OPTIMISING BREEDING STRATEGIES INCORPORATING RESISTANCE TO GASTOINTESTINAL HELMINTHS IN MEAT SHEEP IN KENYA

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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.

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DECLARATION AND APPROVAL

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This thesis has been submitted for examination with our approval as the official University supervisors.

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Sign .....

Date 29/01/2009

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Date 29/01/09

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DEDICATION

This work is dedicated to:

My late father Elijah Gicheha, though departed I continue enjoying your contributions both biologically and materially, and the fruits of your continued emphasis on the importance of education;

My mother Veronica Njeri Gicheha for the struggle she endured to bring us up and educate us alone, you are a heroine mum;

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ABSTRACT

Sheep diseases and parasites, especially Gastro-intestinal (GI) helminths are major constraints to improved productivity. A cheaper and more sustainable strategy to controlling GI helminths is to exploit the inherent resistance to GI helminths in sheep by incorporating this attribute in the breeding objective. This study therefore aimed at optimising breeding strategies that incorporate resistance to GI helminths (RES) in meat sheep. A deterministic approach was used to genetically and economically evaluate the efficiency of five two-tier nucleus breeding systems for monetary genetic gain and profitability. These systems differed in whether one was closed or open, in the type of animals that were involved in the movement of genetic superiority and in the number of selection groups in each system. The systems were compared under four alternative breeding objectives. The first and second objectives respectively assumed that flock size cannot be increased due to Non-feed related constraints (FLOCK) and that flock size is restricted due to limited feed resources (FEED) while the third and fourth respectively assumed that sheep performed only tangible roles (TR) and both tangible and intangible roles (IR). Economic values for RES were estimated under different scenarios based on previously published genetic and phenotypic parameters in a selection index objectively optimising gains on yearling weight. These economic values were used to evaluate the efficiency of schemes breeding for RES. The open nucleus breeding system with commercial-born ewes being introduced in the nucleus had the highest annual genetic gain under all breeding objectives (i.e., KSh 46.11, 124.89, 209.27 and 163.32 in FLOCK, FEED, TR and IR, respectively) but profitability was highest under FLOCK (KSh 176.02) and IR (KSh 642.70). In the closed nucleus breeding system that utilised young rams, annual genetic gains were (KSh) 43.60, 117.57, 196.88 and 153.89 in FLOCK, FEED, TR and IR, respectively. The corresponding profits per ewe were (KSh) 175.64, 495.67, 828.68 and 628.85. The annual monetary genetic gain and profit per ewe were highest for the breeding scheme with the highest level of recording (scheme 4). In all objectives, the difference in the profit per ewe between a scheme that included records on faecal egg count (FEC) measured once in rams immediately after weaning (scheme 3) and another (scheme 4) that included a second FEC measured at 7.5 months was small (1.3 to 3.7%), indicating that there is little benefit taking a second measurement of FEC. The results suggest that no breeding system is universal. Based on profitability, the optimal nucleus breeding system changes with the breeding objective and incorporating RES in the breeding objective always result in higher returns and profitability. Successful establishment of any nucleus breeding system or scheme should therefore focus on the logistics of establishing them.

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LIST OF ABBREVIATIONS

CNS	Closed nucleus system
EU	Egerton University
FAO	Food and Agriculture Organisation of the United Nations
GI	Gastro-intestinal
GoK	Government of Kenya
ILCA	International Livestock Centre for Africa
KSh	Kenya shilling
MLFD	Ministry of Livestock and Fisheries Development
MARD	Ministry of Agriculture and Rural Development
NAHRC	National Animal Husbandry Research Centre
ONS	Open nucleus systems

CHAPTER ONE
GENERAL INTRODUCTION

1.1. Background information

The sheep production in Kenya has a significant economic role both at household and national levels. The sheep population in Kenya is estimated to be between 6.5 and 8 million, out of which 95% are hair sheep producing an estimated 15-20% of the red meat consumed in the country (MLFD, 2003). In the traditional management systems, sheep perform both tangible and intangible roles. Tangible roles include meat from animals slaughtered for home consumption, as a source of easily convertible capital for financing purposes, manure and skins. Intangible roles include sheep acting as an insurance against emergencies, a means of risk aversion, playing cultural and ceremonial functions and a source of prestige (Upton 1985; Grandin et al., 1991; Jaitner et al., 2001; Kosgey et al., 2004). Sheep also play a complementary role in the utilisation of vast natural pastureland where crop production is not feasible (Baker and Rege, 1994).

Though sheep have physiological adaptation and ability to produce and reproduce under the prevailing harsh environmental conditions in Kenya, diseases and parasites remain major constraints on sheep productivity, presenting a significant constraint on sheep productivity and cost of production is the gastro-intestinal (GI) helminths infestation (Wanyangu et al., 1996; Baker et al., 1999). However, some sheep breeds have been identified to have superior natural resistance to diseases and parasites, which could be exploited to improve productivity and reduce cost of production. Among the resistant breeds are the Red Maasai of East Africa, Djallonké of West Africa, Scottish Blackface, St. Croix and Florida Native (Preston and Allonby, 1979; Baker, 1995).

Infection with GI helminths is associated with reduced productivity, increased cost of production, increased susceptibility to other infections and increased use of antihelminthics (Baker, 1995). The GI helminths could be controlled through management interventions. Although this may have immediate benefits, it is not cost effective since it involves recurring costs (Franklin, 1986). Breeding for resistance to GI helminths (RES) is the best alternative because once achieved, it remains permanent through time without further maintenance costs. There is therefore need to consider raising sheep breeds that are resistant to helminths by incorporating RES as a trait in the breeding objective. Breeding objectives comprise economic and breeding values for traits a producer would like to improve because of their influence on revenues and costs. Economic values are an indication of the relative importance

of traits in a given system and are derived when breeding objectives are defined in economic terms (Ponzoni, 1992).

Inclusion of RES in the breeding objective will result in resistant meat sheep genotypes that will perform better under the environmental constraints that characterise smallholder and pastoral production systems. For this to be achieved, efficient and sustainable breeding systems and schemes need to be developed to ensure production and rapid dissemination of superior animals to sheep producers. The design of efficient breeding strategies involves definition of the breeding system and identification of selection criteria (Ponzoni, 1992). Well-defined and organised breeding systems and schemes are largely lacking in Kenya though farmers have a high need for resistant meat sheep genotypes.

Breeding systems comprise the genetic (superior genotypes) and the structural aspects of the breeding strategy, which include the number of tiers and the movement of the genetic improvement (Ponzoni, 1986). Such systems must be designed considering the constraints that compromise productivity of sheep in the tropics. The constraints include; small and single-sire populations, lack of proper and systematic animal identification, inadequate performance and pedigree recording, low levels of literacy, lack of or inadequate organisational structures and low levels of disease, nutrition, breeding and general management (Turner, 1982; Kiwuwa, 1992; Jaitner et al., 2001; Wollny et al., 2002;Kosgey, 2004). Pastoral communities are further faced with the problem of infrastructure necessary for data collection due to their migratory nature. Needed to support their livelihoods are the infrastructure necessary for setting up a breeding programme targeting genetic improvement in the animal populations maintained by these pastoral communities (Franklin, 1986; Kiwuwa, 1992).

Nucleus breeding systems have been proposed as a good strategy for genetic improvement of small ruminants in developing countries that are faced with these constraints (Turner, 1982; Hodges, 1990; Jasiorowski, 1990; Kiwuwa, 1992). In such systems, genetic improvement is generated in a small fraction of the population (referred to as the nucleus), while at the same time controlling the inbreeding (van Arendonk and Bijma, 2003). The genetic progress is disseminated to the commercial population through use of males originating from the nucleus (Kinghorn, 2000). Use of nucleus breeding systems is a good avenue to disseminate sheep genotypes that are resistant to GI helminths. However, no attempts have been made to optimise different breeding strategies that incorporate RES in meat sheep in Kenya. Breeding strategies need to be optimised for their genetic and economic efficiencies within the constraints of the changing local farming conditions. This will result in

breeding strategies that are sustainable and able to bring about general improvement in productivity and profitability of production enterprises utilising resistant sheep genotypes.

1.2. Objectives

The overall aim of this study was to optimise breeding strategies that incorporate resistance to gastrointestinal helminths in meat sheep in Kenya. The specific objectives were:

1. To compare the genetic and economic efficiencies of alternative two-tier nucleus breeding systems for meat sheep.
2. To estimate economic values for resistance to gastrointestinal helminths in meat sheep.
3. To compare the genetic and economic efficiencies of alternative schemes breeding for resistance to gastrointestinal helminths in meat sheep.

1.3. Hypotheses

H_O: There are no differences in the genetic and economic efficiencies of alternative two-tier nucleus breeding systems for meat sheep.

H_O: In meat sheep, resistance to gastrointestinal helminths and other traits in the breeding objective are of equal economic importance.

H_O: The alternative schemes breeding for resistance to gastrointestinal helminths in meat sheep have equal genetic and economic efficiencies in terms of genetic progress and return on investment in genetic selection.

CHAPTER TWO
LITERATURE REVIEW

2.1. Sheep production in Kenya

Sheep production in Kenya is largely from the indigenous breeds produced in the arid and semi-arid lands (ASALs) where crop production is not feasible (Rege, 1994; Peeler and Omore, 1997). In the arable areas, sheep production is integrated into crop production systems. Table 1 presents the statistics for the sheep population, skins figures, off-take, total meat produced and value for the years 2000 to 2002. The population, which has a direct bearing with the number of skins, calculated off-take, total meat and the monetary value of the products, fluctuated over the reported period. Total meat produced recorded an upward trend for the period despite the fact that the population was highest in the year 2001 with a decline in the year 2002. The national sheep flock is estimated at 7 million and is growing at a rate of 3.6% annually as a result of the increasing human population size and subsequent reduction in land sizes (Peters, 1989; MLFD, 2002). These factors explain to a larger extent the rise in off-take, and associated with this are rise in total meat produced, skins and the value of the flock.

Table 1. Estimated sheep populations, skin figures, meat quantity in percentage and monetary value of the products in Kenya Shillings (KSh) over a three-year (2000-2002) period

Year	2000	2001	2002
Population ('000)	7,055	8,238	7,353
Skins ('000)	1,862	1,673	2,662
Calculated off-take (%)	23.5	20.3	36
Total meat	26,999	33,698	38,598
Value (million KSh)	4,050	3,637	5,790

Source: MLFD (2002).

2.1.1. Production systems

Sheep production systems can be classified based on the product, economy and climate (Peeler and Omore, 1997). The level of production and intensity determine the economic characteristic of a system. It is the level of production and costs of maintaining a female that explicitly determine the suitability of a production system (Dickerson, 1970). Based on the level of production, two production systems can be identified; large and small-scale production systems. Large scale production systems can wholly be commercial or almost entirely subsistence (pastoral) while small scale production systems might range from

subsistence to largely commercial. In Kenya, as is the case in most of the tropics, subsistence production systems are more common than commercial systems (Baker and Rege, 1994).

