietary ME for growth (ARC, 1980; Hirooka *et al*. 1998).

The metabolizable energy for gestation (MErP) after the 141st day in MJ/day is predicted as indicated in equation 26 below;

$$\mathrm{MErP} = (\mathrm{BW} \times 0.025) \times \left[\left(0.0201 \times \mathrm{e}^{-0.0000576\mathrm{T_g}}\right) \times \left(10^{151.665 - 15164 \times \mathrm{e}\left(-0.0000576\mathrm{T_g}\right)}\right) \right] \div 0.113$$

(Equation 26)

where the term $(\mathrm{BW} \times 0.025)$ is a correction factor for calves with BW greater than 40 kg, while 0.113 is utilization of ME by the conceptus for growth. After calving down lactation period follows, and the metabolizable energy requirement for lactation (MErL) in MJ/day is predicted as shown in equation 27 below;

$$\mathrm{MErL} = \mathrm{MY} \times (0.00406 \times \mathrm{FY}) \div (0.35q + 0.420) \quad \text{(Equation 27)}$$

where MY is the milk yield in kg/day (equation 28 below) and FY the fat yield in the milk in g/kg, while $(0.35q + 0.420)$ represents the efficiency of utilization of ME for milk production. Milk yield in this model is predicted using the Wood's lactation curve (Wood, 1967) as depicted in equation 28 below;

$$\mathrm{MY} = \left(a \times T_l^{b} \times e^{-c \times T_l}\right) \quad \text{(Equation 28)}$$

If total milk yield (TMY) in a lactation period is known, a is estimated as indicated in equation 29 below;

$$a = \sum_{T_l}^{\mathrm{PBW}} \left(T_l^{b} \times e^{-c \times T_l} \div \mathrm{TMY}\right) \quad \text{(Equation 29)}$$

where a, b and c are Wood's equation parameters and T_l is the lactation period in days. The Wood's parameters b and c are given in Table 4. The values used in the model for b were 0.1498, 0.1, and 0.1196 and -0.0122, -0.0186 and -0.0299 for c in the first, second, third and above parities, respectively (Ojango and Pollot, 2001). A faster increase in yield and more persistent milk yield result in a larger b, while a higher peak in milk yield result in a smaller value of c (Ferris *et al.*, 1983). During the first two weeks after parturition, the dam´s milk in this model is assumed to be equal to the milk requirement of her calf regardless of the genetic potential of her milk production. In Central Uganda, daily milk yield was significantly affected by the management system, year, parity, stage of lactation and the interaction effect of the year with management system and stage of lactation (Nassuna-Musoke *et al.*, 2007). In that study, the season and calendar month did not have any effect on the mean daily milk yield, and this was attributed to the constant climatic stress.

3.2.8. Calves' energy requirements

It is assumed that during the first 2 weeks of life, calves depend entirely on milk to meet their daily ME requirements and that, thereafter, additional dietary feed is provided to cater for any deficiencies after taking milk. The ME from cow's milk (MEimilk) assuming that the metabolizability of cow's milk is 0.91 (Hirooka *et al.* 1998) was calculated as shown in equation 30 below;

$$\mathrm{MEimilk} = 0.91 \times \mathrm{MY} \times \mathrm{EVmilk} \quad \text{(Equation 30)}$$

The ME intake from dietary feed (MEifeed) was obtained as indicated in equation 31 below;

$$\mathrm{MEifeed} = \left[\frac{\mathrm{MER}}{(0.35q + 0.503)} + \frac{\mathrm{MErG}}{(0.78q + 0.006)}\right] - \mathrm{MEimilk} \qquad \text{(Equation 31)}$$

where MER is the maintenance requirements (equation 24 above), MErG the metabolizable energy requirement for growth (equation 25) and MEimilk the ME from cow's milk.

3.3. Incorporation of risk

Revenues and costs were estimated using risk-rated profit models as described by Kulak *et al.* (2003). Imperfect knowledge concerning risk attitudes of the producers and variances of market prices compared to the traditional profit model, which assumes perfect knowledge of all relevant parameters, are accounted in this model. The general risk-rated profit (P_r) equation was estimated as shown in equation 32 below;

$$P_r = E(P_t) - 0.5\lambda \mathrm{Var}(P_t) \qquad \text{(Equation 32)}$$

where $E(P_t)$ is the expected profit, λ, the Arrow-Pratt coefficient of absolute risk aversion and $\mathrm{Var}(P_t)$ the variance of the profit due to variability in input and output prices. An inflation rate of 3.09% (Table 4) in October 2010 was used to change the input and output prices (KNBS, 2010). The expected profit was estimated as depicted in equation 33 below;

$$E(P_t) = \mu_{po} f(g, e) - e\mu_{pi} \qquad \text{(Equation 33)}$$

while the Var(Pt) was computed as shown in equation 34 below;

$$\mathrm{Var}(P_t) = E[P_t - E(P_t)]^2 \qquad \text{(Equation 34)}$$

where μ_{po} and μ_{pi} are the expected values of input and output prices, respectively, g the vector of the variables determined by the genotype of the animal (genetic traits) and e the vector of the variables determined by the environment. Substituting equations 33 and 34 in equation 32, the risk-rated profit for the production systems were, therefore, computed as indicated in equation 35 below;

$$P_r = \mu_{po} f(g, e) - e\mu_{pi} - 0.5\lambda E\left[P_t - E(P_t)\right]^2 \qquad \text{(Equation 35)}$$

The Arrow-Pratt coefficient, λ, is used to measure the intensity of the farmer's aversion to risk. When a zero value of λ is used, it indicates that a decision maker is risk neutral, while a positive value indicates that an individual wants higher profits. The higher the value of λ used the higher the risk aversion. Arrow-Pratt coefficients of 0.0001 and 0.02 were used in this study because such values are scarce and complex to estimate (Kulak *et al.*, 2003; Peters *et al.,* 2010). Failure to account for risks has been observed to result to overestimation of profits and economic values (Hirooka and Sasaki, 1998).

3.4. Results

Figure 10 shows the simulated milk yield in the six reproductive cycles. The milk yield increased during the first three weeks in all cycles. In the 3rd to 6th reproductive cycles, the peak milk yield was achieved earlier and was higher than in the 1st and 2nd cycles. The total milk yield was highest in the 1st reproductive cycle since the production was more persistent than in the rest throughout the lactation period.

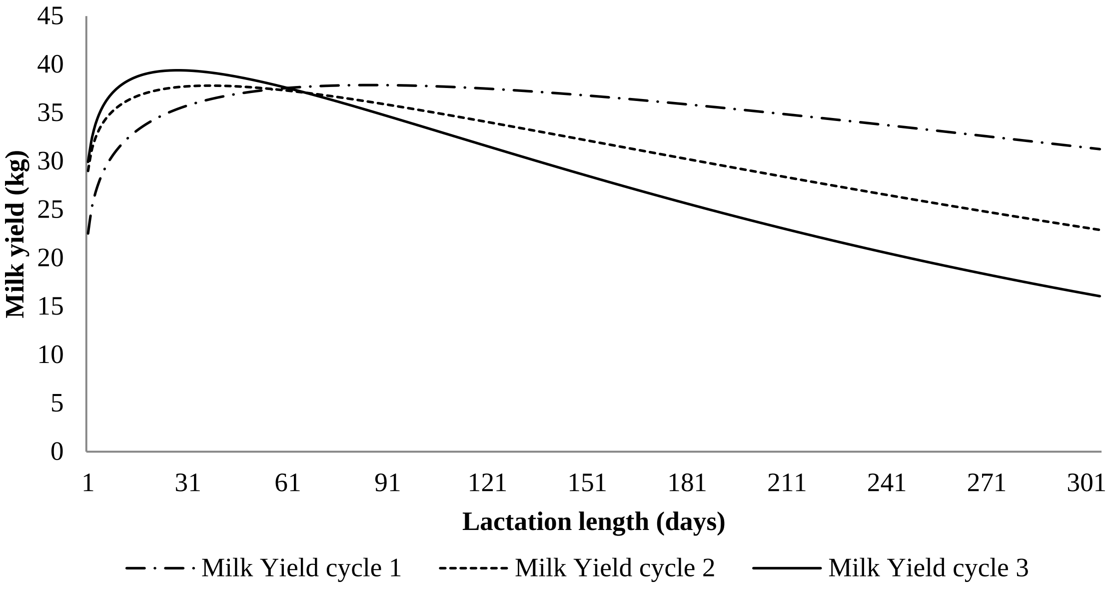

Figure 9: Simulated milk yield in the first, second and third reproductive cycles

The simulated growth rate from birth to the time of exit from the herd after the sixth reproductive cycle is shown in Figure 11. As expected, the growth rate in earlier ages was faster than in later ones. The ME available under FP was equated to a fixed amount of ME from *Panicum infesticum,* while under FH the ME available was determined by the herd animal requirements. Figure 12 shows simulated ME requirement for lactation, maintenance and growth per reproductive cycle. Lactation and maintenance formed the greatest total energy requirements, with growth forming the least. Growth energy requirement was high in the 1st cycle because it included the growth period in the model.

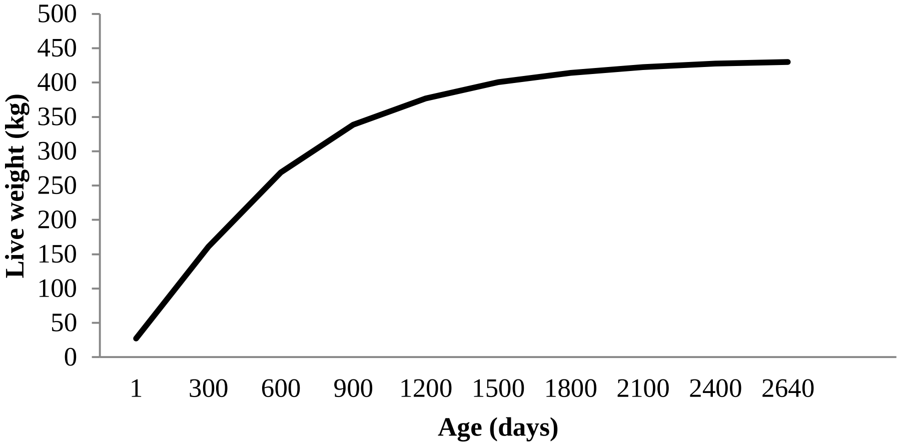

Figure 10: Simulated growth curve from birth to the time of exit from the herd after the sixth reproductive cycle