Small-scale meat production system

Under this production system, livestock and crop production are integrated on the same land. This comprises most of the sheep production systems and is projected to remain important with the increase in human population pressure (Steinfeld et al., 1996). In Kenya, this system is found mainly in the medium to high potential areas where land sizes are small. The animals may be housed, and grass and fodder is cut and carried to the animals. They may also be tethered to graze on a specific area or tethered and fed on crop residues. Occasionally, they are left to graze freely unattended (Gatenby, 1986; Rege, 1994). Unlike commercial farmers, smallholders tend to keep animals for multiple needs rather than for specialised economic purposes (Kosgey et al., 2003). In this system, livestock may provide agricultural inputs, such as manure, and render the enterprise more secure by using residual capacities of production factors with low opportunity cost such as non-arable land and excess labour (Kosgey et al., 2003). Livestock convert crops and crops residues into high value animal products and balance production and market risks (Jahnke, 1982; Wilson, 1985; Agishi, 1988; Peters, 1988; Ayalew et al., 2003). Environmental stresses of heat, poor nutrition, animals of low genetic merit and diseases give adaptability traits greater importance compared to production traits. Traits contributing to survival such as disease resistance, survival rate and reproduction performance are therefore highly rated in this production system (Franklin, 1986; Osinowo and Abubakar, 1988; Ponzoni, 1992).

Large-scale meat production system

This system is mainly found in medium to low production potential areas where crop production may not be feasible due to topographical constraints (hilly and rocky areas) or the weather patterns cannot sustain crop production. The areas are characteristically dry due to high evapo-transpiration. Livestock in these areas serve both tangible and intangible roles (Kosgey et al., 2003). Farmers own large numbers of animals, which are raised under extensive or communal grazing and management (Adu and Lakpini, 1988). Small and large groups of animals owned by several individuals migrate over large areas and breeding and disease control are minimal (Kosgey et al., 2003). Various animal species (cattle, sheep, camels, donkeys and goats) are grazed together, which ensures complementarity in forage use (Adu and Lakpini, 1988). Indigenous breeds tend to dominate due to their adaptability to prevailing harsh environmental conditions. Some members of pastoral communities are

increasingly adopting the agro-pastoral system due to decreased land sizes, sedentarisation, clan conflicts in pasture and water management, and changing lifestyles, encouraged further by encroachment of farmers from the farming communities (Kosgey et al., 2005).

2.1.2. Marketing structures

Marketing of livestock and livestock products in Kenya was a preserve of the government through its Livestock Marketing Division (LMD) until 1987 (GoK, 1987) when the industry was liberalised. The effects of liberalisation led to the collapse of the LMD, and specifically the Kenya Meat Commission (KMC). This led to the evolution of unstructured marketing that is driven more by short term profit making and less investment in the development of the industry. The result was exploitation of producers by numerous middlemen. However, with time a market structure with distinct marketing channels has evolved though not yet clearly defined (Otieno et al., 1993). These marketing channels may be simple, where the farmer may sell directly to a buyer, or complex in which case the animals and/or their products may be sold several times from the farmer through the sequence of middlemen to the final consumer (Gatenby, 1986; Arora et al., 2002; Makokha, 2002).

Figure 1 shows a schematic representation of various players and their interactions in the marketing of animals and/or animal products in Kenya. There is excessive interaction between different players but despite the many channels, the market lacks clearly defined stratification (MARD, 1998). The implication is that it is not a requirement for a producer to sell to an assembler or an assembler to an itinerant trader. In the case of a live animal, a producer may even sell directly to a retailer or the consumer. The market would best be divided into primary, secondary and terminal markets (Kilungo and Myhenyi, 2001). Smallholder farmers and pastoralists are the main producers and constitutes the primary market. In primary and secondary markets, animals and/or animal products are traded for resale to middlemen and slaughter. The other notable characteristic of the sheep market under smallholder and pastoral production systems in the tropics is that of heterogeneity – e.g., meat, milk, manure and specific animals slaughtered for ceremonies and/or sacrifices (Kosgey et al., 2003).

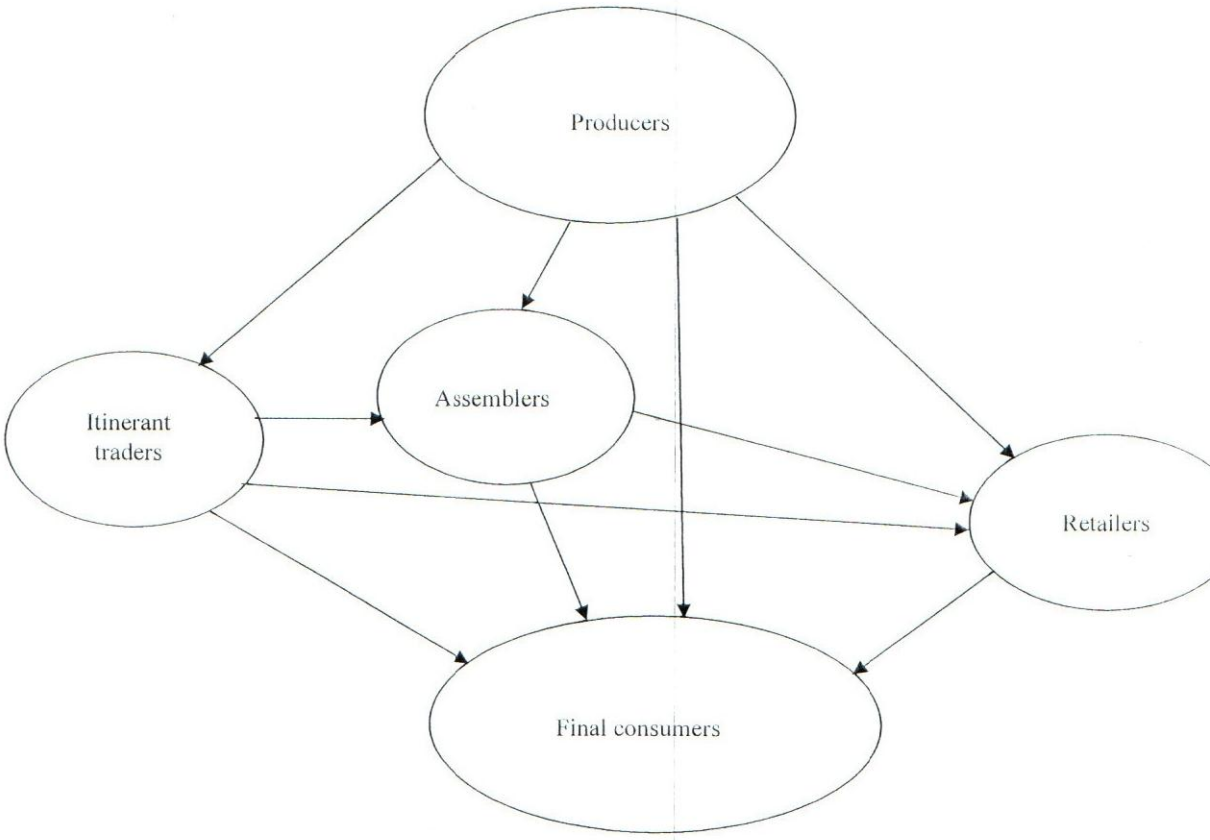


Figure 1. Schematic representation of the various players and their interactions in the marketing of animals and/or animal products in Kenya

Generally, under the pastoral production system, competition in sheep marketing channels is insufficient to provide reliable and remunerative prices. Mahmoud, (2003) recently explained this to be because of: (i) traders have insufficient information to find where there are healthy animals ready for purchase; (ii) traders' transport costs make travelling to pastoralists unprofitable; (iii) traders have insufficient access to transactional credit to operate at efficient scales; (iv) a lack of easily enforceable contract law, but clan and ethnic ties drive inefficient exchange, thereby making it difficult for new entrants to compete with incumbents in the marketing channel and (v) institutional arrangements of sales. Poor communication and transport infrastructure and high risk of livestock theft create transaction costs that are so high as to wipe out any gains from trekking animals to markets. National policies with respect to both cross-border movement of people and animals, and control of domestic animal diseases through movement restrictions and quarantines disrupt the natural flow of animals from rangeland areas with a surplus of cattle to highland areas where demand for sheep is higher.

2.1.3. Breeding

Conventional breed improvement involving selection, crossing and multiplication in the tropics is most effectively undertaken by government agencies (Peacock et al., 1990). Breeding stations for sheep and goat in Kenya were formally established in the 1970s to improve sheep and goats production through supplying high quality breeding stock of sheep and goat to farmers (MLFD, 2002). The breeding stations are public institutions falling under the Ministry of Livestock and Fisheries Development (MLFD) and the Kenya Agricultural Research Institute (KARI) which are charged with developing extension packages for sheep production, preservation of the gene pool, training and demonstration centres for farmers. There are nine sheep and goat stations spread throughout the country, but all are currently running only at 25% of their potential because of inadequate funding, obsolete farm infrastructure and transport problems (MLFD, 2002). For instance, Narok Sheep and Goats Breeding Station located in high sheep production area did not have a single animal as of December 2002. This might jeopardise implementation of any meaningful sheep breeding programme in this station. Implementation of sophisticated breeding programmes in stations requires adequate infrastructure for performance testing and to support large flock sizes (Turner, 1982).

Sheep breeding is informally practised under agro-pastoral and pastoral production systems. In these systems, rams mostly run with the ewe flock, resulting in less controlled mating and minimal selection for any trait. Use of artificial insemination is none existent. The age at first mating averages 11 months in the smallholder systems and 9 months in the pastoral systems (Kosgey et al., 2005). Purebreeding and indiscriminate crossbreeding are practised in both systems. Conventional breeding methods have been difficult to implement due to communal pasture grazing systems, small animal populations with single-sires, low levels of literacy, lack of proper recording practices and infrastructure, resulting into poor breeding strategies (Kiwuwa, 1992). Consequently, nucleus-breeding schemes have been proposed as more viable for achieving genetic improvement (Hodges, 1990).

2.1.4. Constraints to productivity in sheep

The major constraints that have been identified include high prevalence of disease and parasites. Table 2 shows the most common diseases of sheep. Mortality through disease and parasites has been estimated at 53% of all the sheep deaths recorded (GoK, 1990). Ecto-and endo-parasites increase costs of, and compromise production (Wanyangu et al., 1996). *Haemonchus contortus* is the most important G1 helminth in terms of increasing the cost and

losses of production. Wanyangu et al. (1996) estimated that controlling and treating *H. contortus* infection in small ruminants alone cost Kenya KSh. 2.2 billions annually while Albers et al. (1987) showed that the infection reduces average daily gain by up to 60%. Another parasite of considerable economic importance in sheep production is *Fasciola hepatica*, known to cause considerable reduction in the digestibility of nutrients and overall productivity in the hosts. Infected animals exhibit impaired productivity, possibly due to reduced feed intake and poor feed utilisation (Sykes and Coop, 1976; Dargie et al, 1979). Amongst the ecto-parasites affecting sheep productivity, ticks and mites are the most important. Protozoan diseases, e.g., trypanosomosis, is the single most important constraint to sheep production. Other significant diseases in sheep production include contagious caprine pleuropneumonia, coccidiosis, enteritis and mastitis. Pneumonia constitutes the most important bacterial health problem to sheep production, being responsible for 6 to 31% of the morbidity rates (Njau et al., 1988) while the most common and significant viral diseases are contagious ecthyma (Orf) and Peste des petits ruminants with morbidity rates of 50 to 100%. Other major reproductive problems of free-roaming small ruminants include; abortion, still births, metritis, dystocia and pre-natal mortality (Falade and Sellers, 1976; Smith and van Houtert, 1988).

Table 2. Some common diseases of sheep

Type	Condition
Infectious	Broncho-pneumonia, contagious caprine pleuro-pneumonia, caseous lymphadenitis, contagious ecthyma, enteritis, peste des petits ruminant
Parasitic	Coccidiosis, helminthiosis, trypanosomiasis, tick-borne diseases.
Nutritional	Energy and protein deficiencies
Reproductive	Abortion, metritis, mastitis
Traumatic	Hernias, fractures

Seasonal fluctuation in feed quality and quantity is a pervasive production limitation in pasture-based sheep production systems and is worse during drought periods. In pastoral production systems, the communal grazing due to communal land tenure system present limitation in that no effort is applied to improve and increase pasture production, and furthermore formal knowledge in pasture production is largely lacking (Gall and Huhn, 1980; Devendra, 1992). There are no formal or informal laws limiting pasture usage or guarding

against overgrazing. Communal land ownership tends to encourage competition on the number of animals kept, which leads to overgrazing.

Other constraints include poor marketing systems, especially for the ASALs, poor infrastructure and lack of efficient market networks. Improvement of transport infrastructure in these areas and enactment of laws to safeguard the producers from exploitive middlemen are desirable (MLFD, 2003). High incidences of insecurity in areas considered important in meat sheep production form an important constraint to production especially amongst pastoral communities. This is usually coupled with frequent droughts leading to competition in grazing and watering of the animals (MLFD, 2002).

Pastoral flock structures are fragile, with most pastoralists keeping a high share of reproductive stock that is difficult to restock commercially when range conditions improve. Moreover, restocking typically has to draw on imported animals from other areas that may not be well-adapted to the local range or epidemiological conditions. Introducing such animals into flocks may also dilute valued local genotypes. There is the need therefore for improved flock management advisories as well as coordinated commercial breeding and distribution systems that attend to locally adapted traits (Mahmoud, 2003).

2.2. Performance of sheep in the tropics

2.2.1. Production traits

Table 3 presents the levels of performance in production traits of some sheep breeds in the tropics. Production traits directly influence productivity. Most body traits such as birth weight (BW), weaning weight (WW), mature ewe live weight (ELW), consumable meat percentage (CM) is referred to as production traits. Production performance of sheep in the tropics is very variable due to the diverse production circumstances under which they are raised and breed variation (Storbart et al., 1986). Generally, Awassi sheep productive performance is higher compared to the other breeds. For instance, the breed has the highest BW, and ELW but the Dorper has the heaviest WW (21.7 kg) and the Djallonké (10.0 kg) the lightest. The Dorper breed has emerged as the most important sire breed for use in crossbreeding for mutton production in the semi-arid areas of Kenya. Here, it performed better than the Red Maasai under similar production conditions (Kiriro, 1994). This is because the Dorper breed has been subjected to several generations of selection than the Red Maasai. The high mature weight of the Awassi sheep is desirable, indicating that using this

breed for meat production will improve the profitability of the production enterprise (Table 3). This breed is, however, not utilised in Kenya.

Table 3. Production, reproductive and survival performances of different sheep breeds in the tropics

Genotype	Trait[a]										
	BW (kg)	WW (kg)	YW (kg)	ELW (kg)	LS	LF (%)	PRWS (%)	PWS (%)	ES (%)	Country	Source
Dorper	3.9	21.7	28.0							Kenya	Kiriro (1986)
Red Maasai	3.1	17.8	28.0							"	"
Sabi	2.8	17.8	23.0	35.8	1.2	102	87.0			Zimbabwe	Matika et al. (2003)
Timadhite	3.0									Morocco	Bourfia (1988)
Galway					1.6					"	"
D'man					1.8					Egypt	Lahlou-Kassi and Marie (1981)
Ben-Hsen					1.1					"	"
Awassi	4.3	17.5		60.0			90.0				Goddard (1982)
Djallonké	2.0	10.0	20.8				72.0	75.0	68.0	West Africa	Filius et al. (1985)
African Fat Tail	2.6	11.9	31.0					82.5	75.6	Rwanda	Wilson and Murayi (1988)
Adal (Afar)	2.5	13.0	25.8							Ethiopia	Galal (1983)
Horro	2.6	10.4	33.5				67.0	71.4		Ethiopia	Yohannes et al. (1998)
Menz	2.3	13.5	23.4					80.2		Ethiopia	Mukasa-Mugerwa et al. (1994)
Macina	2.7	10.3	24.4							Mali	Wilson (1991)
Mossi	4.0	10.6	21.2							Burkina Faso	"
Ossimi	3.0	19.2	33.5					86.0		Egypt	Lahlou-Kassi (1987)

[a] BW, birth weight; WW, weaning weight; YW, yearling weight; ELW, ewe live weight; LS, litter size; LF, lambing frequency; PRWS, pre-weaning survival; PWS, post-weaning survival; ES, ewe survival.

Growth traits form an important component of the meat sheep breeding objective. This factor was considered by Kosgey et al. (2003) while developing a breeding objective for meat sheep in Kenya. Growth traits considered in that breeding objective were yearling weight (YW), ELW and CM. Live weight is the major determinant of carcass weight and yield of consumable meat. Faster growing sheep are young when slaughtered at the same weight and therefore produce more tender meat with less fat. Horro sheep from Ethiopia and Ossimi of Egypt have the heaviest YW (33.5 kg) and Djallonké of West Africa lightest YW (20.8).

2.2.2. Reproductive and survival traits

Functional traits are not directly related to yield but rather to specific physiological functions of the animal such as health status and disease resistance, reproduction, locomotion and survival. Genetic improvement of these traits helps to reduce production costs and increase the profitability of the flock. They are important in selecting sheep for meat production in semi-arid areas where reproductive rate of hair sheep is low (de Boer, 1981) and disease prevalence is high (Allonby, 1975). Low reproductive rates and a higher disease incidence lead to low selection differential, resulting in reduced genetic gains. Mortality in offspring from birth to weaning increases loss of income from farm animals. The effects of survival on income are relatively more important in sheep with smaller number of progeny weaned per dam (Dickerson, 1970).

Reproductive traits include litter size (LS), lambing frequency (LF), lambing interval (LI), age at first service (AFS), prolificacy and ovulation rate. Table 3 presents the levels of performance in some reproductive traits of various sheep breeds in the tropics. The D'Man has the largest and the Sabi the lowest LS. Litter size is directly related to the number of lambs weaned per 100 ewes mated which is the most important trait in controlling financial returns from a flock (Rae and Barton, 1970). In a breeding flock, a higher reproductive rate permits greater selection intensity because of surplus breeding stock and this leads to an increase in the annual rate of genetic gain. Reproductive traits are lowly heritable with values ranging from about 1–19% (Koots et al., 1994). This means that they are predominantly determined by non-genetic factors. Consequently, it has been assumed that reproductive traits will take a long time to improve via within breed selection. Notably, the more intensive the meat production system, the more desirable is the production of large numbers of young per breeding female (Kosgey et al., 2003). Under harsher conditions, optimal production levels are achieved by maintaining reasonable levels of performance in the young, while limiting

the drain on the resources of the breeding female. Genes that affect the function of the ovary of the female animal also influence the growth of the testis in males, so that testis sizes are a simple genetic indicator of genetic merit for the female reproduction (Land et al., 1974).

The term adaptation has been used to describe an animal's ability to adjust to environmental conditions or to infer genetic modifications that make an animal more suitable for existence under specific environmental stresses (Cundiff et al., 1982; Franklin, 1986). Survival in itself is not an all or none trait but consists of several components. Some biological components of survival include reaction to cold and heat stresses, disease resistance or tolerance, endo- and ecto-parasitic resistance and the ability to survive on low quality feed. Survival traits are lowly heritable and therefore selection offers little scope for improvement. The Awassi sheep has the highest pre-weaning survival rate (PRWS) compared to the other breeds (Table 3). Post-weaning survival is highest in Ossimi sheep of Egypt (86%) and lowest in the Horro sheep of Ethiopia (71.4%). Under pastoral production systems more emphasis is put on survival traits than reproductive traits since animals have to walk long distances in search of water and pasture under harsh climatic conditions (Kosgey et al., 2005).

2.3. Breeding for disease resistance in sheep

Though diseases are a major constraint to improving sheep productivity and profitability, some have a genetic basis and sheep that express resistance can effectively be bred. Albers et al. (1987) defined resistance as the ability of an animal to suppress the establishment of parasites and/or eliminate parasite load. Parasites, particularly GI helminths and protozoa, are major constraints to animal productivity throughout the world. One protozoan disease in particular, trypanosomosis, is the single most important constraint in sub-Saharan Africa (Rege, 1994). Good diet has been associated with resistance to trypanosomosis (Gibson, 1963). However, this has been disputed (Little et al., 1990) and in its place host resistance has been identified as the single most important factor that influences resistance. This offers an opportunity to select animals that have the ability to resist trypanosomosis infection and/or produce under the disease challenge. The N'Dama cattle, for example, have been shown to be trypanotolerant.

Fleece rot and footrot are two bacterial skin diseases of potential significance in sheep. The latter is more important while considering meat sheep production in the tropics (Kosgey et al., 2003). Fleece rot has been used as an indicator trait for genetic improvement in resistance to body strike in Australia (Raadsma, 1991). Exploitation of genetic variation in

resistance to fleece rot is feasible through selection of sheep within flocks, between flock within strains, and between strains. Some sheep have the ability to resist establishment of the footrot, whereas others remain chronically infected. The role of the epidermal skin barrier and subsequent inflammatory response are thought to be important in innate resistance. The option of exploiting genetic differences in footrot through direct selection is clearly not practical because it requires challenging all animals before selection. An available option would be to use genetic markers linked to resistance (Raadsma, 1991).

There has been evidence of genetic resistance to helminths based on the number of worms in sheep at necropsy and eggs per gram of faeces (epg) and anaemia measured by the packed red cell volume (PCV). This offers a reprieve to producers who would consider utilising the resistance. The faecal egg count (FEC) is widely used as an indicator of nematode infections (Gray and Woolaston, 1991). It is heritable and relatively easy to measure, is repeatable within infection cycles and there are positive phenotypic and genetic correlations between infection cycles (Baker, 1995). The PCV is a measure of the host's ability to restrict the development of anaemia. It is a good indicator of host resistance to parasites especially blood-sucking parasites such as ticks or *H. contortus* (Woolaston and Eady, 1995). Worm count is the best indicator of host resistance to helminths, but it can only be measured after slaughter. The increasing appearance of nematode strains resistant to anthelminthics has increased the need for the utilisation of genotypes that are resistant to GI helminths.