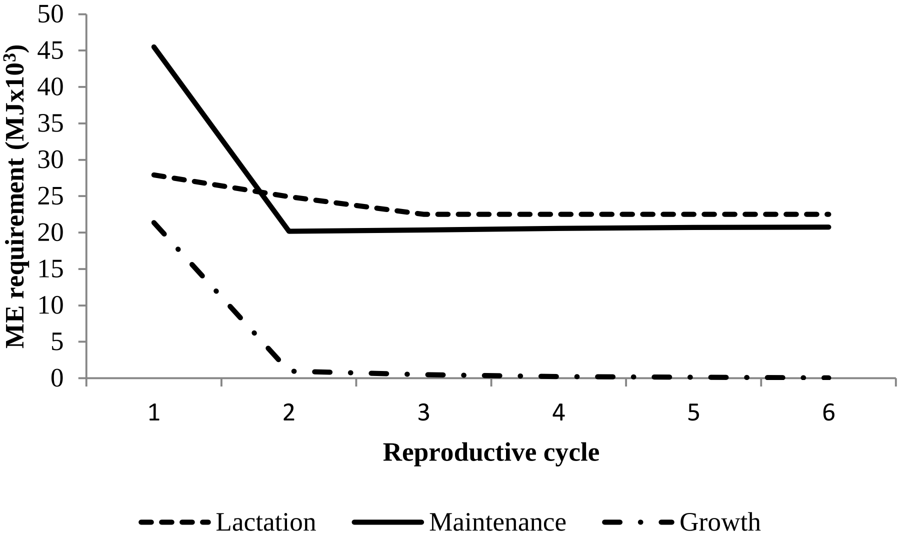

Figure 11: Simulated metabolizable energy requirement for lactation, maintenance and growth per cow per cycle

Table 5 shows the simulated herd composition and cow performance per reproductive cycle while fixing the pastures and herd. The reproductive cycle length was highest in the 1st cycle because it included the growth period, while the other reproductive cycles were periods from weaning to weaning in different reproductive cycles. The herd proportions fluctuated along the cycles due to mortalities, culling and replacement. Live weight and the average feed intake increased with age but at a declining rate as the animal aged.

Table 5: Simulated herd composition and cow performance by each reproductive cycle under the base input condition

	Reproductive cycle					
	1	2	3	4	5	6
Period of the reproductive cycle (days)	915.000	374.000	375.000	375.000	375.000	375.000
Proportion of live cows at the end of the cycle	0.874	0.877	0.881	0.881	0.882	0.882
Proportion of live cows culled during the cycle	0.015	0.024	0.031	0.043	0.054	0.065
Proportion of replacement heifers	0.147	0.155	0.157	0.157	0.157	0.157
Proportion of culled cows at weaning	0.015	0.024	0.031	0.043	0.054	0.065
Live weight at mating (kg)	251.540	339.283	384.810	408.771	421.270	427.824
Live weight at weaning (kg)	332.507	380.353	405.669	419.309	426.606	430.510
Average intake of a cow (GJ)	71.365	49.453	47.203	47.411	47.508	47.556

Kg – kilograms; GJ – giga joules.

The simulated inputs, outputs and biological and economic efficiencies under FH and FP are shown in Table 6. Feed intake per cow in this model was equated to ME requirement and, therefore, feed intake was similar under both production circumstances (Table 6). The weights at culling and milk yield were also the same due to the equivalent feed intake per cow. The biological efficiency for milk and live weight production were higher under FP and FH, respectively. The FH was more efficient economically than FP for milk production (Table 6).

Table 6: Simulated outputs and biological and economic efficiencies for fixed-herd and pasture circumstances

	Circumstances	
	Fixed herd	Fixed pasture
Feed intake (GJ/cow)	310.495	310.495
Weight at culling (kg/cow)		
Cull cows	385.744	385.744
Cull heifers	251.540	251.540
Total Milk yield (kg/cow)	54,927.420	54,927.420
Biological efficiency		
Milk production	0.143	0.148
Live weight production	0.002	0.001
Economic efficiency based on milk sales on:		
Volume	3.825	3.736
Volume and butter fat content	4.378	4.277

Kg – kilograms; GJ – giga joules.

Table 7 shows the simulated costs and revenues for FH and FP as well as the profit before and after incorporating risk. Feeds in both circumstances accounted for the greatest fraction of the variable costs. This was followed by marketing, labour, health and reproductive costs, respectively. The risk-rated profits were lower than that without risks. The differences ranged from -0.03 to -6.56, with FP reporting higher variance compared to FH.

Table 7: Simulated costs, revenues, profits with and without risks (Kes, 1US$ = Kes 83.00) for fixed-herd size and fixed-pasture production circumstances

	Variables	Circumstances	
		Fixed herd	Fixed pasture
Production costs	Feed	871.463	733.389
	Labour	121.846	163.395
	Milking labour	37.257	34.930
	Marketing	144.243	260.953
	Health	61.634	50.946
	Reproduction	10.885	9.637
Total production cost		*1247.329*	*1253.250*
Revenue	Milk	4783.633	4428.616
	Milk butter fat	713.456	660.507
	Culls	131.349	124.668
	Male calves	11.349	10.660
Total revenue		*5,639.788*	*5,224.451*
Profit without risk		*4,392.459*	*3,971.201*
Risk-rated profit			
λ = 0.0001		*4,391.019*	*3,969.929*
λ = 0.02		*4,104.417*	*3,716.846*

3.5. Discussion

A deterministic model was developed for pasture-based dairy cattle in the developing countries in the tropics. This model was used to model FH and FP production circumstances. The model was able to simulate milk yield, growth and energy requirements, which were later used to determine the costs and revenues of the herds for the purpose of computing the profitability of the two production circumstances. Risk was also incorporated in the model to account for variances in market prices where Arrow-Pratt coefficients of absolute risk aversion (λ) of 0.0001 and 0.02 were adopted to measure the intensity of the farmer’s aversion to risk. Arrow-Pratt coefficients of 0.02 resulted in changes in profit ranging between -6.40% and -6.56% in FP and FH production circumstances, respectively, and -0.03% for 0.0001 in the two production circumstances. Since feed accounted for the greatest fraction of the variable costs, FH was more sensitive to risk. The inflation rate changes over time and a sensitivity analysis was done, which indicated a positive change in all the prices. The risk-rated profit is, therefore, assumed to change in the same direction even with different price variations. Animal traits, nutritional and management variables were used in the model to simulate efficiencies of the system. Similar studies without incorporating risk have been carried out in meat sheep, dairy cattle, beef cattle and goats in the tropics by Kosgey *et al.* (2003), Kahi and Nitter (2004), Rewe (2004) and Bett (2005). This model can be applied in other circumstances in the tropics provided the input variables and herd management strategies are adjusted accordingly.

Although feed availability is greatly affected by the seasonal variations in the tropics, feed in the current model was assumed to be available throughout the year and that the feed intake was determined by the energy requirements for growth, maintenance, lactation and gestation for all the animal classes. The variables used in the model were obtained from previous studies in the tropics, mostly from large-scale farms that are the main sources of breeding stock for the smallholder farms. Modeling has been used to simulate the empty-body and carcass composition, daily protein gains, beef marbling score (Hirooka *et al.*, 1998) and availability and quality of feed used, but this is difficult in cases where there is insufficient knowledge on these production systems (Groen *et al.*, 1997). Meat and milk marketing is currently based on quantity, but meat and milk quality could be traits of economic importance in the future.

The milk production curves from the current model corresponded to the lactation curve described by Ojango and Pollot (2001) and Grossman and Koops (2003). The increased milk yield in the first phase of lactation can be attributed to an increase in the number of active mammary gland cells and milk secretion per cell, while the decline later is due to a decrease in the mammary gland cells and hormonal changes (Dijkstra, *et al.*, 1997; Pollot, 2000; Grossman and Koops, 2003). The total milk yield is also significantly affected by parity (Nassuna-Musoke *et al.*, 2007).

The simulated herd composition results from the present model were as expected and are similar to those reported by Hirooka *et al.* (1998). Small discrepancies were, however, observed, but these can be explained by the different production systems and management variables employed in the model. The FH was more profitable than FP and, therefore, had higher economic efficiencies. This can be explained by the lower revenue and higher production costs under FP than FH. Labour, marketing, health and reproduction costs were slightly higher in FP for cows, and this was because of the large herd size. This shows that increasing the population of dairy cattle is not the most appropriate way to increase the efficiency of producing milk, but improving the traits of economic importance and incorporating a selection and herd management policy could result to higher economic efficiency.

3.6. Conclusions

A fixed-herd size production circumstance is more applicable for the pasture-based dairy production system in the tropics in terms of profitability. The profit derived from the traditional profit model was lower than the risk rated profit model and therefore risk should be incorporated whenever estimating profitability. This is important to avoid overestimating profit and economic values. The fixed-pasture production circumstance is, however, more efficient in terms of energy utilization. Additionally the model in this study can be improved with increased knowledge of the production systems in the tropics about pasture availability and quality. This study has demonstrated the viability of the dairy cattle production systems in the tropics for the large- and small-scale farmers who get their breeding stock from the large-scale farms. However, there is still the need to estimate economic and biological values for the traits of economic importance for use in any future genetic improvement with different scenarios.

CHAPTER FOUR

ECONOMIC AND BIOLOGICAL VALUES IN PASTURE-BASED DAIRY PRODUCTION SYSTEMS AND THEIR APPLICATION IN GENETIC IMPROVEMENT IN THE TROPICS

4.1. Introduction

Bio-economic simulation models can be used to examine changes in the profit or production efficiency due to genetic change and to derive economic values (Tess *et al.*, 1983a; de Plessis and Roux, 1998). Biological values are also important, especially in cases where economic information is lacking (Hirooka *et al.*, 1998). The biological value of a trait is the change in biological efficiency due to a unit change in genetic merit of a trait of interest, all other traits being constant. In Kenya, effective genetic improvement programme are absent for any cattle breed because of constraints like low effective population size, high cost of reproductive technologies, lack of systematic identification, poor animal performance and pedigree recording, genotype by environment interaction and organizational shortcomings, among others (Kosgey *et al*., 2006; Kahi *et al*., 2004). A study by Okeno *et al*. (2010) evaluated the breeding strategies for improvement of dairy cattle in Kenya, and used the breeding objective and economic values from a study by Kahi *et al*. (2004). The influence of economic values on genetic improvement has not yet been addressed. In this Chapter, economic and biological values of production and functional traits are estimated and their effects on selection indices and genetic responses in pasture-based dairy production systems investigated.

4.2. Materials and methods

The bio-economic model developed in Chapter 3 to estimate the economic efficiency of different dairy cattle production circumstances was used in the current study. Briefly, the model incorporated risks and was able to simulate a pasture-based dairy production system, and derive economic and biological efficiencies. The traits that influence the efficiency of production were generally categorized as production and functional traits. Production traits have been defined as characteristics of an animal associated with a product, while functional traits are the characteristics that influence the efficiency of production by reducing or increasing the cost of production (Groen *et al*., 1997; Vargas *et al*., 2002). The economic efficiencies for production and functional traits were estimated based on milk marketed in terms of volume and butter fat content. They were computed as the ratio of returns to costs. The returns were derived from sale of cull cows, male calves, culled heifers and milk, while costs included feed and non-feed inputs like health, reproduction, labour, marketing and fixed costs. The input variables used for estimation of biological and economic efficiency are as presented in Table 4.