2.3.1. Breeding for resistance to GI helminths

Breeding sheep for RES seems to be the most promising application that can be used to complement the strategic use of dewormers and improved pasture management. From an economic point of view, resielence allows sheep to maintain existing levels of production even if they are infected. There is a substantial body of evidence that supports the fact that some sheep breeds are naturally more resistant to internal parasites than other breeds. The best documented examples of sheep breeds showing resistance to endo-parasites in Africa are the Red Maasai sheep in East Africa and the Djallonké sheep in West Africa (Preston and Allonby, 1979). The Targhee breed has been shown to be more resistant to endo-parasites than Rambouillet (Scrivner, 1964). There is also evidence that selection for resistance to internal parasites in sheep is feasible. Producers could reduce costs by breeding sheep like the Red Maasai, Djallonké and Targhee or their crosses that are resistant to internal parasites. A possible short-term alternative could be the use of independent culling levels to select for

internal parasite resistance traits. A performance recording system that can handle the collection of measurements of internal parasite resistance would be a critical component.

The FEC and PCV are measurements that can be used to monitor parasite infection in sheep. The FEC is cheaper and logistically simpler to measure. There exists a strong correlation between FEC and the severity of helminths infection (Windon, 1991) especially when infection is by *H. cortotus* and *Trichostrongylus colubriformis*. The FEC has become the accepted measure of a sheep's resistance to worms. However, it is important to consider the proper timing for FEC measurement (s).

There is mounting evidence that genetic differences in FEC will be far more pronounced after the immune system has been triggered by an initial infection (Windon, 1991). The immunological reactions caused by the infective larvae appear to differ in sheep of different resistance status. Age is probably less critical than previous parasite exposure in determining the optimal time to measure FEC. For example, Woolaston et al. (1991) observed selection line differences in FEC in 3–4 months old weaners. Piper (1987) reported significant sire effects on FEC in 18-months old merinos. In both cases, animals were known to have had exposure to larvae at pasture. These results support the argument that an initial priming of young animals is necessary to allow genetic differences in FEC to be identified. In most instances, the distribution of FEC is skewed, resulting in the mean FEC being greater than the median (most common FEC) and a small proportion of animals having a disproportionately high FEC. To correct data for fixed effects such as management group or sex, it is necessary to examine the distribution of the data and if necessary transform the data so that it is normally distributed. An example is shown by high coefficient of variation (CV) of 111% obtained by Rege et al. (1994). The CV was reduced to 23.5% when the logarithm transformation was applied. Choice of a power log transformation may vary between data sets. A detailed range of options are listed by Elliott (1977), who further noted that normalisation of FEC depends on the original distribution of FEC.

2.3.2. Causes of variation in FEC

The effects of infection with internal parasites on production of a particular livestock species depend mostly on the age of the individual, season, physiological status, the breed, the parasite species involved and the intensity of the parasite population within the definitive host. These factors act together to result in different levels of egg counts per gram. Rege et al. (1994) reported that lambs and pregnant ewes had higher eggs count per gram (epg) than old and non-lactating counterparts. Egg count was high during pre-weaning as well as the post-

weaning periods, the latter falling in dry season. This was as a result of feed quantity and quality during these periods that lreduced resistance to helminths. During the post-weaning period that fell in the wet season, which is when worms prevail, egg count was high though resistance was also high due to availability of nutrients necessary to support the resistance to worms. Rege et al. (1994) concluded that variation in FEC was due to seasons. According to Baker et al. (1999), age and physiological status of the ewe affect susceptibility to infection with GI nematode parasites. That study indicated that lambs were more susceptible than the mature sheep while lactating ewes had higher susceptibility to GI helminth infections than non-lactating ewes, mature rams and wethers.

There is also a substantial body of evidence that supports variation among breeds in resistance to internal parasites, particularly *H. contortus, Ostergia circumcincta* and *Trichostrongylus spp.* Baker et al. (1999) showed breed effect as having an influence on the level of infection. When the Red Maasai and Dorper sheep were reared in similar GI helminths challenged environment, the Red Masaai showed higher resistance to GI helminth infection (higher PCV and FEC) than the Dorper. Earlier studies had indicated breed effect in resistance to GI helminths (Preston and Allonby, 1979; Mugambi et al., 1997; Wanyangu et al., 1997). As alluded to earlier, other breeds identified as having superior natural resistance to helminths are the Djallonké of West Africa, Scottish Blackface and St. Croix (Preston and Allonby, 1979). Tropical indigenous sheep breeds are the most resistant to both ecto- and endo-parasites (Owen and Axford, 1991). The genotype of the host influences the immune response to helminth and therefore affects the epg (Soulsby, 1985). Although the productivity of tropical livestock is often lower than of the temperate animals, tropical animals maintain reasonable performances under parasite burden, making them the best adapted genotypes in the tropics.

2.3.3. Genetic markers for resistance to GI helminths

Breeding for resistance to helminths using current methods relies on obtaining measurements of FEC and/or PCV as phenotypic indicators of RES. Screening adequate numbers of animals to implement a selection programme based on these measurements is therefore labour intensive and not cost-effective. Although FEC is repeatable (0.50), heritable (0.31) and correlated with worm burden (Gray, 1991), reservations have been expressed on the accuracy of these measurements as indicators of resistance (Woolaston, 1990). An alternative to direct selection is to apply genetic markers in large numbers of animals, at an

early age and at reduced cost, allowing an accurate assessment of an animals' genotype without the need to refer to phenotypic indicators of RES (Woolaston, 1990).

A genetic marker for a trait is a DNA segment which is associated with, and hence segregates in a predictable pattern as the trait. These markers assist in 'identifying or tagging' of particular genes or small segments of the chromosome linked with genes affecting the trait of interest (Rege, 1994). Large numbers of such markers have enhanced the likelihood of detection of major genes influencing quantitative traits. The chances of the existence of major genes for most traits of interest and of their identification are considered to be high (Mackinnon, 1992). The process of selection for a particular trait using genetic markers is called marker assisted selection (MAS). The process can accelerate the rate of genetic progress by increasing the accuracy of selection and by reducing the generation interval (Smith and Simpson, 1986). Marker identification and subsequent use has enhanced future prospects for breeding for resistance to diseases. Already, identification of carriers of genes for resistance to *H. cortotus* and *T. colubriforms* has occurred and introduction of the genes into susceptible populations seems feasible (Gogolin–Ewens et al., 1990).

Infection with GI helminths, like any other disease condition, triggers an immune response in the host. The major histocompatibility complex (MHC) is a cluster of genes considered as the engine-room of the immune response and whose genes play a number of major roles in enabling the host to distinguish between 'self and non-self' and consequently to mount an immune response against all things foreign (Warner et al., 1989). Earlier studies in laboratory animals suggested that different MHC alleles may be associated with resistance to certain diseases. Livestock are subjected to many infectious diseases and there is therefore need to search for the MHC and these diseases. However, the MHC does not appear to be strongly associated with infectious diseases but with parasitic diseases, consequently offering an opportunity for its utilisation in breeding for RES.

In sheep, disease association studies have been done for internal parasites, flystrike and footrot (Raadsma, 1991). These studies show the potential of MHC usage in selecting for disease resistance. The MHC associated with RES is located in the sheep genome on chromosome 20 (Crawford et al., 2002). Several studies have shown significant associations between regions on ovine chromosome 20 and indicator traits for internal nematode resistance (Schwaiger et al., 1995; Buitkamp et al., 1996). The DRB1 locus within the ovine MHC has been associated with resistance to *T. circumcincta* in Scottish Blackface. However, in a different analysis of the data, the results were not confirmed and a microsatellite for the DY locus (*DYA* 13.5 cM) was found to be significant (Buitkamp et al., 1996). Janssen et al.

(2002) found the markers *OarCP73* (18.1 cM), *DYMS1* (position unknown) and *BM1815* (26.8 cM) to have a significant association with haematocrit level, IgL (L3 stage larvae specific immunoglobulin) level and logarithm transformed FEC, respectively, following an artificial challenge with *H. contortus*.

2.4. Development of breeding objectives

Care should be taken in the definition of a breeding objective because a wrong choice would result in sub-optimal genetic progress and in worse scenarios in deterioration of the population (James, 1982). Decision about which traits should be included in the breeding goal should be based purely on economic grounds and not whether they are difficult or easy to measure or change genetically (Ponzoni and Newman, 1989). Traits of great economic importance have been omitted in different breeding objectives of grazing ruminants due to cost or measurement complexity. Resistance to GI helminth and feed intake are examples of such traits (Ponzoni, 1986). This constitutes a major omission since helminthosis is expensive to control and treat while feed intake accounts for a high proportion of the production costs in pasture-based production systems.

In any production system, a producer has to identify animal traits that directly influence profitability. These traits of economic importance are usually combined to form a breeding objective (Ponzoni, 1986). Breeding objectives should account for inputs such as feed, husbandry and marketing costs as well as income from sale of surplus offspring and cull-for-age ewes and rams (Ponzoni and Newman, 1989). Development of a breeding objective requires a critical analysis of costs and returns associated with the production system. There are four distinct phases in the development of a breeding objective (i) specification of the breeding, production and marketing systems, (ii) identification of sources of income and expense, (iii) determination of biological traits influencing revenues and costs and (iv) derivation of the economic value of each trait in the breeding objective (Ponzoni, 1986).

2.4.1. Specification of breeding, production and marketing systems

Breeding system

The identification of the role of the breed in industry is a good starting point for the definition of the breeding objective (Harris et al., 1984). Some breeds have more roles, but for most, a predominant one can be identified. Generally, breeds are used either as purebreds

(e.g., Merino and Romney Marsh), as part of a crossbreed dam (e.g., Border Lercester) or as terminal sire breeds (e.g., Suffolk and Dorper). Identification of the role of the breed in the industry is important because it affects the fraction of the genes of the breed at the commercial level and determines which of the breed traits are of economic importance to the commercial producer. The primary goal of most commercial producers is to maximise monetary gains from their flocks and the breeding objective is a detailed description of the desired animal. Milk and wool production from sheep in Kenya is not emphasised, and consequently, existing breeding objectives do not include traits related to these products (Kosgey et al., 2003; 2004).

Production and marketing system

In the description of the production and marketing system, inputs and outputs should be quantified. Input costs can be categorised into either variable or fixed. Variable costs are dependent on the level of production. The converse is true for fixed costs. Examples of fixed costs include rates, interests and living costs (Ponzoni and Newman, 1989). The description should be holistic and the following should be specified: ages at breeding, timing of offspring production, expected fertility and fecundity, ages or weights for weaning, intensive feeding, marketing and slaughter. The nature of feed, labour, land, buildings and equipment required and the corresponding cost at various stages are all necessary to fully describe the systems. There is a wide variety of production systems in the topics. They vary from fully intensive systems where land size is limiting as observed with smallholder farmers in medium to high potential areas, to those based on extensive rangelands observed with pastoral farmers (Preston, 1977).

2.4.2. Identification of sources of revenues and costs

Income is the sum of the products of the number of sale animals in each class of livestock and the value per individual. In a marketing system where quantity rather than quality determines the price, the value of an individual animal is influenced by the weight and the price per kilogramme of each class of sale animal. There are also other sources of income that are derived from the animal. In sheep, these include skins, manure and to a lesser extent milk. Table 4 shows the main sources of revenues and costs, and traits influencing them for breeds used for different roles. Costs listed are only those considered to vary with the level of expression of the traits.

Table 4. Main sources of revenues and costs, and traits influencing them in breeds used for different roles

Most common role of breed	Sources of revenues and costs	Traits influencing revenues and costs
Pure-bred and part of crossbred dams	Revenues	
	Wool, surplus offspring, cull-for-age animals	Ewe reproduction rate, sale weight and live weights
	Costs	
	Feed, wool marketing, marketing of surplus offspring	Feed intake, weight, ewe reproduction rate, disease resistance, easy-to-care traits
Terminal sire	Revenues	
	Sale of offspring	
	Costs	
	Feed, marketing, veterinary services, labour	

Morris et al. (1979), Jones (1982) and Ponzoni (1982) included increased feed requirements likely to result from genetic change in some traits (e.g., reproduction rate and live weight) as variable cost. Increased feed requirements were considered to be a function of those traits. James (1982) stressed the dangers involved in making this assumption and emphasised that increased feed requirements should not be included as a variable cost, but that instead, feed intake should be a trait in the breeding objective. Ideally, feed intake should be included as a trait in the breeding objective although genetic parameter estimates and their reliability could be a hindrance because few such reports exist (Barwick, 1992).

Identification of revenues (R) and costs (C) in a production system enables the development of a profit function. Profitability (P) is given by:

$$P = R - C \qquad (1)$$

An alternative method of expressing profit was proposed by Harris et al. (1970) as:

$$E = R / C \qquad (2)$$

where E is the efficiency, or its inverse. Cost per unit product, (Q), also proposed by Dickerson (1970) is expressed as:

$$Q = C / R \qquad (3)$$

All traits which contribute to P and E should be considered for inclusion in the breeding objective regardless of their heritability and/or measurement problems. Recently, economic theory has been shown to provide a valuable background from which to make the most appropriate choice between the use of profit or efficiency derivation of economic values for traits in the breeding objectives (Amer and Fox, 1992; Amer, 1994; Amer et al., 1994).

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2.4.3. Determination of biological traits influencing revenues and costs

In principle, all traits influencing revenues and costs should be included in the breeding objectives (James, 1982) even if one or more traits cannot be measured directly. The profit equation is expressed as a function of the principal biological traits contributing to each source of income and expense. The list of traits that are considered important will differ between each strata, namely producers, traders (assemblers, itinerant traders and retailers) and final consumers, i.e., each level of the industry may have a different set of traits of economic importance. In meat sheep, growth-related traits, reproduction and survival are important (Kosgey et al., 2003; 2004). Litter size and lambing frequency were the most important traits in a breeding objective for smallholder production presented by Kosgey et al. (2003). In addition, yearling weight was considered important under pastoral production system. Since it is the satisfaction of the consumer a producer wishes to improve, the consumers' breeding objectives should be transferred back to the producer through market forces. However, this seldom happens.

2.4.4. Derivation of economic values of traits in the breeding objective

Development of a breeding objective requires a critical analysis of costs and returns associated with the production system. Dickerson (1970) used a profit equation that identified and evaluated all costs associated with female production and reproduction, and growth of progeny as well as all sources of revenues generated by the sale of progeny for meat and of milk, and/or wool from breeding females. The economic contributions of changes in biological performance were used to establish the effect of genetic change on profit. Distributing fixed and variable costs across an enterprise is challenging when considering the value of genetic change in both market and breeding animals because partitioning costs among different elements of performance is not always straightforward.

In all cases, a profit function is required in the derivation of economic values for traits in a breeding objective. The profit function considers biological traits influencing revenues and costs. Profit functions may take different forms (Dickerson, 1970; Harris, 1970), each resulting in a somewhat different evaluation of the livestock system. Brascamp et al. (1985) calculated profit on a per female, per individual and per unit produced basis, assuming constant numbers of females, individuals, and units of product sold, respectively. Profit equations appropriate for calculating economic values for breeding objective traits should not be influenced by management decisions that are unrelated to genetic improvement. Smith et al. (1986) discussed the effect that the scale of an enterprise may have on a profit equation

and suggest that profit that could be obtained from changing the size of an operation should not be considered in the calculation of economic values. Therefore, genetic improvement that results in a change in profit should affect the efficiency of the production system on a per-unit of product basis.

Ponzoni (1988) evaluated profit as income minus expense, income divided by expense, and expense divided by income to derive economic weights of a breeding objective for Merino sheep. For each of the three different profit evaluations, production data was used to calculate profit and compare the consequences of using different equations in deriving a breeding objective. Ponzoni (1988) concluded that economic values were consistent for all three profit equations. Changes to the enterprise that were independent of selection did not influence profit when calculated as a function of either a difference or as a ratio. This was in agreement with Brascamp et al. (1985) and Smith et al. (1986).

Generally, different methods are available for the estimation of economic values. They are partial budgeting (Dekkers, 1991), partial differentiation (Brascamp et al., 1985; Ponzoni, 1986; Smith et al., 1986; Beckman and van Arendonk, 1993; Visscher et al., 1994) and regression methods. Economic weights for goal traits are estimated by the partial derivative of profit with respect to each goal trait expressed at the population mean (Brascamp et al., 1985; Smith et al., 1986). Regression considers an analysis of performance testing or data collection (Fewson, 1993). An appropriate economic target parameter is chosen which includes all input and output components. The objective traits under consideration are regarded independent variables. A multiple regression analysis enables estimation of the marginal value of each trait. However, such an analysis can sometimes be very complex especially where breeding values for the different traits are highly correlated, making interpretation of the results very difficult (Amer, 1994). When profit equations are linear, mean performance does not influence marginal economic values. If profit is non-linear, the value of genetic change is influenced more strongly by the current level of performance. Brascamp et al. (1985) suggests that most non-linear profit relationships can be generalised by a linear approximation because of slow changes in mean performance resulting from selection.

The profit function methods do not apply in the case of resistance to GI helminths because disease resistance has a multi-fold influence on input and output, which in turn affect profit. Methods such as restricted index have been suggested but have weaknesses and are arbitrary (Pesek and Baker, 1969). Sivarajasingam (1995) described an objective method for estimation of economic values for disease resistance. In this method, for a given set of

assumptions, the breeding objective is matched to the expected responses in traits and production trait responses are maximised relative to overall gains. This method is suitable since the economic value (s) obtained is not arbitrary and is adopted for the present study in estimation of economic value for resistance to helminth.

2.5. Genetic and phenotypic parameters

The potential for genetic improvement is largely dependent on the heritability of the trait and its genetic relationship with other traits of economic importance upon which some selection pressure may be applied (Falconer, 1981). Information on heritabilities is essential for planning efficient breeding programmes and for predicting response to selection.

Table 5 shows estimates of genetic parameters for production, survival and reproductive traits of sheep. Heritability estimates are higher for production traits than for reproductive traits. Female reproductive traits are highly influenced by the environment whereas high heritability estimates for productive traits are due to the high genetic variances attributed to these traits (Koots et al., 1994). These imply that the reproduction traits can be improved more through manipulation of the production environment than selection. For most production traits, selection can play a major role in their improvement. The heritability estimate for feed intake and resistance to fleece rot are low, but there are possibilities to improve these traits through selection. Of interest, is the moderate heritability estimate for FEC. This offers an excellent opportunity to breed sheep that are resistant to GI helminths.

Genetic correlations are essential in predicting indirect responses to selection and are needed in order to determine the optimum weighting and expected response to multiple trait selection. Different traits may be influenced by the same genes implying that expression of one trait depends on the other. This relationship may be positive or negative. Where it is positive, improving one trait leads to a similar trend in the other trait. The converse holds where the relationship is negative. Genetic correlations are measures of the extent to which the same genes or closely linked genes cause co-variation in two different traits. Genetic correlations between traits are essential in predicting indirect responses to selection and are needed in order to determine the optimum weighting and response to multiple trait selection (Woolaston et al., 1991). The genetic correlations between dressing percentage and mature weight, WW and number of lambs weaned per ewe lambing (NLW/EL) are weak and negative. The genetic correlations between most reproduction traits are strong and positive. There are very few reported estimates of genetic correlations between resistance to helminths

and production traits in sheep. Phenotypic correlation between FEC and YW is close to zero (Baker, 1995).

Table 5. Estimates of genetic parameters for production, survival and reproduction traits for sheep

Breed	Trait 1[a]	Trait 2[a]	Parameter estimates[b]			source
			h^2	r_g	r_p	
Merino	Dressing %		0.39			Fogarty et al. (2003)
Inra401		Mature weight		-0.22	-0.07	Bibe et al. (2002)
		WW		-0.17	-0.09	
Merino	Mature weight		0.47			Lee et al. (1995)
"		Dressing %		-0.22	-0.07	Fogarty et al. (2003)
	Fleece rot		0.17			Li et al. (1999)
	Feed intake		0.12			Lee et al. (1995)
Hyfer	NLW/EJ		0.08			Fogarty et al. (1994)
Dorset		NLB/EJ		1.00	0.77	Brash et al. (1994)
Hyfer		WW/EJ		0.94	0.93	Fogarty et al. (1994)
Composite		NLW/EL		-0.04	-	Rosati et al. (2002)
		WW/EL		0.16		"
		NLBA/EL		0.21	-0.08	"
Dorset		EL/EJ		0.45	0.46	Brash et al. (1994)
Merino		Mature weight		0.35	0.09	Swan et al. (2001)
Red Maasai	YW		0.42			Baker (1995)
		FEC		0.31	0.08	"
	FEC		0.31			"
	BW		0.12			Kiriro (1994)
Merino		WW		0.06	0.27	Lewer et al. (1994)
	WW		0.19			"

[a]NLW/EJ, number of lambs weaned per ewe joined; NLB/EJ, number of lambs born per ewe joined; WW/EJ, weight of lambs weaned per ewe joined; NLW/EL, number of lambs weaned per ewe lambing; WW/EL, weight of lambs weaned per ewe lambing; NLBA/EL, number of lambs born alive per ewe lambing; EL/EJ, number of ewe lambing per ewe joined; YW, yearling weight; FEC, faecal egg count; WW, weaning weight.

[b]h^2, heritability; r_p, phenotypic correlations; r_g, genetic correlation.

The phenotypic correlation between two traits describes the extent to which individuals above average for one trait tend to be above, below or near average for the trait. It measures the linear association between traits. It is any indirect response in unselected traits

occurring simultaneously with response in the trait under selection. The phenotypic correlation can be partitioned into genetic and environmental components. The phenotypic correlations between dressing percentage and other production traits are weak and negative (Table 5). The phenotypic correlations between reproductive traits are strong and positive. For example, the phenotypic correlation between NLW/EJ and number of lambs per ewe joined (NLB/EJ), WW/EJ and EL/EJ are 0.77, 0.93 and 0.46, respectively. The implies that NLW/EJ is a good indicator trait for NLB/EJ, WW/EJ and EL/EJ.

2.6. Response to selection

The main objective of animal genetic improvement is to choose animals which have the greatest combined genetic value to be parents of the next generation (Hazel, 1943). In essence, response to selection is the change in overall performance between the offspring of selected parents relative to that of the average of the population. Response to selection can be direct (i.e., change in a trait due to selection directed at the same trait), expected (estimated selection response based on genetic and phenotypic parameters) or realised (true changes in a trait from field evaluation) (Pirchner, 1983).