4.2.1. Estimation of economic values

Profits, returns on investment and costs per unit production should be the main goal in any livestock improvement programme (Dickerson, 1970; Harris, 1970), but economic efficiency is a more appropriate basis for estimating economic values (Smith *et al*., 1986). In this Chapter, the breeding objective was expressed as production efficiency and not profit. The economic values were estimated using both simple and risk-rated models. The simple model assumed perfect knowledge of the production systems and market dynamics and, therefore, estimated economic values as the difference between economic efficiency after a unit change in genetic merit of a trait in the breeding objective and economic efficiency before genetic improvement (Hirooka *et al*., 1998). Conversely, the risk-rated model assumed imperfect knowledge of the production environment and accounted for future costs and price variances of inputs and outputs. The risk-rated economic values were, consequently, estimated following the procedures of Robinson and Barry (1987) and Kulak *et al.* (2003). Like in Kulak *et al.* (2003) the general risk-rated economic values (REV) were computed as shown in equation 36 below;

$$\mathrm{REV}=\mathrm{E}\left(\mathrm{EE_t}\right)-0.5\lambda\mathrm{Var}\left(\mathrm{EE_t}\right) \qquad \text{(Equation 36)}$$

where E(EE$_t$) is the expected values of economic efficiencies, λ the Arrow-Pratt coefficient of absolute risk aversion and Var(EE$_t$) the variance of the economic efficiency. E(EE$_t$) was computed as indicated in equation 37 below;

$$\mathrm{E}\left(\mathrm{EE_t}\right)=\frac{\mu_{\mathrm{po}} f\left(\mathrm{g,e}\right)}{\mathrm{e}\mu_{\mathrm{pi}}} \qquad \text{(Equation 37)}$$

while Var(EE$_t$) was estimated as depicted in equation 38 below;

$$\mathrm{Var}\left(\mathrm{EE_t}\right)=\mathrm{E}\left[\mathrm{EE_t}\text{-}\mathrm{E}\left(\mathrm{EE_t}\right)\right]^2 \qquad \text{(Equation 38)}$$

where μ_{po} and μ_{pi} are the expected values of input and output prices, respectively, *g* the vector of the variables determined by the genotype of the animal (genetic traits), *e* the vector of the variables determined by the environment and EE_t is as defined in equation 36 above. The risk-rated economic values were, therefore, computed as depicted in equation 39:

$$\mathrm{REV}=\frac{\mu_{po}f\left(g,e\right)}{e\mu_{pi}}-0.5\lambda E\left[EE_t-E\left(EE_t\right)\right]^2 \qquad \text{(Equation 39)}$$

When the λ is equated to zero, it indicates that the decision-maker or producer is risk neutral and, therefore, ranks alternatives according to expected efficiency, while positive λ indicates that individuals require higher returns. Arrow-Pratt coefficient values are scarce and, consequently, hypothetical values of 0.0001 and 0.02 were used (Kulak *et al.*, 2003). An inflation rate of 3.09% for the month of October 2010 obtained from the Central Bank of Kenya Consumer Price Index (Table 4) was used to estimate the price variations.

4.2.2. Estimation of biological values

Biological value is the change in biological efficiency after a unit improvement in each trait in the breeding objectives while holding the other traits constant. The biological efficiency of milk production (BE_{MP}) and live weight (BE_{LWP}) were estimated as shown in equations 40 and 41:

$$BE_{MP}=\frac{\sum_{n=1}^{N}TMY_{lcow}}{\sum_{n=1}^{N}TME_{lcow}} \qquad \text{(Equation 40)}$$

$$\mathrm{BE}_{\mathrm{LWP}}=\frac{\sum_{n=1}^{N}\left(TLW_{ccow}+TLW_{cheifer}\right)}{\sum_{n=1}^{N}\left(TME_{ccow}+TME_{cheifer}\right)} \qquad \text{(Equation 41)}$$

where N is the maximum allowed reproductive cycles, TMY_{lcow} the total milk yield from the lactating cows and TME_{lcow} the total metabolisable energy (ME) utilized by the lactating cows, TLW_{ccow} the total live weight of culled cows, $TLW_{cheifers}$ the total live weight of culled heifers, TME_{ccow} the total ME utilized by the culled cows and $TME_{cheifer}$ the total ME utilized by the culled heifers. The difference between biological efficiency after a unit increase in genetic merit of a trait in the breeding objective and before the improvement was considered as the biological value.

4.2.3. Production and functional traits

The traits that were considered for selection were milk yield (MY), daily gain (DG), weaning weight (WWT), calving interval (CI), milk fat yield (FY), productive lifetime (PLT), pre-weaning survival rate (PreSR), post-weaning survival rate (PostSR) and age at first calving (AFC). Kahi and Nitter (2004) reported that a breeding objective with dual-purpose nature is efficient and realistic for the improvement of dairy cattle under pasture-based production systems. In Kenya, dairy cattle production is mainly dual-purpose, with milk payment mainly based on volume, but FY is of interest for future markets. Additionally, fat yield is correlated to energy requirements for production, and this translates to feed requirements and, subsequently, costs (Korver, 1988). Age at first calving and CI are important because they determine the days a cow is in milk and the number of calves in the PLT for replacement or sale (male calves). Dry animals have a negative impact on profit due to the cost of maintaining them (i.e., feed, health and labour). Mortality rate, both pre- and post-weaning are major constraints in developing countries and, therefore, the need to include survival in the breeding objective (Kahi *et al*., 2000; Bebe *et al*., 2003). The ability of an animal to survive and produce in a given period reflects its adaptability to the prevailing conditions and, consequently, pre- and post-weaning survival rate can be linked to adaptability (Kahi and Nitter, 2004). Productive life time is important in determining how long an animal remains productive in the herd and is related to survival, hardiness and productivity. This influences the replacement rate, which has a cost and also affects the herd composition (Groen *et al*., 1997).

4.2.4. Prediction of genetic gains using economic and biological values

The genetic gains for traits in the breeding objectives were predicted using the selection index methodology (Hazel, 1943). Selection index methodology uses deterministic modelling approach and, therefore, the outputs are determined by the input parameters. Estimation of the indices requires weighting factors and information on selected individuals. The information sources for the selected candidates were obtained from both own performance and pedigree information (BLUP). The weighting factors were derived from genetic and phenotypic parameters (Table 3) estimated from performance data of dairy cattle populations in Kenya (Rege, 1991; Ojango and Pollot, 2001; Amimo *et al*., 2006). The risk-rated economic and biological values for traits in the breeding objective obtained in the present study were used in estimation of genetic response. Since traits in the breeding objective were not expressed with the same frequency or at the same time, Gflow computer programme (Brascamp, 1978) was used to calculate the cumulative discounted expressions to discount the economic and biological values. A discounting rate of 5% with an investment period of 25 years was considered.

The economic and biological values and genetic responses for breeding objective traits were estimated under two production systems: FH and FP. In the FP, the number of animals in the model was determined by pasture availability and, consequently, excess animals were culled. Conversely, in the FH, a fixed-herd size was assumed and the energy requirements of these animals were assumed to be met. In each production system, the economic values were calculated assuming milk marketing based on volume (current marketing trend) (MV) and milk volume and butter fat content (future marketing trend) (MVFC) circumstances. The biological values adopted in the two production systems were evaluated assuming milk production and live weight. The genetic gains were, therefore, dependent on the economic or biological values adopted in the model.

4.3. Results

4.3.1. Economic and biological values

The risk-rated economic and biological values for traits considered in the breeding objective of pasture-based dairy cattle production, assuming FH and FP production systems and milk volume, and volume and fat content marketing circumstances are reported in Table 8. Generally, the economic values were affected by both the production system and marketing circumstance adopted in the model. The economic values estimated under FH were higher than those estimated under FP, while those derived assuming MV were superior to those obtained in MVFC irrespective of the production system adopted (Table 8). When the λ was 0.02, the economic values for MY, CI and PLT under FP-MV were Kes 85.478, 0.202, and 46.359, respectively, while their corresponding values under FP-MVFC were Kes 81.591, 0.210 and 36.053. The negative economic value for FY under MV (Kes -0.128) compared to the positive value of Kes 5.317 in MVFC was expected as the former marketing circumstance did not account for fat content as a source of revenue. The economic values for growth (DG, WWT and MLW) and survival traits (PreSR and PostSR) and AFC were generally low and negative under the two marketing circumstances in FP (Table 8). Conversely, the economic values obtained under the FH production system followed the same trend as those reported under FP, but were higher. For instance, the economic values for MY, CI and PLT were 14.98, 58.94 and 59.53%, respectively, higher than those obtained under FP-MV.

The risk-rated economic values assuming $\lambda=0.020$ were lower than those estimated for $\lambda=0.0001$ under the two production systems and marketing circumstances. The economic values for growth traits (DG, WWT and MLW) estimated under FP-MV assuming $\lambda=0.020$ were, correspondingly, Kes -0.975, -1.765 and -6.678, while their corresponding values when a low value of risk aversion was applied were Kes -0.846, -1.634 and -6.536 (Table 8).

Table 8: Biological and economic values (Kes, 1US$ = Kes 83.00) for traits in the breeding objective under different production and marketing circumstances

System	Circumstance [b]	Traits [a]									
		MY	DG	WWT	MLW	CI	FY	PLT	PreSR	PostSR	AFC
Economic values when the λ=0.02											
Fixed-pasture	MV	85.478	-0.975	-1.765	-6.678	0.202	-0.128	46.359	-0.124	-0.236	-14.982
	MVFC	81.591	-1.144	-2.125	-7.698	0.210	5.317	36.053	-0.185	-0.293	-17.246
Fixed-herd	MV	100.533	-1.808	-5.051	-3.858	0.492	-0.133	114.560	-0.566	-0.259	-0.133
	MVFC	98.479	-2.102	-5.902	-4.457	0.542	5.431	113.720	-0.695	-0.320	-0.176
Economic values when the λ=0.0001											
Fixed-pasture	MV	85.485	-0.846	-1.634	-6.536	0.328	-0.001	46.399	0.003	-0.109	-14.820
	MVFC	81.615	-0.973	-1.952	-7.509	0.377	5.471	36.132	-0.017	-0.125	-17.031
Fixed-herd	MV	100.536	-1.672	-4.907	-3.716	0.623	-0.001	114.560	-0.433	-0.126	-0.001
	MVFC	98.491	-1.922	-5.711	-4.271	0.716	5.592	113.724	-0.518	-0.145	-0.001
Biological value [c]											
Fixed-pasture	Milk	0.738	-0.056	-0.131	-0.428	0.000	0.000	-1.290	0.000	0.000	0.000
	Live weight	-0.007	0	0.006	-0.004	0.000	0.000	0.044	0.002	0.000	0.000
Fixed-herd	Milk	0.791	-0.091	-0.288	-0.234	0.000	0.000	0.598	-0.021	0.000	0.000
	Live weight	-0.009	-0.001	-0.001	0.009	0.000	0.000	0.106	0.003	0.000	0.000

[a] MY, milk yield (kg); DG daily gain (kg); WWT, weaning weight (kg); CI, calving interval (days); FY, milk fat yield (kg); PLT, productive lifetime (days); PreSR, pre-weaning survival rate (%); AFC, age at first calving (days).