2.6.1. Selection criteria

It is necessary to make a clear distinction between the breeding objective and selection criteria. While the breeding objective comprises traits which a producer attempts to improve genetically because they influence returns and costs, selection criteria are the characteristics used in assessing the breeding value of individuals (Hazel, 1943). The selection criteria can be combined in a selection index (I) in which each characteristic is weighted so that the correlation between aggregate genotype and selection index is maximised. Traits in the breeding objective may or may not be used as selection criteria, i.e., as indicators of the breeding values of the animals. In fact, it is only rarely that exactly the same sets of characteristics occur in both the objective and criteria. Where traits are different from the ones in the breeding objective, the indicator traits must be strongly linked to the breeding objective traits and are usually easier or cheaper to measure. In choosing a selection criterion, the following are considered; ease or practicality of measurement and the degree of relationship (genetic correlation) with traits in the breeding objective (Hazel, 1943). Selection accuracy is optimised when information sources are increased and more characters are included as criteria (Pirchner, 1983).

In the context of breeding for RES, potential selection criteria and genetic markers have been examined (Gray and Raadsma, 1986; Albers et al., 1987; Piper, 1987). In the absence of suitable genetic markers, it appears that FEC is sufficiently correlated to RES as to be a selection criterion. The decline in PCV during *H. contortus* infection essentially measures the same trait as the logarithm of FEC (Piper, 1987). Both measures have approximately the same heritability, costs and ease of measurements, and therefore equally attractive alternatives when *H. contortus* is the predominant parasite. The FEC is used to measure RES although other parameters such as peri-parturient rise in egg count have been used to measure resistance (Courtney et al., 1985). Windon and Dineen (1984) used antibody response and indirect indicators of anaemia for *H. contortus*. Riffkin and Yong (1984) used purified nematode antigens and then recorded response in treated sheep.

2.6.2. Selection index theory

Once a linearised breeding objective has been developed and economic values of traits estimated, selection index theory (Hazel, 1943) can be used to derive a linear selection index that predicts the breeding objective. The selection index method involves combining the measurements of two or more characters into a single value for each individual (Dickerson, 1970). Hazel and Lush (1942) first examined three methods of selection for net merit. These were tandem selection, independent culling levels and selection index. A typical selection index equation takes the form below:

$$I = b_1 X_1 + b_2 X_2 + \ldots + b_n X_n \qquad (4)$$

where I represents the index value for the source of information, b_1, b_2 ... b_n are the weighting factors for the sources of information X_1, X_2,.....X_n on an individual animal or its relatives (Falconer, 1981). The weighting factors (b) are calculated as coefficients that minimise the squared differences between the breeding objective and the predicted genetic merit (I). A formula incorporating P, G and economic values (v) of traits in the breeding objective gives the index coefficients as:

$$b = P^{-1}Gv \qquad (5)$$

where P is a phenotypic variance-covariance matrix of the characters in the selection criteria, G is a genetic variance-covariance matrix between the characters in the criteria and traits in

the breeding objective and v is a vector of economic values of the traits in the breeding objective.

Lin (1978) noted that selection index method is not optimal in estimating or predicting breeding values of animals since this resulted in biased estimates. Henderson (1973) developed a robust estimate (Best Linear Unbiased Prediction) to achieve increased accuracy in the prediction of unbiased breeding values.

2.6.3. Best Linear Unbiased Prediction

BLUP, also described as the 'best index' by Henderson (1973) is a generalised procedure for combining information on the individual and all relatives in a selection programme. It greatly increases the accuracy of selection especially for traits with low heritabilities. BLUP eases the process of data compilation from different sources such as flocks, breeds and, sires, among others. This is usually complex and tedious statistical procedure when using selection indices since this process requires assessment of correction factors for different years, flocks, seasons, etc. In addition, the true genotypic means of individuals are not known in reality. However, selection index theory still remains a useful tool for approximating the accuracy of BLUP selection and predicting selection response.

2.7. Breeding strategies and structures

2.7.1. Breeding strategies

Genetic improvement of livestock depends on access to genetic variation and effective methods for exploiting this variation. Genetic diversity constitutes a buffer against changes in the environment and is key in selection and breeding for adaptability and production on a range of environments. It is this variation within and between animal populations that is used to determine which breeding strategy to be adopted for different population. There are three main pathways considered in the utilisation of the diversity; (i) selection between breeds (or strains), (ii) cross-breeding, and (iii) selection within breeds (or strains) (Baker and Gray, 2004). It is important to match a particular strategy with an appropriate production environment (Carles, 1983; Sölkner et al., 1998). For instance, an appropriate breeding strategy in tropical countries would be one that aims at improving productivity without deteriorating adaptation to the environment.

Due to the fact that the environment constitutes many factors interacting at different economic, social and cultural levels, choice of a breeding strategy is cumbersome (Kosgey et

al., 2003). The first step in the improvement of productivity through the aforementioned three pathways involves the choice of a breed or cross, and considering whether the breed, or the 'parent' breeds in the case of cross-bred animals, can be improved further by within-breed selection. The within-breed selection is usually carried out in individual populations and the main intention is to increase the average level of genetic merit of the populations. Replacing a purebreed for another is a suitable strategy where large genetic differences between breeds (or strains) in traits of significance is of importance – it can be utilised to achieve dramatic and rapid genetic change. This strategy is costly especially if both males and females are targeted for replacement. It is usually not feasible to replace whole flocks especially when the strategy is considered at the national scale and where it is possible, it can take a very long time to achieve (Simm et al., 1996). Mating of different breeds (crossbreeding or upgrading) has been used in the tropics. Crossbreeding offers the opportunity to exploit heterosis, i.e., the extra performance of the crossbred over the average of the parental breeds due to non-additive genetic effects. Baker and Gray (2004) noted that the increase in performance due to heterosis ranges from 0 – 10% for growth traits and from 5 – 22% for fertility and mortality traits. The benefits of crossbreeding may have been exaggerated (Ayalew et al., 2003) to an extent that improvement of livestock is often confused with crossbreeding (Wollny, 2003). Crossbreeding has been unsuccessful and unsuitable in the long-term due to the incompatibility of the genotypes and the production circumstances under smallholder and pastoral small ruminant production systems (Kosgey et al., 2005). This is undesirable since it leads to erosion of the small ruminant genetic resources in the tropics (Wollny et al., 2002).

2.7.2. Breeding structures

A typical livestock industry collectively constitutes nucleus breeders, commercial farmers, consumers and retailers (Blair and Garrick, 1994). It is the nucleus breeders who generate genetic improvement by selecting animals based on their estimated breeding values for traits of interest. The nucleus breeders are at the peak of the industry structure. Their product (superior genotypes) need be disseminated to the next levels of the industry structure consisting of farmers who run commercial units. The dissemination of genetic superiority is mainly through sires. This means that nucleus breeders obtain a significant proportion of their income from the sale of breeding stock, whereas for the farmers, the main source of income is from the sale of products such as meat, skins, milk and wool. Such an industry can be viewed as a pyramid consisting of tiers, which should include not only the nucleus and commercial

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units, but also processors, retailers and consumers (Haris et al., 1984; Blair and Garrick, 1994).

Due to a number of constraints identified in livestock production in the tropics, Hodges (1990) and Jasiorowski (1990) recommended nucleus breeding structures as appropriate for genetic improvement, especially in small ruminants production. In these structures, genetic improvement is generated in a small fraction of the population (referred to as the nucleus). A nucleus breeding unit would require the pooling of superior animals with the highest genetic merit from many sources to form the foundation (Hazel 1943). Depending on the complexity and requirements of the breeding programme, a nucleus scheme can have different number of tiers and migration policies (closed or open).

In a closed nucleus system, replacements come from within the nucleus-bred animals only and genetic superiority is disseminated to the base flock through males and females not needed for replacement in the nucleus (James, 1977). The best males are used in the nucleus while the next best are used in the lower tier(s). Inbreeding is the main constraint because closely related animals tend to be selected due to their closeness in expressing a character of interest. Further, there is reduced selection intensity and the risk of not using commercial sector-born ewes in the nucleus (Jones and Napier, 1980). A closed nucleus system can either be geographically dispersed or centralised. In the former, various groups of 'elite' flocks are maintained by farmers or breeders where selection is the main activity with the superior genotype being disseminated to the rest of the population (Bondoc and Smith, 1993). Centralised closed nucleus structures are similar to the dispersed closed structures only that the flocks are centralised in specific locations under the control and supervision of government (breeding stations) or private breeders (Rege et al., 2001). This structure allows for concentration of selection decisions on a centrally managed flock. Closing the nucleus has the advantage of avoiding unimproved genetic material from the commercial population.

In open nucleus systems, replacements may come from both the nucleus-born animals and the base population, and therefore there exists a two-way flow of genes. It has been defined as one in which female nucleus replacements are selected from the nucleus and the commercial populations, but male replacements are only selected from the nucleus-born animals (Roden, 1994). These systems have higher costs of measurements due to the fact that there is selection of ewes and rams from commercial flocks and the consequent cost of transferring individuals between flocks (Jones and Napier, 1980). The advantage of the open nucleus structure is that it enables use of the best commercial sector ewes that would not have been utilised for breeding if the nucleus were closed. There is also increased selection

intensity leading to higher responses and decreased inbreeding (Jackson and Turner, 1972). An open nucleus structure can either be dispersed or centralised. The Food and Agriculture Organisation of the United Nations has been considering the open nucleus breeding structure as a possibility of improving the organisation of the nucleus flocks in developing countries (Smith, 1988).

2.8. Simulations in breeding programme design

The net financial return of an enterprise depends on the interaction among a great many factors. Some of these factors relate to the animal, its diet and environment, prevalence of disease and to circumstances outside the production enterprise. These circumstances include the premiums paid for products of different quality, relative price structure of feeds and products and the availability and cost of capital, labour, breeding stock and other resources. All these factors are considered in a breeding programme as the genetic, economic or biological input variables. These factors interact in a complex manner such that it is virtually impossible for an individual to assess with confidence the consequences of alternative breeding programmes. However, simulation can be used to analyse complex interactions. Use of simulation models allows for simultaneous consideration of a large number of factors in complex production systems. A model can be deterministic, stochastic or a combination of the two. An advantage of deterministic models is that they can provide more insight into the nature of the problem by describing the process in terms of means and (reduction) in (co)variances and correlations. They also lend themselves to future developments. Stochastic simulation allows inbreeding, and its complex interactions with selection, and the effects of chance events to be accurately evaluated and accounted for in the prediction. It also allows accurate prediction of the variation in selection response. Each of these aspects is particularly important in numerically small populations (Roden, 1995).