[b] MV, milk marketing based on volume; MVFC, milk marketing based on volume and fat content.

[c] economic and biological values are $x10^{-3}$.

The derivation of biological values in the present study was meant to monitor if the economic efficiency could translate to biological efficiency. The biological values obtained in the current study followed the same trend as observed under economic values (Table 8). For example, the biological values were sensitive to production systems and circumstances (milk and live weight). Milk yield had positive biological values of 0.738 and 0.791 under FP and FH production systems, respectively, but reported negative corresponding values of -0.007 and -0.009 when marketing was based on live weight. The growth traits had negative biological values except WWT and MLW which had positive values of 0.006 and 0.009 under FP and FH, respectively. Although the PLT and PreSR had positive biological values in all the production systems and the two marketing circumstances, they had negative values of -1.290 and -0.021, respectively, under FP and FH.

4.3.2. Assessment of the effect of economic and biological values on genetic gain

Table 9 shows the estimated genetic gains for the individual breeding objective traits. To predict genetic gain for the breeding objective traits, one round of selection was carried out on the selection index with a selection intensity of one. Generally, the genetic responses for individual traits in the breeding objective followed the same trend as observed under biological and economic values (Table 8). The gains were affected by both production system and circumstance considered in the model. The genetic responses for all traits in the breeding objective were higher under FH and MV compared to FP and MVFC, except response for FY which was higher when MVFC was considered (Table 8). For instance, the genetic responses for MY under FP and FH assuming MV were 3.459 and 4.068 kg, respectively, while the corresponding responses under MVFC was 3.302 and 3.985 kg. The high genetic gain for MY under MV compared to MVFC under the two production systems was expected because milk was sold only based on volume. Conversely, the low genetic response observed under MVFC and positive response for FY is an indication of the antagonistic relationship between these traits. The genetic gains achieved under FH were generally higher compared to those realized under FP apart from the gains in DG, WWT and PreSR which were lower. Under the FP and FH, CI and PLT had a positive genetic gain while AFC had negative gain, which is undesirable, particularly in developing countries where breeding stocks are scarce (Table 9).

The level of risk aversion affected the rate of genetic gains of traits in the breeding objective. For instance, the adoption of economic values estimated assuming λ=0.0001 in the model resulted to higher genetic gains compared to λ=0.02. This is an indication that failure to account for risks undertaken by producers over estimate economic values and therefore, genetic gains. The use of biological values in the model resulted to low genetic gains for traits in the breeding objectives (Table 9). The positive values of 0.443 and 0.460 for MY assuming milk as the marketable product is an indication of improved biological efficiency. Conversely, the negative values for growth traits, i.e., -0.034, -0.078 and -0.257 for DG, WWT and MLW, respectively, under FP (Milk) is a confirmation of the negative interaction between growth traits and MY.

Table 9: Genetic gain in individual traits in the breeding objective estimated under fixed-pasture and fixed-herd production circumstances, with milk marketing based on volume (MV) or volume and butter fat content (MVFC) and biological values for milk and live weight production

Indices[a]	Circumstance	Traits								
		MY	DG	WWT	MLW	CI	FY	PLT	PreSR	AFC
I_{rrev} (λ=0.02)										
Fixed-pasture	MV	3.459	-0.061	-0.111	-0.420	0.013	-0.008	2.913	-0.008	-0.941
	MVFC	3.302	-0.072	-0.134	-0.484	0.013	0.334	2.265	-0.012	-1.084
Fixed-herd	MV	4.068	-0.114	-0.317	-0.242	0.031	-0.008	7.198	-0.036	-0.008
	MVFC	3.985	-0.132	-0.371	-0.280	0.034	0.341	7.145	-0.044	-0.011
I_{rrev} (λ=0.0001)										
Fixed-pasture	MV	3.460	-0.034	-0.066	-0.265	0.027	0.000	3.759	0.000	-1.201
	MVFC	3.303	-0.039	-0.079	-0.304	0.031	0.437	2.927	-0.001	-1.380
Fixed-herd	MV	4.069	-0.068	-0.199	-0.150	0.050	0.000	9.281	-0.035	0.000
	MVFC	3.986	-0.078	-0.231	-0.173	0.058	0.447	9.213	-0.042	0.000
I_{bv}										
Fixed-pasture	Milk	0.443	-0.034	-0.078	-0.257	0.000	0.000	-0.774	0.000	0.000
	Live weight	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fixed-herd	Milk	0.460	-0.053	-0.167	-0.136	0.000	0.000	0.348	-0.012	0.000
	Live weight	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000

[a] I_{rrev} (λ=0.02) index derived with economic values risk-rated at λ=0.02; I_{rrev} (λ=0.0001) index derived with economic values risk_rated at λ=0.0001; I_{bv} index derived with biological values,

[b] See Table 2

4.4. Discussion

The objective of the current study was to estimate economic and biological values of production and functional traits, and investigate their effects on selection indices and genetic response in pasture-based dairy production systems in Kenya. The economic values were estimated using risk-rated profit model functions assuming two production circumstances; (fixed-herd (FH) and fixed-pasture (FP)); and two marketing scenarios (milk marketing based on volume (MV), and volume and fat content (MVFC)). Conversely, the biological values for traits in the breeding objectives were estimated under FH and FP production circumstances assuming milk yield and live weight as the traits of economic importance in dairy production. These economic values were not discounted and, therefore, were weighed by cumulative discounted expressions (McClintock and Cunningham, 1974) before being used in evaluation of genetic gains.

The positive economic values for MY, CI and PLT obtained is an indication that selection targeting these traits would lead to improved profitability of the farm enterprise. The positive genetic gains obtained for these traits under the two production circumstances investigated in the present study confirm this phenomenon. However, it should be noted that the positive genetic gain obtained for CI (Table 9) is undesirable because it reduces the number of offspring per cow’s productive life time. This may pose far reaching effects, especially in developing countries in the tropics where breeding or replacement stocks are scarce. The positive economic values for MY, CI and PLT have also been reported in dairy cattle in developing countries (Kahi and Niter, 2004; Komlosi *et al*., 2009; Krupová *et al*., 2010). The negative economic values for growth traits (DG, WWT and MLW) and FY obtained in this study could be attributed to the increased energy demands by the animals due to the higher growth rate and weights. The genetic improvement for DG and WWT would have more negative effects on the economic efficiency of production because of increased energy demands of the growing stock. The negative economic values of DG and WWT indicated that revenues from sale of culls because of higher weight would not compensate high costs emanating from the corresponding rise in energy requirement. Animals with large body sizes have also been demonstrated to consume more feed as they required more energy for maintenance compared to small sized animals, and this tend to increase the cost of production (Vischer *et al*., 1994). There is also a positive correlation between increased butter fat production and requirement for high energy content feeds (Hurtaud *et al*., 2010). Although the results agree with previous studies that have reported negative economic values for MLW and FY in developing countries, the negative economic values for DG and WWT contradicts the positive values reported in the literature (Kahi and Nitter, 2004; Krupov'a *et al.,* 2009; Komlosi *et al.*, 2010). The revenue from sale of culls and marketing of milk based on butter fat could not compensate the corresponding increase in energy for raising the female replacement and lactating cows as well as marketing costs. An optimum size of dairy cattle for the production situations in Kenya should therefore be determined.

Inclusion of AFC as a breeding objective trait aims at reducing the unproductive life of the cow (Kahi and Nitter, 2004) and shortening the generation interval. By reducing the AFC, the herd replacement policy is influenced, especially for the fixed-pasture production system, which in return affects the production levels and replacement rate that then influences the product output levels of heifers and adult cows (Kahi and Nitter, 2004). The negative economic value (Table 8) and genetic gains (Table 9) of this trait is desirable and concur with previous studies (e.g. Komlosi *et al*., 2010; Kahi and Nitter, 2004). The negative economic values for PreSR under the FH circumstance could be due to the increased number of young stock. This, therefore, affects the culling policy and the herd feed demands, particularly for the growing animals.

The differences between the economic values (Table 8) for traits in the breeding objectives assuming an Arrow-Pratt coefficient of absolute risk aversion of 0.0001 and 0.02 obtained in the present study is a confirmation that not accounting for risks may lead to over estimation of economic values in a breeding programme. The difference between the economic values with and without risks has been demonstrated to range from −47.26% to 67.11% (Kulak *et al*., 2003; Bett *et al*., 2011; Okeno *et al*., 2012), and such differences could lead to loss in efficiency of selection index by up to 76% (Vandepitte and Hazel, 1977). This is confirmed in genetic evaluation in the current study where the genetic response for traits in the breeding objective were higher when a value of $\lambda = 0.0001$ was used compared to $\lambda = 0.02$ (Table 9). This, therefore, indicates the need to consider risks like changes in future costs of inputs and price of outputs when estimating economic values.

The differences between risk-rated economic and biological values obtained in the current study were very large and affected the genetic gains of traits in the breeding objective (Table 8). Although, the use of economic values to define breeding objectives in different livestock species has been widely used (e.g. Kahi and Niter 2004; Banga *et al*., 2009;

Komlosi *et al*., 2010), there is need to consider also the biological values. The use of biological values are critical, especially when developing breeding objectives targeting genetic improvement in smallholder dairy cattle production systems because they are characterized by poor or lack of economic and biological data necessary for computing economic values (Hirooka *et al*., 1998; Bett *et al*., 2011). The differences between biological values observed under FH and FP production circumstances, and milk and live weight scenarios was an indication that the biological values and, consequently, biological efficiencies are sensitive to production scenarios as economic values. For instance, the biological efficiency of producing milk and live weight was mainly affected by the MY, growth traits (WWT and MLW), CI and PostSR, which are the traits that greatly influenced the energy requirements of the individual animals. Due to the increased energy demands, MY had negative effects on the biological efficiency for live weight production, but positive for milk production. The positive biological values for MY, WWT and PostSR show that improvement in these traits could lead to improved profitability because of increased efficiency of feed conversion. This analysis shows that feed availability is a major limitation to profitability. Breeding of animals, which can efficiently utilize tropical pasture has been recommended since pastures are readily available while concentrates are expensive (Kahi and Nitter, 2004). Such strategies will benefit smallholder farmers who own majority of the dairy cattle in Kenya. However, efforts should be made to estimate economic values to define breeding objectives in smallholder dairy production systems once the economic and biological data become available. From the present study, it has been demonstrated that genetic responses for individual traits achieved when economic values were used were higher than those obtained when biological values were employed. This could be explained by the fact that not all inputs and output could be defined in terms of energy (Hirooka *et al.,* 1998; Kahi and Nitter, 2004).

4.5. Conclusion

The results in this study have shown that definition of the breeding objective for pasture-based dairy production system in Kenya would result to faster genetic gains when economic values were used compared to use of biological values. The notable difference between the economic values with and without risks and their effect on genetic gains is a pointer that failure to account for risks undertaken by producers could result to overestimation of the genetic merit of a breeding programme. It should, however, be noted that application of biological values in the definition of breeding objectives could be an alternative, especially in circumstances where input and output parameters are scarce or difficult to measure.

CHAPTER FIVE

GENERAL DISCUSSION

5.1. Study objective

Due to the inefficient production, consumption of animal products per capita is not yet met in the developing countries. Increased human population, urbanization and incomes are the leading factors to this change in consumer taste and preference. Consequently, there has been simultaneous growth in production of animal products through an increase in the animal population rather than on their productivity. The current study aimed at investigating genetic improvement as a possible option to improve productivity per cow compared to increasing animal population. This would be achieved by implementing local genetic improvement programmes for dairy cattle to satisfy production aiming at; increasing milk yield per cow, improving growth rate and increasing fertility and longevity of cows. The objective of the present study was to develop breeding objectives for dairy cattle production in developing countries in the tropics. This was to be achieved through deterministic simulation, deriving economic and biological values, development of selection indices and estimation of genetic gains under different production scenarios. This study was based on three research questions, i.e., (i) which bio-economic model was appropriate for the dairy production circumstances in Kenya?; (ii) what were the biological and economic values for production and functional traits for dairy cattle in Kenya?; and (iii) what were the effects of biological and risk-rated economic values on genetic response to traits in the breeding objectives?

5.2. Methodology

5.2.1. Development of a bio-economic model

A deterministic bio-economic simulation model was developed for dairy cattle production circumstances in Kenya. The bio-economic model developed in this study simulated the Kenya pasture-based dairy production system. Kahi and Nitter (2004) developed profit functions to estimate economic values for a pasture-based dairy production system. The model developed in this study was integrated. A bio-economic simulation model used by Hirooka *et al.* (1998) to develop breeding objective for beef cattle in Japan was adapted in this study. In that study the model was recommended to other production systems but with modifications to suit the different conditions.

5.2.2. Model strengths and limitations

The bio-economic model developed was able to simulate the pasture-based dairy production system with fixed-pasture and herd circumstances. A deterministic model was used, where mathematical equations represented the production system with absolute certainty, compared to stochastic simulation that involve generation and propagation of a population at animal level (Brown and Rothery, 1993). The results in the present study, therefore, are completely determined by the biological and economic inputs. Apart from this, deterministic methods require a short computation time compared to stochastic methods and it gives more insight into genetic gains and inbreeding levels. In the model, it was assumed that management was optimal and that feed intake was based on the animal requirements for maintenance, growth, lactation and gestation. This assumes that there are no discrepancies in efficiency of feed utilisation between the genotypes (Kahi *et al*., 1998). In developing countries, these management regimes are mostly not optimal, especially in smallholder farms because the feed resource availability, herd size, financial resources, land size, structures and production levels determine the management system (Bett, 2005). Simulation of all the conditions and sub-systems under the pasture-based production system was not possible, but the most important aspects in dairy production like nutrition, milk yield, growth and herd dynamics were simulated.

5.2.3. Estimation of biological and economic values, and their application in genetic improvement

From the model, biological and economic values of production and functional traits under fixed pasture and herd production systems where milk is marketed based on quantity and quality circumstances were estimated. Economic values in this study were estimated using the ratio of returns to cost of production. Since traits are expressed at different frequencies and at different times the economic values were later discounted using cumulative discounted expressions derived as described by Brascamp (1978) using the Gflow programme (Hill, 1974). The selection index methodology (Hazel, 1943) was used to estimate genetic progress for the traits in the breeding objective. A sensitivity analysis was carried out where risk was incorporated in the estimation of economic values using the Arrow-pratt coefficients of risk aversion.

5.3. Economic and biological values

Economic values are applied in the breeding goal to ensure that selection emphasis for each trait in the breeding goal is of economic importance (Amer *et al*., 2001). The breeding goal, therefore, combines both the genetic and economic importance of an individual expressed as an equation (Hazel, 1943; Beckman and van Arendonk, 1993). The economic and biological values for milk yield, daily gain, weaning weight, mature live weight, calving weight, butter fat yield, productive life time, pre- and post-weaning survival rates, and age at first calving were estimated (Table 8). The economic values for milk, fat yield and calving interval being positive, indicate that they would lead to an increase in the profitability of a smallholder dairy production system under pasture limitation and fixed-herd production systems. Inclusion of the traits with negative economic values would negatively affect profitability. The economic and biological values were sensitive to the price levels, production circumstances and marketing scenarios (Table 8). The sensitivity of the economic values to risk gives information on the likely direction of future genetic improvement and production system, which have important implications for practical breeding programmes (Smith, 1988; Kosgey *et al*., 2003). This gives an indication on the target traits for future genetic improvement based on their contribution towards profitability of the production system. It also shows that economic values were robust (Conington *et al*., 2004).

The positive economic value for MY, is an indication that its inclusion in the breeding objective would increase revenue than cost. Fat content in the milk and growth traits (DG, WWT and MWT) increase the energy requirement and therefore feed intake and which may have negative effects, especially under limited pasture (Rewe, 2004; Kahi and Nitter, 2004). A reduction in CI increases the number of calving per year resulting in an increase in feed and management costs. Increasing the number of animals may therefore, not be profitable when there are restrictions on herd-size (Rewe, 2004) therefore producers should use strict replacement policies with high selection intensities to ensure a FH for higher profitability. A reduction in the AFC improves the productive life time of animals in the herd but could increase the energy demands of the herd. Survival influences the productive herd life, which determines the lifetime profitability of an animal since the costs of production are largely influenced by the ability of animals to cope with the prevailing environmental stresses (Baker and Rege, 1994). Improvement of survival early in life has been reported to have positive effects on profitability (Omasaki, 2010). The negative relationship between survival and productive traits is a challenge because improved adaptability negatively influences production. Since heat tolerance, resistance/tolerance to diseases, and ability to produce and reproduce under these conditions is important in the tropics, ways have been proposed to improve the two traits (Franklin, 1986; Burrow, 2001; Rewe, 2004). Improvement of productive traits under stressful factors would indirectly also improve adaptability, and estimation of reliable genetic and phenotypic parameters to allow development of optimal selection indices. The biological values estimated in this study indicate that future studies in the tropics, and especially in areas where feed is a limitation, should estimate biological values and then evaluate their implication on genetic progress. Inclusion of biological values in the breeding objective is, therefore, important because it would express the importance of traits selection in terms of energy demands. This would then give a direction on animals feed requirements, which is the largest cost in any livestock enterprise.

Most of the semen entering the country is imported from countries that put no emphasis on the ability to utilise tropical pastures and adaptation to other tropical environmental stresses. Such countries also put more emphasis on yields of fat and protein than on milk volume, yet in Kenya payment of milk is mostly based on milk volume. This limits the economic impact of fat and protein percentage on the direction of genetic improvement. The interaction between genotype and environment should be considered before wholesale importation of semen as a means of achieving sustainable genetic progress in the country (Kahi and Nitter, 2004). This study supports the conclusion by Kahi and Nitter (2004) that within-country evaluation of bulls should be carried out to match the genotype with the environment to ensure that the genetic progress achieved using appropriate selection indices, is sustainable in the long run.

5.4. Profitability of breeding objective

The breeding objective resulted in a general increase in efficiencies after genetic improvement of animal performance. This confirms that genetic improvement is important in improving the efficiency of cattle production. The sensitivity of economic efficiencies after incorporating risks shows that change in prices has a significant impact on genetic improvement. Incorporation of risk and changes in product and input prices lead to change in the economic efficiency of production in both the FH and FP production circumstances. This indicates that the modeled production system was sensitive to changes in economic parameters. The economic efficiency was most sensitive to increased feed cost and least sensitive to live weight, which is consistent with the findings of Bett (2005) for the Kenya Dual Purpose Goat and Kahi *et al.* (2004) for dairy cattle. The reduced cost of feed and increased live weight prices have a greater influence on the revenues than the cost of the system.

In developing countries, limitation of feed resources is a great challenge to dairy production and, therefore, improvement targeting high FY and LW could be counterproductive. This is because improvement of these traits would result to increased energy demands, which cannot be supplied due to the limited pasture. This calls for breeding of animals that can efficiently utilize tropical pastures as they can easily fit within the limited feed resource base within the smallholder farmers and yield high profitability (Kahi *et al.*, 2004). Consequently, genotype by environment interactions should be considered by farmers when selecting semen to achieve genetic progress.

5.5. Implementing a breeding programme

More productivity and an increase in smallholder incomes can be achieved with greater commercialization, implementation of the right policies of the dairy sub-sector and use of improved breeding, feeding, value addition and marketing technologies. Implementation of a nucleus breeding programme can be a good strategy for genetic improvement of cattle in developing countries where finances, expertise and structure required for operating an efficient improvement programme based on AI and field recording in the whole population is a challenge (Smith, 1988). To ensure the sustainability of the genetic improvement programme full cooperation of all the stakeholders should be emphasized e.g. farmers and government. The farmers should be educated about the potential benefits of participating in the breeding programme. In Kenya, large scale dairy farms can operate decentralized nucleus herds, which can be used to produce bulls to be used to transmit the superior genes to the participating herds (small-scale farmers). An efficient collaboration between the current government organization involved with animal breeding like the Kenya Animal Genetic Resource Center, Livestock Recording Centre, Kenya Stud Buk, breed societies, non-governmental organization, and professional bodies could be a good starting point. Table 10 shows projects funded by non-government and governmental institutions that are working throughout Kenya to improve livestock productivity and their objectives or mandates.

Table 10: Institutions and non- government organization dairy sub-sector improvement projects in Kenya

Project/institutions	Function/role
The Smallholder Dairy Project (SDP)	To support sustainable improvements to the livelihoods of poor Kenyans through their participation in the dairy sub-sector.
Kenya Dairy Sector Competitiveness Programme	To increasing smallholder household income through the sale of quality milk.
East Africa Dairy Development (EADD) project	To help one million people (179,000 families) living on small 1-5 acre farms lift themselves out of poverty through more profitable production and marketing of milk.
Smallholder Dairy Commercialization Programme	To fosters market-driven development of the informal dairy industry.
Kenya Animal Breeding and Genomics Association	To provide services through advancement of animal breeding and genomics and viable production systems while sustaining natural genetic resources for improved livelihoods.
Kenya Animal Genetic Resources Centre	To develop and promote optimum productivity of national livestock population, through provision of high quality disease free animal germ plasm and related breeding services for socio-economic development.
Kenya Livestock Breeders Organization	To promoting and coordinating livestock breeding in Kenya.
Kenya Stud Book	To record and maintain accurate and authentic ancestral and identification information of animals with due regard to dates of birth and extended pedigree details.
Dairy Recording Services of Kenya	To systematically measure and record daily milk yields of dairy stock plus the systematic sampling of the milk for quality analysis all of which is summarized in form of reports at the end of a lactation period.