Many computer simulation models have been developed in recent years to assist in the management and evaluation of production systems of pigs (Whittemore, 1986; Black et al., 1987; Pomar et al., 1999), poultry (Emmans, 1981; Kleny and Gous, 1988; Talpaz et al., 1991) and ruminants (Blackburn and Cartwright, 1987). In addition, simulation models exist to support breeding of various livestock species (Hirooka et al., 1998). Computer simulation programmes also exists. The computer programme ZPLAN (Karras et al., 1997) is used to simulate and evaluate different breeding plans in any livestock species while SelAction computer programme (Rutten et al., 2002) was developed to predict selection responses and rates of inbreeding from livestock breeding programmes. In running SelAction, variance

components are needed as input for the programme to enable the user to evaluate various breeding programme designs. Consequently, breeding programme structures with discrete (e.g., fish or poultry breeding) or overlapping generations (e.g., pig or cattle breeding) can be evaluated for selection on multiple traits. With SelAction, BLUP breeding values (animal model) can be used as information sources. It also accounts for reduction of genetic variance due to selection ("Bulmer effect"), and for reduction of selection intensity due to finite population size and correlated index values of family members.

In the literature, there are very many examples of cases where simulations have been used to determine the effectiveness of breeding schemes. Ruane and Thompson (1989) used Monte Carlo simulation procedures to estimate efficiency of a closed adult multiple ovulation and embryo transfer (MOET) nucleus in dairy cattle with discrete generations. Keller et al. (1990) used deterministic simulation to predict genetic response for closed nucleus breeding schemes for beef cattle relying on MOET. Dekkers and Shook (1990) applied semi-stochastic simulations to the United States of America dairy industry in economic evaluation of alternative breeding schemes of an artificial insemination firm operating in a large dairy cattle population with competitive semen market. Kahi et al. (2003) and Kahi et al. (2004) applied deterministic simulation to evaluate Hereford cattle breeding schemes incorporating direct and indirect measures of feed intake and to develop breeding schemes for pasture based dairy production systems in Kenya, respectively. The differences between stochastically and deterministically simulated responses are attributable to the reduction in between family variances due to selection. Due to computational limitations, most of the known stochastic models do not allow for the evaluation of the efficiency of selection schemes applied to large populations but rather to only small nucleus flocks (James, 1977).

This study used deterministic simulations to optimise breeding strategies breeding for RES. Use of computer simulation models allows for the testing of various alternatives with the aim of optimising the breeding strategies in question. Alternative strategies were compared based on their genetic (genetic gains) and economic (profitability) efficiencies using the gene flow and selection index methodologies (Hazel, 1943; McClintock and Cunningham, 1974) Comparisons were made for different selection pathways based on the four-pathway model (Rendel and Robertson, 1950). Criterion for the optimisation of different strategies results from investigations of different models of disseminating the genetic gain from the nucleus to the production unit (Hill, 1974). The introduction of return-cost analysis enabled the optimisation of breeding strategies on monetary profit basis, taking into account the breeding costs (Lidhe, 1968; Brascamp, 1973).

CHAPTER THREE

EFFICIENCY OF ALTERNATIVE TWO-TIER NUCLEUS BREEDING SYSTEMS

3.1. Introduction

Nucleus breeding systems are attractive genetic improvement strategies for livestock in developing countries which lack the money, expertise and structure required for operating an efficient improvement programme based on AI and field recording in the whole population (Smith, 1988). The strategy does not require expensive infrastructure because recording is only done in the nucleus herd. The best males are kept for breeding in the nucleus while the remaining selected males are for mating in the co-operating herds. However, the actual genetic progress and problems which may arise when operating nucleus breeding systems under the less favourable technical conditions of developing countries need investigation to asses the viability of implementing such genetic improvement strategy. In most of the tropics, no attempts have been made to compare the efficiency of nucleus breeding systems for meat sheep production although genetic and economic efficiencies could vary with the breeding systems adopted. The objective of this chapter was therefore to compare the genetic and economic efficiencies of alternative two-tier nucleus breeding systems for meat sheep in Kenya in relation to their implementation within the constraints of the slowly changing local farming conditions in smallholder and pastoral production systems.

3.2. Material and methods

The computer programme ZPLAN (Karras et al., 1997) was used to simulate and compare alternative two-tier nucleus breeding systems for meat sheep under production circumstances in Kenya. The programme uses gene flow methods and selection index procedures to simulate different breeding plans in any livestock species. Based on genetic, biological and economic variables, the programme calculates genetic gain for the aggregate breeding value, the annual response for each selection and the correlated trait defined, and the profit per female animal in the population by subtracting breeding costs from returns. The calculations assume that the input parameters and selection strategies remain unchanged over an investment period with one round of selection. Reduction in genetic variation and inbreeding is not considered. Further, the programme applies order statistics to obtain adjusted selection intensities for populations with finite sizes.

3.2.1. Breeding objectives

The primary step in the evaluation of the efficiency of alternative breeding systems is the definition of the breeding objective. In Kenya, breeding objectives for meat sheep have been developed for smallholder (Kosgey et al., 2003) and pastoral (Kosgey et al., 2004) production systems under different circumstances. For the smallholder production system, two breeding objectives were described that differed in the factors that restrict an increase in the flock size. The first breeding objective (fixed flock size, FLOCK) simulated a situation where the flock size cannot be increased due to other constraints (e.g., limited financial resources and farm structures among others.) apart from feed resources. The second objective (fixed feed resources, FEED) specifically assumed that the flock size is restricted due to limited amount of feed resources. This situation adequately represents most production systems in the developing countries where feed scarcity is common (Kosgey et al., 2003). Similarly, under pastoral production, two breeding objectives were defined which differed in the roles sheep play in the system (Upton, 1985; Grandin et al., 1991; Jaitner et al., 2001; Kosgey et al., 2004). The first objective (tangible role, TR) assumed that sheep performed only tangible roles in the system. The second objective (intangible role, IR) assumed that sheep performed both tangible and intangible roles.

In the present study, traits considered in the breeding objective included LS, LF, PRWS, PWS, ES, YW, ELW and CM. The respective economic values are shown in Table 6 and were estimated by Kosgey et al. (2003 and 2004). The economic values for traits were estimated using a bio-economic model. The input parameters to the bio-economic model were changed to reflect the production systems under consideration. For FLOCK and FEED, the inputs parameters were reflective of the more intensive smallholder production system. The economic values were estimated as the marginal change in profit after a unit increase in the trait of interest for FLOCK. For FEED, they were estimated as the differences between the marginal change in profit after a unit increase in the trait of interest and profit associated with marginal change in feed intake after a unit increase in the trait of interest (Smith et al., 1986). Similar bioeconomic model and method as used for FLOCK were used to estimate economic values for TR. However, relevant adjustments of input parameters were made to reflect pastoral production circumstances (Kosgey et al., 2004). For example, in pastoral production systems, no costs are incurred in forage production and no concentrate supplements are provided. Therefore, feed costs were assumed to be negligible and ignored. This bioeconomic model was also used for IR but extensions were made to include intangible roles (i.e., financing and insurance) of sheep (Kosgey et al., 2004). The economic values per

ewe per year were assessed without discounting since weighting by discounted expressions is done internally in ZPLAN (Karras et al., 1997).

Table 6. Estimates of economic values (KSh)[a] of traits in breeding objectives addressing fixed flock size (FLOCK) and fixed feed resource (FEED) scenarios, and accounting for tangible roles only (TR) or both tangible and intangible roles (IR) of sheep

	Breeding objectives[c]			
Trait[b]	FLOCK	FEED	TR	IR
LS	-37.10	905.80	1757.70	1320.20
LF (%)	-29.40	712.60	1382.50	1038.80
PRWS (%)	00.00	13.30	25.90	19.60
PWS (%)	7.00	16.80	25.90	19.60
ES (%)	35.00	25.20	23.10	21.70
YW (kg)	46.20	71.40	88.20	71.40
ELW (kg)	-2.10	9.80	43.40	11.90
CM (%)	35.70	35.70	14.70	43.40

[a]1 US$ = KSh 70.
[b]LS, litter size; LF, lambing frequency; PRWS, pre-weaning lamb survival; PWS, post-weaning survival; ES, ewe survival; YW, yearling weight; ELW, mature ewe weight; CM, consumable meat percentage;
[c]See text for description of the breeding objectives.

3.2.2. Population structures and selection groups

Five two-tier nucleus-breeding systems, comprising of a nucleus (breeding unit) and a commercial (C) population sector were considered. The five breeding systems were; a closed nucleus system with downward movement of young rams from the nucleus to the commercial sector to breed both sires and dams for the sector (CNSyr); a system similar to CNSyr but with downward movement of dams from the nucleus to the commercial sector to breed sires and dams in this sector (CNSyre); an open nucleus system with a certain proportion of commercial-born ewes being introduced in the nucleus to breed nucleus ewes while at the same time utilising young rams from the nucleus to breed sires and dams for both the nucleus and commercial sector (ONSyre); a system similar to CNSyr but utilising old rams from the nucleus to produce sires and dams in the commercial sector (CNSor); and a system similar to ONSyre but utilising old rams from the nucleus to breed rams and dams for the commercial sector (ONSore). Apart from whether the system is closed or open and the type of animals that are involved in the movement of genetic superiority, the other difference between the five systems was also in the number of selection groups in each system. Table 7 shows the selection groups present in each of the two-tier nucleus breeding systems.

Table 7. Selection groups modelled in each of the two-tier breeding systems

	Nucleus breeding systems[b]				
Selection group[a]	CNSyr	CNSyre	ONSyre	CNSor	ONSore
$S_N^{OR}>S_N$	√	√	√	√	√
$D_N>D_N$	√	√	√	√	√
$S_N^{YR}>D_N$	√	√	√		
$S_N^{OR}>D_N$	√	√	√	√	√
$D_N>D_N$	√	√	√	√	√
$D_C>D_N$			√		√
$S_N^{YR}>S_C$	√	√	√		
$S_N^{OR}>S_C$				√	√
$D_N>S_C$		√			
$D_C>S_C$	√	√	√	√	√
$S_N^{YR}>D_C$	√	√	√		
$S_N^{OR}>D_C$				√	√
$D_N>D_C$		√			
$S_C>D_C$	√	√	√	√	√
$D_C>D_C$	√	√	√	√	√

[a] S_N^{YR}, S_N^{OR} and S_N, Young rams, old rams and sires, respectively, in the nucleus; D_N, Dams in the nucleus; S_C and D_C, sires and dams, respectively, in the commercial sector.
[b] See text for description of the breeding systems.

The nucleus generated genetic gains and sire selection was the main activity. There was performance and pedigree recording in the nucleus but none in the commercial sector. In all systems, a total population of 50,000 ewes was considered. The size of the nucleus was considered to be 5% (2,500 ewes) of the total population. Mating was considered entirely natural. Generally, young rams from the nucleus were selected to breed nucleus ewes ($S_N^{YR}>D_N$) but not in CNSor and ONSore. They were further used to produce rams ($S_N^{YR}>S_C$) and ewes ($S_N^{YR}>D_C$) for the commercial sector in CNSyr, CNSyre and ONSyre, with 70% of the commercial ewes being mated by young rams from the nucleus (Table 8). In all systems, 30% of the commercial ewes were mated by sires born within the sector ($S_C>D_C$). There was selection of old rams to produce both rams ($S_N^{OR}>S_N$) and ewes ($S_N^{OR}>D_N$) for the nucleus in all systems. The old rams not used in the nucleus were used in the commercial sector to breed rams ($S_N^{OR}>S_C$) and ewes ($S_N^{OR}>D_C$) in CNSor and ONSore. Dam selection occurred to differentiate ram dams ($D_N>S_N$) and all ewes in the nucleus ($D_N>D_N$) in all systems. The proportion of ram dams was assumed to be 5% of the nucleus. Further, in ONSyre and ONSore, to open up the nucleus, commercial sector ewes were also introduced to breed ewes ($D_C>D_N$). The degree of opening the nucleus was assumed to be 20%. In CNSyre, 6% of the dams born in the nucleus were introduced in the commercial sector to produce rams ($D_N>S_c$) and dams ($D_N>D_c$). In all the systems, there was selection of dams in the commercial sector to breed sires ($D_C>S_C$) and dams ($D_C>D_C$) in this sector.