Source: Respective organizations’ websites.

5.5.1. Choice of breeding structure

An unstructured population can be organised by putting in place a two-tier nucleus breeding system to maximise genetic improvement, reduce inbreeding rate and reduce the total cost of recording in smallholder dairy cattle production systems (Bondoc and smith, 1993). An open nucleus breeding system can provide 10% more genetic improvement than a closed nucleus of the same size because of a higher expected mean genetic value of nucleus replacements and because such a system will integrate farmers’ resources, reduce overhead costs and encourage more farmer participation (Bondoc and smith, 1993). This structure ensures that performance testing, pedigree, and trait recording and genetic evaluation is adequately performed (Jaitner *et al*., 2001). The important considerations for breeding structure are dissemination of genes throughout the population and accurate record keeping. The nucleus breeding scheme reduces the cost implication of recording and selection by only recording the animals in the nucleus then gradually introducing recording in the participating herd (Smith, 1988).

In Kenya small-scale, dairy farmers source their replacement stock from the large-scale farms while the large scale commercial ranches source breeding stock from established breeders; this is a closed breeding scheme (Rewe, 2004). If well organise with incentives to the farmers this three tier system can be gradually changed to an open nucleus system (Kahi *et al*., 2004; Rewe, 2004).

5.5.2. Choice of selection criteria

Breeding objectives have been described in this study and selection criteria used to estimate genetic progress for the breeding objective traits. Several traits and sources of information were used in the selection criteria. In future studies, other traits that are of economic importance to the smallholder dairy farmers can be included to improve the accuracy of selection. Additional sources of information if possible could be included. Some of the traits used could end up being expensive to measure and record for the farmers, which may be discouraging cooperating with the breeding programme (Kahi *et al*., 2004). To ensure that the best animals are chosen as parents for the next generation, genetic evaluation should be done to estimate their estimated breeding values using methods like BLUP.

5.6. Designing a sustainable breeding plan for dairy cattle in the tropics

The current study has shown the efficiency of a fixed-herd and pasture circumstance in dairy production in the tropics after improvement of the breeding objective traits and price changes. This is a possible way to increase cattle productivity without increasing the population to meet the demand for dairy products. Well-organized open two-tier nucleus breeding programmes have been recommended, and used to facilitate genetic and economic benefits (Kahi *et al*., 2004; Bett *et al*., 2011).

The main goal in animal breeding is selection of animals based on well-defined breeding objectives that suit the future production and marketing requirements of the average commercial producer. To achieve this, well designed breeding programmes that are able to maximize genetic progress or economic benefits are important. The annual genetic response of traits in the breeding objective, and the economic and biological efficiency from a production system, are important in evaluating genetic improvement in any selection scheme. In developing countries in the tropics, there are no effective genetic improvement programmes for any cattle breed owing to various constraints like small herd sizes, lack of systematic identification, inadequate animal performance and recording and organization shortcoming (Kahi *et al.*, 2004).

An open nucleus breeding programme is appropriate for subsistence production systems (Cunningham, 1980). A two-tier open nucleus rather than an unstructured population is recommendable to reduce inbreeding rate, to minimize the total cost of recording in smallholder dairy cattle genetic improvement and to maximize genetic improvement (Bondoc and Smith, 1993; Kosgey, 2004). In other studies, a network and utilization of facilities for testing purposes and data analyses in the region has been recommended (Wollny, 1995). This is in a situation where large- and small-scale livestock farmers cooperate in developing decentralized breeding schemes and standardized recording systems. This data can then be used to estimate breeding values. The potential effects of using exotic breeds to improve the indigenous animals or use of capital intensive technology should be evaluated. The use of decentralized open nucleus schemes using standardized data recording schemes could be most suitable in the developing countries to improve livestock and to conserve animal genetic resources. In these countries, the indigenous genetic resources have a huge unexploited potential, which is not yet exploited and conserving such valuable germplasm should be emphasised (Wollny, 1995; Kosgey, 2004). Use of young bull system progeny of local bulls has been reported to be more profitable than a closed progeny testing scheme, and continuous semen importation which is not a viable alternative (Okeno *et al.,* 2010). This means that there is need for an effective local selection programme.

5.7. Conclusions

The current study provides breeding objective traits for a system where pasture is limiting for dairy production. The model that was developed provided very crucial data on the biological and economic properties of the FH and FP dairy production circumstances. The model is important in estimating the impact of changes in production factors on the economic efficiency and economic values of traits. A well-organized breeding programme can be used to achieve genetic improvement of traits of economic importance, which would translate to improved production efficiency of farmers. An integrated model that incorporated risk developed in the present study was used to derive economic and biological values. The effect of genetic improvement on the overall efficiency of a FH and FP circumstance was evaluated. Desirable genetic changes in the breeding objective traits were achieved. This is, however, expected to differ with different breeding and recording schemes. The current study did not include adaptation traits like disease resistance as well as the other intangible roles the dairy cattle play (e.g., insurance and savings). Genetic improvement of milk production, growth, fertility, survival and longevity traits have positive effects on profitability of pasture-based dairy production systems in Kenya and, especially under no pasture restriction. An advancement of this study can be carried out to estimate the economic values for such traits and their influence on genetic improvement.

References

Ageeb, A.G. and Hayes, J.F., 2000. Genetic and environmental effects on the productivity of Holstein-Friesian cattle under the climatic conditions of Central Sudan. Tropical Animal Health and Production 32: 33-49.

Ageeb, A.G., Hayes, J.F., 2004. Reproductive responses of Holstein-Friesian cattle to the climatic conditions of Central Sudan. Tropical Animal Health and Production 32: 233-243.

Alderman, G., Cottrill, B.R., 1993. Energy and Protein Requirement of Ruminants. An advisory Manual prepared by the AFRC Technical Committee on Responses to Nutrients. CAB INTERNATIONAL, Wallingford, UK, 1-159.

Amer, P.R., Hofer, A., 1994. Optimum bias in selection index parameters estimated with uncertainty. Journal Animal Breeding and Genetics 111, 89–101.

Amer, P.R., Simm, G., Keane, M.G., Diskin, M.G., Wickham, B.W., 2001. Breeding objective for beef cattle in Ireland. Livestock Production Science 67: 223–239.

Amimo, J.O., Mosi, R.O., Wakhungu, J.W., Muasya, T.K., Inyangala, B.O., 2006. Phenotypic and genetic parameters of reproductive traits for Ayrshire cattle on large-scale farms in Kenya. Livestock Research for Rural Development, Volume 18, Article #147. Retrieved September 2, 2008 from http://www.cipav.org.co /lrrd/lrrd18/ 10/ amim 18147 .htm, 4 pp.

ARC, 1980. The Nutrient Requirements of Ruminant Livestock. Commonwealth Agricultural Bureaux, Farnham Royal, Slough, UK, 351 pp.

Baker, R. L. and Rege, J. E. O., 1994. Genetic resistance to disease and other stresses in improvement of ruminant livestock in the tropics. In: Proceedings of the 5th World Congress of Genetics Applied in Livestock Production 28: 97-103.

Banga, C.B., Neser, F.W.C., Westhuizen, J van der, Garrick, D.J., 2009. Economic values for dairy production traits under different milk payment systems in South Africa. South African Journal of Animal Science 39: 112–115.

Bebe, B.O., Udo, H.M.J., Rowlands, G.J., Thorpe, W., 2003a. Smallholder dairy systems in the Kenya highlands: Cattle population dynamics under increasing intensification. Livestock Production Science 82: 211–221.

Bebe, B.O., Udo, H.M.J., Rowlands, G.J., Thorpe, W., 2003b. Smallholder dairy systems in the Kenya highlands: Breed preferences and breeding practices. Livestock Production Science 82:117–127.

Bebe, B.O., Udo, H.M.J., Thorpe, W., 2002. Development of smallholder dairy systems in the Kenya highlands. Outlook on Agriculture 31: 113–120.

Behnke, R., Muthami, D., 2011. The Contribution of Livestock to the Kenyan Economy. IGAD LPI Working Paper No, pp. 3 – 11.

Bekman, H., van Arendonk, J.A.M., 1993. Derivation of economic values for veal, beef and milk production traits using profit equations. Livestock Production Science 34: 35–56.

Belonsky, G.M., Kennedy, B.W. 1988. Selection on individual phenotype and best linear unbiased predictor of breeding value in a closed swine herd. Journal of Animal science 68:1124.

Bett, C.R., 2005. Developing Breeding Goals for the Kenya Dual Purpose Goat. M.Sc. Thesis, Egerton University, Kenya, pp. 70-84.

Bett, R.C., Kosgey, I.S., Kahi, A.K., Peters, K.J., 2011. Definition of breeding objectives and optimum crossbreeding levels for goats in the smallholder production systems. Small Ruminant Research 96: 16–24.

Bondoc, O.L. and Smith, C.H. 1993. The effects of genotype by environment interactions in dairy cattle open nucleus-breeding schemes. Journal of Animal Breeding and Genetics 110: 186-193.

Bondoc, O.L., Smith, C., Gibson, J.P., 1989. A review of breeding strategies for genetic improvement of dairy cattle in developing countries. Animal Breeding Abstracts 57: 819–829.

Bourdon, R. M., 1998. Shortcomings of current genetic evaluation systems. Journal of Animal Science 76: 2308-2323.

Brascamp, E.W., 1978. Methods on Economic Optimization of Animal Breeding Plans. Report B-134, Research Institute for Animal Husbandry “Schoonoord,” Zeist, The Netherlands, 117 pp.

Brody, S. 1945. Bioenergetics and Growth. Reinhold, New York, 1023 pp.

Brown, D., Rothery, P., 1993. Models in Biology: Mathematics, Statistics and Computing. John Wiley and Sons, New York, USA, 688 pp.

Burrow, M.H., 2001. Variances and covariance between productive and adaptive traits and temperament in a composite breed of tropical beef cattle. Livestock Production. Science 70: 213 - 233.

Cartwright, T.C., 1979. The use of systems analysis in animal science with emphasis on animal breeding. Journal of Animal Science 49: 817–825.

Conington, J., Bishop, S.C., Waterhouse, A., Simm, G., 2004. A Bioeconomic Approach to Derive Economic Values for Pasture-Based Sheep Genetic Improvement programs. Journal of Animal Science 82: 1290–1304.

CSIRO, 1990. Feeding Standards for Australian Livestock, Ruminants. CSIRO Publication, East Melbourne, Victoria, Australia, pp. 1-236.

Cunningham, E.P., 1980. Methods for Recording, Evaluation and Selection in Adverse Environments. FAO/UNEP Technical Consultation on Animal Genetic Resources, Conservation and Management, Rome, Italy, 12 pp.

Cunningham, E.P., 1999. The application of biotechnologies to enhance animal production in different farming systems. Livestock Production Science 58: 1-24.

Danny, B.L., Hudson, A.G., Larry, V.C., Keith, E.G., 1973. Factors affecting dystocia and the effects of dystocia on subsequent reproduction in beef cattle. Journal of Animal Science 36: 695-705.

Delgado, C., Rosegrant, M., Steinfeld, H., Simeon, E., Courbois, C., 1999. Livestock to 2020. The Next Food Revolution. Food, Agriculture and the Environment Discussion Paper 28. (FAO, IFPRI, ILRI), pp. 1-79.

Dickerson, G.E., 1970. Efficiency of animal production-molding the biological components. Journal of Animal Science 30: 849-859.

Dijkstra, J., France, J., Dhanoa, M.S., Maas, J. A., Hanigan, M.D., Rook, A.J., Beever, D.E., 1997. A model to describe growth patterns of the mammary gland during pregnancy and lactation. Journal of Dairy Science 80: 2340–2354.

Du Plessis, M., Roux, C.Z., 1998. Economic weights for Holstein Friesian traits in South Africa. South African Journal of Animal Science 28: 140–145.

Falconer, D.S., Mackay, T.F.C., 1996. Introduction to Quantitative Genetics. 4th Edition, Longman, England, UK, 244 pp.

FAO, 1991. Animal Genetic Resource Information. Food and Agricultural Organization of the United Nations, Rome, Italy, pp. 52–59.

FAO, 2006. World Agriculture: towards 20015/2030. Summary Report. Food and Agriculture Organization of the United Nations, Rome, 8 pp.

Ferris, T.A., Mao, I.L., Anderson, C.R., 1983. Selecting for lactation curve and milk yield in dairy cattle. Journal of Dairy Science 83: 1438–1448.

Franklin, I. R., 1986. Breeding ruminants for the tropics. In: Proceedings of the 3rd World Congress of Genetics Applied to Livestock Production II: 451-461.

Gachuiri, C.K., Lukuyu, M.N., Ahuya, C., 2012. Dairy Farmers Training Manual. Kenya Dairy Sector Competitiveness Programme by USAID and Ministry of Livestock Development, pp. 2 – 5.

Garrick, D.J., 1993. The importance of industry structure. In: H.T. Blair, S.N. McCutcheon (Eds.), Proceedings of A.L. Rae Symposium on Animal Breeding and Genetics, Massey University, New Zealand, pp. 110-119.

Gilmour, A.R., Gogel, B.J., Cullis, B.R., and Thompson, R., 2008. ASReml User Guide Release 2.0 VSN International Ltd, Hemel Hempstead, HP1 1ES, UK, pp. 2-15.

Goddard, M.E., Haye, B.J., 2007. Genomic selection. Journal of Animal Breeding and Genetics 124: 323 – 330.

Groen, A.F., 1989. Economic values in cattle breeding. 1. Influence of production circumstances in situations without output limitations. Livestock Production Science 22: 1-16.

Groen, A.F., Steine, T., Colleau, J.J., Pedersen, J., Pribly, J., Reinsch, N., 1997. Economic Values in Dairy Cattle Breeding, with Special Reference to Functional Traits. Report of an EAAP-Working Group. Livestock Production Science 49: 1–21.

Groeneveld, E., Kovac, M., Mielenz, N., 2010. VCE User’s Guide and Reference Manual Version 6.0, pp. 13-119.

Grossman, M., Koops, W.J., 2003. Modeling extended lactation curves of dairy cattle: A biological basis for the multiphasic approach. Journal of Dairy Science 86: 988-998.

Gutierrez, J. P., Alvarez, I., Fernandez, I., J. Royo, L.J., Dıez, J., Goyache, F., 2002. Genetic relationships between calving date, calving interval, age at first calving and type traits in beef cattle. Livestock Production Science 78:215–222.

Haley, C.S., Visscher, P.M., 1998. Strategies to utilize marker-quantitative trait loci associations. Journal of Dairy Science 81: 85 – 97.

Harris, D.L., 1970. Breeding for efficiency in livestock production: Definition of the economic objectives. Journal of Animal Science 30: 860–865.

Haye, B.J., Bowman, P.J., Chamberlain, A.J., Goddard, M.E., 2009. Invited review: Genomic selection in dairy cattle: progress and challenges. Journal of dairy science 92: 433 – 443.

Hazel, L.N., 1943. The genetic basis for constructing selection indexes. Genetics 28: 476–496.

Henderson, C.R., 1973. Sire Evaluation and Genetic Trends. In: Proceedings of Animal Breeding and Genetic Symposium in Honor of Dr J.L Lush. America Society of Animal Science, America Dairy Science Association, Champaign, Illinois, USA, 1041 pp.

Hill, W.G., 1974. Prediction and evaluation of response to selection with overlapping generations. Animal production 18: 117–139.

Hirooka, H., Groen, A.F., Hiller, J., 1998. Developing breeding objectives for beef cattle production. I. A bio-economic simulation model. Animal Science 66: 607–621.

Hirooka, H., Sasaki, Y., 1998. Derivation of economic weights for carcass traits in Japanese Black cattle from field records. Journal of Animal Breeding and Genetics 115: 27–37.

Hofer, A., 1998. Variance component estimation in animal breeding: a review. Journal of Animal Breeding and Genetics 115. 247–265.

http://www.kdb.co.ke/index.php?option=com_content&view=article&id=211&Itemid=275, accessed on 20th June, 2013.

Hurtaud, C., Faucon, F., Couvreur, S., Peyraud, J.L., 2010. Linear relationship between increasing amounts of extruded linseed in dairy cow diet and milk fatty acid composition and butter properties. Journal of Dairy Science 93: 1429–1443.

Ilatsia, E., Muasya, T., Muhuyi., W. Kahi, A., 2007. Milk production and reproductive performance of Sahiwal cattle in semi-arid Kenya. Tropical Science 47: 120–127. doi: 10.1002/ts.205.

Ilatsia, E.D., Migose, S.A., Muhuyi, W.B., Kahi, A.K., 2011. Sahiwal cattle in semi-arid Kenya: genetic aspects of growth and survival traits and their relationship to milk production and fertility. Tropical Animal Health and production 43: 1575-1582.

Jaitner, J., Sowe, J., Secka-Njie, E., Dempfle, L., 2001. Ownership pattern and management practises of small ruminants in The Gambia - implications for a breeding programme. Small Ruminant Research 40: 101-108.

James, J.W., 1977. Open nucleus breeding systems. Animal Production 24: 287-305.

Joandet, G.E., Cartwright, T.C., 1975. Modelling beef production systems. Journal of Animal Science 41: 1238–1246.

Kahi, A.K., Nitter, G., 2004. Developing breeding schemes for pasture based dairy production systems in Kenya. 1. Derivation of economic values using profit functions. Livestock Production Science 88: 161–177.

Kahi, A.K., Nitter, G., Gall, C.F., 2004. Developing breeding schemes for pasture based dairy production systems in Kenya. II. Evaluation of alternative objectives and schemes using a two–tier open nucleus and young bull system. Livestock Production Science 88: 179–192.

Kahi, A.K., Nitter, G., Thorpe, W., Gall, C.F., 2000. Crossbreeding for dairy production in the lowland tropics of Kenya. II. Prediction of performance of alternative crossbreeding strategies. Livestock Production Science 63: 35-65.

Kahi, A.K., van Arendonk, J.A.M., Kosgey, I.S., 1998. Factors influencing the outcome of economic comparison of dairy cattle genotypes. In: Food, Land and Livelihood: Setting Research Agendas for Animal Sciences. 27th - 30th January 1998, Nairobi, Kenya, pp. 95-96.

Kluyts, J.F., Neser, F.W.C., Bradfield, M.J., 2003. Development of breeding objectives for beef cattle breeding: Derivation of economic values. South African Journal of Animal Science 33: 142 – 158.

KNBS, 2010. Consumer Price Index and inflation rates for the month of October 2010. Last retrieved from http://www.knbs.or.ke/ on 20th February, 2011.

Komlósi, I., Wolfová, M., Wolf, J., Farkas, B., Szendrei, Z., Beri, B., 2009. Economic weights of production and functional traits for Holstein-Friesian cattle in Hungary. Journal of Animal Breeding and Genetics 127: 143–153.

Korver, S., 1988. Genetic aspects of feed intake and feed efficiency in dairy cattle: A review. Livestock Production Science 20: 1-13.

Kosgey, I.S., 2004. Breeding objectives and breeding strategies for small ruminants in the tropics. Ph.D. Thesis, Wageningen University, pp. 1-278.

Kosgey, I.S., Baker, R.L., Udo, H.M.J., Van Arendonk, J.A.M., 2006. Successes and failures of small ruminant breeding programs in the tropics: A review. Small Ruminant Research 61: 13 – 28.

Kosgey, I.S., van Arendonk, J.A. M., Baker, R.L., 2003. Economic values of traits of meat sheep in medium to high production potential areas of the tropics. Small Ruminant Research 50: 187-202.

Krupová, Z., Huba, J., Dano, J., Krupa, E., Oravcová, M., Peškovicová, D., 2010. Economic weights of production and functional traits in dairy cattle under a direct subsidy regime. Czech Journal of Animal Science 54: 249–259.

Kulak, K., Wilton, J., Fox, G., Dekkers, J., 2003. Comparisons of economic values with and without risk for livestock trait improvement. Livestock Production Science 79: 183–191.

Lewis, R.M., Simm, G., 2000. Selection strategies in sire referencing schemes in sheep. Livestock Production Science 67: 129-141.

Madsen, P., Jensen J. A., 2006. User’s Guide to DMU: A Package for Analyzing Multivariate Mixed Models, Version 6. 8830 Tjele, Denmark: Danish Institute of Agricultural Sciences, Department of Animal Breeding and Genetics, Research Centre Foulum, pp. 1-32.

Makuza, S.M., McDaniel, B.I., 1996. Effects of days dry, previous days open and current days open on milk yields in cows in Zimbabwe and North Carolina. Journal of Dairy Science 79: 702-709.

McClintock, A.E., Cunningham, E.P., 1974. Selection in dual purpose cattle population: Defining the breeding objectives. Animal Production 18: 237–247.

Meuwissen, T.H.E., Hayes, B.J., Goddard, M.E., 2001. Prediction of total genetic value using genome-wide dense marker maps. Genetics 157: 1819–1829.

Meyer, K., 1988. DFREML. Programs to estimate variance components for individual animal models by restricted maximum likelihood. User Notes, Edinburgh University., Scotland, UK, pp. 1-12.

Meyer, K., 2007. WOMBAT - a tool for mixed model analyses in quantitative genetics by REML. Journal of Zheijang University Science B, 8:815–821.

MLD. 2010. Kenya National Dairy Master Plan, Volume I: A National Situational Analysis of the Dairy Subsector, Ministry of Livestock Development, pp. 4–73.

Mpofu, N., Smith, C., van Vuuren, W., Burnside, E.B., 1993. Breeding strategies for genetic improvement of dairy cattle in Zimbabwe. 1. Genetic evaluation. Journal of Dairy Science 76: 1163–1172.

Muasya, T.K., 2005. Genetic Evaluation of the Dairy Cattle Herd at the University of Nairobi Veterinary Farm. MSc Thesis, University of Nairobi, pp. 1-80.

Mueller, J.P,. 1984. Single and two-stage selection on different indices in open nucleus breeding systems. Genetic, Selection, Evolution. 16: 103 – 120.

Muhuyi, W.B., Lokwaleput, I., 1998. Sahiwal-Friesian crossbreds for milk production at Loldia Estate in a semi-arid area of Kenya. Sixth KARI- Scientific Conference, 9 – 13th November, 1998. Abstract.

Mulder, H.A., Bijma, P., 2005. Effects of genotype by environment interaction on genetic gain in breeding programs. Journal of Animal Science 83: 49–61.

Mulder, H.A., Veerkamp, R.F., Ducro, B.J., van Arendonk, J.A.M., Bijma, P., 2006. Optimization of dairy cattle breeding programs for different environments with genotype by environment interaction. Journal of Dairy Science 89: 1740–1752.

Muriuki, H.G., 2011. Dairy Development in Kenya. Food and Agriculture Organization of the United Nations Rome, 6 pp.

Musani, S.K., Mayer, M., 1997. Genetics and environmental trends in a large scale commercial Jersey herd in central Rift Valley, Kenya. Tropical Animal Health and Production 29: 108-116.

Mwai, O., Malmfors, B., Anderson-Ekrund, L., Philipsson, J., Rege, J.E.O., Hanotte, O., Fulss, R., 2005. Capacity Building for Sustainable Use of Animal Genetic Resources in Developing Countries. ILRI –SLU project progress report for the period 1999 – 2003. SLU (Sweden University of Agriculture Sciences), Uppsala, Sweden and ILRI (International Livestock Research Institute), Nairobi, Kenya, 65 pp.

Nassuna-Musoke, G.M., Kabasa, J.D., King, M.J., 2007. Lactation curve of temperate Friesians on smallholder farms in tropical Central Uganda. Journal of Animal and Veterinary Advances 6: 950–954.

NDPT, 1998. National Dairy Cattle Performance Testing Scheme. Annual Report, Johannesburg, South Africa, 121 pp.

Nicholson, C., Tambi, E., Staal, S.J., Thorpe, W., 2001. Patterns of Change in Dairy Production and Consumption in Developing Countries from 1985 to 1990. Market-Oriented Smallholder Dairy Research Working Document No. 7, ILRI, Nairobi,73 pp.

Njubi, D., Rege, J. E. O., Thorpe, W., Collins-Lusweti, E., Nyambaka, R., 1992. Genetic and environmental variation in reproductive and lactational performance of Jersey cattle in the coastal lowland semi-humid tropics. Tropical Animal Health and Production 24: 231-241.

Ojango, J.M.K., Pollot, G.E., 2001. Genetics of milk yield and fertility traits in Holstein-Friesian cattle on large scale Kenyan farms. Journal of Animal Science 79: 1742-1750.

Okeno, T.O., Kahi, A.K., Peters, K.J., 2012. Genetic and Economic Evaluation of Alternative Breeding Objectives for Adoption in the Smallholder Indigenous Chicken Improvement Program. Tropentag, September 19-21, 2012, Göttingen, Germany.

Okeno, T.O., Kosgey, I.S., Kahi, A.K., 2010. Genetic evaluation of breeding strategies for improvement of dairy cattle in Kenya. Tropical Animal Health and Production 42: 1073 – 1079.

Omasaki, S.K., 2010. Determination of Production Practices and Development of Breeding Objectives of Fish Farming in Western Kenya. MSc Thesis, Egerton University, pp. 17-74.

Omiti, J., Muma, M., 2000. Policy and Institutional Strategies to Commercialise the Dairy Sector in Kenya. Occasional Paper 6/2000. IPAR (Institute of Policy Analysis and Research), Nairobi, Kenya, 25 pp.

Omore, A., Muriuki, H., Owango, M., Staal, S., 1999. The Kenyan Dairy Sub-Sector. A Rapid Appraisal Report By Ministry of Agriculture and Rural Development- Kenya Agricultural Research Institute – International Livestock Research Institute Smallholder Dairy (Research And Development) Project. International Livestock Research Institute, Nairobi, 50 pp.

Osei, S.A., Effah-Baah, K., Karikari, P., 1991. The reproductive performance of Friesian cattle bred in the hot humid forest zone of Ghana. Revista Mundial de Zootecnia 68: 52-59.

Osinowo, O.A. and Abubakar, B.Y. 1988. Appropriate Breeding Strategies for Small Ruminant Production in West and Central Africa. Proceedings of the OAU/BAR

Workshop on Improvement of Small Ruminants in West and Central Africa. University of Ibadan, Nigeria, November, pp. 21-25.

Peters, K.J., Bett, R.C., Kahi, A.K., Kosgey, I.S., Gicheha, M.G., 2010. Comparison of economic values without and with risk for breeding objective traits derived from producer's preferences. In: Proceedings of the 9th World congress on Genetics Applied to Livestock Production, Leipzig, 1-6 August, 2010, Germany.

Philipsson, J., Rege, J.E.O., Zonabend, E., Okeyo, A.M. 2011. Sustainable Breeding Programs for Tropical Low- and Medium Input Farming Systems. International Livestock Research Institute Training Module. Accessed in June 2013 on http://agtr.ilri.cgiar.org/ Documents/ Modules/ breeding%20programs.pdf

Pirchner, F., 1983. Population Genetics in Animal Breeding. 2nd Edition, Plenum Press, New York, USA, 414 pp.

Pollot, G.E., 2000. A biological approach to lactation curve analysis for milk yield. Journal of Dairy Science 83: 2448–2458.

Ponzoni, R.W., Newman, S., 1989. Development of breeding objectives for Australian beef cattle production. Animal Production 49: 35–47.

Pruzzo, L., Cantet, R.J., Fioretti, C.C., 2003. Risk-adjusted Expected Return for Selection Decisions. Journal of Animal Science 81: 2984-2988.

Rege, J.E.O., 1991. Genetic analysis of reproductive and productive performance of Friesian cattle in Kenya. 1. Genetic and phenotypic parameters. Journal of Animal Breeding and Genetics 108: 412-423.

Rendel, J.M., Robertson, A., 1950. Estimation of genetic gain in milk yield by selection in a closed herd of dairy cattle. Journal of Genetics 50: 1-8.

Rewe, T.O., 2004. Development of Breeding Objectives for Production Systems Utilizing the Boran Breed in Kenya. M.Sc. Thesis, Egerton University, Kenya, pp. 59-75.

Rewe, T.O., Indetie, D., Ojango, J.M.K., Kahi, A.K., 2006. Economic values for production and functional traits and assessment of their influence on genetic improvement in the Boran cattle in Kenya. Journal of Animal Breeding and Genetics 123: 23-36.

Reynolds, L., Metz, T., Kiptarus, J., 1996. Smallholder dairy production in Kenya. World Animal Review 87: 66-73.

Robinson, L.J., Barry, P.J., 1987. The Competitive Firm's Response to Risk. Macmillan Publishing Company, New York. 324 pp.

Roden, J.A., 1994. Review of theory of open nucleus breeding systems. Animal Breeding Abstracts 62: 151-157.

Schaeffer, L.R., 2006. Strategy for Applying Genome-Wide Selection in Dairy Cattle. Journal of Animal Breeding and Genetics 123: 218-223.

Shook, G.E., 2006. Major advances in determining appropriate selection goals. Journal of Dairy Science 89: 1349–1361.

Simm, G., Wray, N.R. 1991. Sheep Sire Referencing Schemes – New Opportunities for Pedigree Breeders and Lamb Producers. Technical Note T264 by The Scottish Agricultural College. Edinburgh, Scotland, pp. 41-44.

Smith, C., 1988. Genetic improvement of livestock using nucleus breeding units. World Animal Review 65: 2–10.

Smith, C., James, J.W., Brascamp, E.W., 1986. On the derivation of economic weights in livestock improvement. Animal Production 43: 545–544.

Tess, M.W., Bennett, G.L., Dickerson, G.E., 1983a. Simulation of genetic changes in life efficiency of pork production. I. A bio-economic model. Journal of Animal Science 56: 336–353.

Tess, M.W., Bennett, G.L., Dickerson, G.E., 1983b. Simulation of genetic changes in life cycle efficiency of pork production. II. Effect of components on efficiency. Journal of Animal Science 56: 354–368.

Thorpe, W., Muriuki, H.G., Omore, A., Owango, M.O., Staal, S., 2000. Dairy development in Kenya: The past, the present and the future. Annual Symposium of the Animal Production Society of Kenya, 22-23 March, 2000. KARI Headquarters, Loresho, Nairobi, Kenya.

Togashi, K., Lin, C.Y., Yamazaki, T., 2011. The efficiency of genome-wide selection for genetic improvement of net merit. Journal of Animal Science 89: 2972–2980.

Tomlinson, S., Lombard, J., Garry, F., 2009. The Relationship Between Dystocia and Dairy Calf Morbidity and Mortality. Integrated Livestock Management, Colorado State University. Last retrieved from http://www.cvmbs.colostate.edu/ILM/participants/summerstudents/2003%20Abstracts/Tomlinson.pdf on 7th January, 2010.

Vandepitte, W.M., Hazel, L.N., 1977. The effect of errors in the economic weights on the accuracy of selection indexes. Annales de Génétique et de Sélection Animale 9: 87-103.

Vargas, B.L., 2000. Bio-Economic Modelling to Support Management and Breeding of Dairy Cows in Costa Rica. Ph.D. Thesis, Wageningen University, The Netherlands, 153 pp.

Vargas, B.L., Groen, A.F., Herrero, M., van Arendonk, J.A.M., 2002. Economic values for production and functional traits in Holstein cattle of Costa Rica. Livestock Production Science 75: 101–116.

Vischer, P.M., Bowman, P.J., Goddard, M.E., 1994. Breeding objectives for pasture based dairy production systems. Livestock Production Science 40: 123–137.

Wambugu, S., Kirimi, L., Opiyo, J., 2011. Productivity Trends and Performance of Dairy Farming in Kenya. Tegemeo Institute of Agricultural Policy and Development, pp. 15 – 43.

Weller, J.I. 1989. Genetic analysis of fertility traits in Israel dairy cattle. Journal of Dairy Science. 72: 2644-2650.

Wilton, J.W., 1979. The use of production systems analysis in developing mating plans and selection goals. Journal of Animal Science 49: 809–816.

Wollny, C., 1995. Breed improvement and future breeding strategies in livestock in Southern Africa. International Symposium of Animal Production through Breeding and Genetics, 10th-11th May, 1995, Harare, Zimbabwe, pp. 61-70.

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