Selection criteria in all the five systems included measurement of BW, WW YW, LS and lambing interval (LI). These traits are measured in most sheep farms in Kenya (Kiriro, 1994). In all animals, the information sources included available records of BW, WW and YW on the individual, sire, dam, dams of the sire and dam, female paternal half-sibs and female paternal half-sibs of the sire and dam. In females, additional information sources included records of LS and LI. In the construction of the transmission matrix in the gene-flow method, productive lifetime, survival rate, age at first lambing and LI are required for each selection group. These and other values shown in Table 8 are also required to calculate the proportion of selected animals and selection intensities. Variable costs are shown in Table 9, and include costs that are directly related to performance and pedigree recording. Costs occur exclusively in the nucleus and are based on Kosgey et al. (2003). The costs only affect profit but not the genetic response. The returns were discounted at 5% and costs at 3%. Generally, the appropriate adjusted discount rates in long-term investments such as genetic improvement should always be low in the 2-5% range (Bird and Mitchell, 1980). An investment period of 15 years was assumed.

Table 8. Population, biological and technical parameters for the nucleus and commercial sector[a]

	Nucleus	Commercial
Population parameters		
Number of ewes	2,500	47,500
Percentage of ram dams in the nucleus	5	
Percentage of ewes that are born in the nucleus in the CNSyre		6
Percentage of ewes mated by young rams from nucleus in CNSyr, CNSyre and ONSyre		70
Percentage of ewes from the commercial sector in ONSore and ONSyre	20	
Productive lifetime (years)		
Old rams for planned mating in the nucleus	2.0	
Young rams rams and ewes in the nucleus	3.0	
Young rams from the nucleus to breed rams and ewes for the commercial sector in systems CNSyr, CNSyre and ONSyre	3.0	
Old rams to breed sires and dams for the commercial sector in systems CNSor and ONSore	2.0	
Rams bred in the commercial sector		5.0
Ram dams	3.0	
Dams in the nucleus to breed dams for the nucleus	3.0	
Dams in the nucleus to produce rams and dams for the commercial sector in system CNSyre	3.0	
Dams in the commercial sector		4.0
Age at first lambing		
Old rams for planned mating in the nucleus	3.0	
Young rams to produce rams and ewes in the nucleus	1.0	
Young rams from the nucleus to breed rams and ewes for the commercial sector in systems CNSyr, CNSyre and ONSyre	1.0	
Old rams to breed sires and dams for the commercial sector in systems CNSor and ONSore	3.0	
Rams bred in the commercial sector		1.1
Ram dams	1.5	
Dams in the nucleus to breed dams for the nucleus	1.5	
Dams in the nucleus to produce rams and dams for the commercial sector in system CNSyre	1.5	
Dams in the commercial sector		1.7
Other parameters		
Pre-weaning survival rate	0.93	0.90
Post-weaning survival rate	0.95	0.92
Lambing rate	1.5	1.3
Number of sires selected per year for breeding in the nucleus	60	
Proportion of male lambs suitable for breeding	0.89	0.80
Proportion of female lambs suitable for breeding	0.90	0.81
Proportion of ewes kept for replacement	0.75	0.75

[a]See text for description of the breeding systems.

Table 9. Variable costs incurred in the breeding nucleus of a population of 2,500 ewes and the average time of cost occurrences in years

Cost element	Cost (KSh)[a]	Years
Identification, pedigree recording and data processing	105.00	1.0
Birth weight	20.00	0.0
Weaning weight	25.00	0.5
Litter size	15.00	1.5
Lambing interval	75.00	3.0

[a]Costs are measurement cost per animal.

3.2.3. Genetic and phenotypic parameters

Ideally, estimates of genetic and phenotypic parameters should come from experiments with the particular population used in the breeding system. Where this is difficult to achieve estimates are usually developed from a search of the literature (Koots et al., 1994). Genetic and phenotypic parameters used in this chapter were obtained from the literature (Brash et al., 1994; Fogarty et al., 1994; Wuliji et al., 2001; Ap Dewi et al., 2002; Cloete et al., 2005). Genetic and phenotypic (co)variance matrices were checked to ensure they were positive definite. The genetic and phenotypic parameters used are presented in Table 10.

Table 10. Estimates of phenotypic (σ_p) standard deviations and heritabilities (h^2) of traits in the breeding objectives addressing fixed flock size (FLOCK) and fixed feed resource (FEED) scenarios and accounting for tangible roles only (TR) or both tangible and intangible roles (IR) of sheep[a]

			Genetic and phenotypic correlations[c]										
Trait[b]	σ_p	h^2	LS	LF	PRWS	PWS	ES	YW	ELW	CM	BW	WW	LI
LS	0.36	0.10						0.01			0.45	0.57	0.67
LF (%)	1.23	0.07	0.32										
PRWS (%)	0.29	0.02	0.02	0.00									
PWS (%)	0.29	0.05	0.05	0.00	0.01								
ES (%)	0.50	0.10	0.10	0.00	0.00	0.01							
YW (kg)	4.00	0.42	0.25	0.00	0.00	0.00	0.00				0.10	0.54	0.00
ELW (kg)	3.71	0.30	0.35	-0.53	0.00	0.00	0.00	0.04					
CM (%)	0.23	0.40	0.53	0.09	0.00	0.00	0.00	0.09	0.00				
BW (kg)	0.14	0.12	0.35	0.10	0.05	0.05	0.05	0.52	0.32	0.60		0.35	0.00
WW (kg)	3.02	0.19	0.17	0.14	0.04	0.00	0.00	0.75	0.36	0.05	0.66		0.56
LI (days)	0.52	0.17	0.17	0.32	0.00	0.00	0.00	0.00	-0.53	0.00	0.00	0.00	

[a]See text for description of the breeding objectives.
[b]LS, litter size; LF, lambing frequency; PRWS, pre-weaning lamb survival; PWS, post-weaning survival; ES, ewe survival; YW, yearling weight; ELW, mature ewe weight; CM, consumable meat percentage; RES, resistance to gastrointestinal helminths; BW, birth weight; WW, weaning weight; LI, lambing interval; FEC, faecal egg count.
[c]Genetic correlations below diagonal and phenotypic correlations above diagonal.

3.3. Results and discussion

3.3.1. Selection group differences, genetic gain, return and profit per ewe for the breeding objectives

Table 11 shows the genetic differences among the most important selection groups in the different nucleus breeding systems. The other selection groups are not shown since they do not contribute to the genetic response and do not incur breeding costs. As expected, within each nucleus breeding system, genetic superiority was highest for the breeding objective with the highest economic values (TR). The sire selection groups had higher genetic superiorities in all the breeding objectives and systems than dam selection groups. This is an indication that sire selection is important to genetic response in the nucleus and in the overall breeding programme.

Table 11. Genetic superiority of major selection groups for different breeding systems and breeding objectives addressing fixed flock size (FLOCK) and fixed feed resource (FEED) scenarios, and accounting for tangible roles only (TR) or both tangible and intangible roles (IR) of sheep production

Selection	Breeding	Nucleus breeding systems[c]				
group[a]	objective[b]	CNSyr	CNSyre	ONSyre	CNSor	ONSore
$S_N^{OR}>S_N$	FLOCK	213.44	213.42	213.44	152.72	152.72
	FEED	609.41	605.42	609.47	436.94	436.94
	TR	1036.46	1028.86	1036.57	742.83	742.83
	IR	814.41	809.85	814.48	583.17	583.17
$D_N>S_N$	"	103.09	103.09	103.09	136.43	136.42
		239.94	239.10	239.95	391.26	391.26
		383.26	381.42	383.29	665.33	665.33
		292.42	291.23	292.44	521.98	521.99
$S_N^{YR}>D_N$	"	162.51	162.50	162.52		
		463.80	461.93	464.19		
		788.29	784.69	789.03		
		584.45	467.03	578.19		
$S_N^{OR}>D_N$	"	213.44	213.42	213.44	152.72	152.72
		609.41	605.42	609.47	436.94	436.94
		1036.46	1028.86	1036.57	742.83	742.83
		814.41	809.85	814.41	583.17	583.17
$D_N>D_N$	"	37.53	37.52	46.21	49.66	61.15
		87.34	87.07	107.55	142.42	175.38
		139.51	138.84	171.80	242.42	298.22
		106.44	106.00	131.08	190.00	234.00

[a]See Table 7 for the description of selection groups
[b]See text for description of the breeding objectives.
[c]See text for description of the breeding systems.

The genetic gains, returns and profits per ewe of the population are shown in Table 12 for the different breeding objectives and systems. Genetic gains, returns and profits per ewe for each

breeding objective was variable within each nucleus breeding system. Genetic gains were highest under all objectives in ONSyre and lowest in CNSor. Utilising young rams in a closed nucleus system (CNSyr) for the dissemination of superior genes in the population resulted in higher annual monetary genetic gain than utilisation of old rams (CNSor). Gains obtained in the early years of a genetic improvement as is the case with programmes utilising young animals provide more rapid return to invested capital than gains of similar magnitude obtained later as is the case of programmes utilising old animals. In this study, the rams from the nucleus used in the commercial population in both breeding systems were assumed to be selected based on the same information and no progeny information was included. Inclusion of progeny information in the selection of old rams could probably have resulted in higher genetic gains in CNSor. Within each nucleus breeding system, TR had the highest and FLOCK the lowest annual genetic gains. This stresses the importance of considering the appropriate economic values in the design of any breeding programme. The breeding system CNSyr can be compared with ONSyre because they only differ in whether the system is closed or open. Correspondingly, CNSor can be compared to ONSore. The open nucleus breeding systems had higher annual genetic gain and profit per ewe than the closed systems, which is in agreement with reports of Kinghorn (2000) that open nucleus systems are superior to closed nucleus systems in terms of genetic and economic efficiencies.

Table 12. Annual monetary genetic gains, returns and profits for different breeding systems and breeding objectives addressing fixed flock size (FLOCK) and fixed feed resource (FEED) scenarios, and accounting for tangible roles only (TR) or both tangible and intangible roles (IR) of sheep production

Breeding objective[a]	Nucleus breeding systems[b]				
	CNSyr	CNSyre	ONSyre	CNSor	ONSore
			Annual genetic gains (KSh)		
FLOCK	43.60	43.60	46.11	38.77	39.97
FEED	118.17	117.57	124.89	111.03	113.29
TR	198.05	196.88	209.27	188.77	192.51
IR	154.60	153.89	163.32	148.16	151.98
			Returns per ewe in the population (KSh)		
FLOCK	233.73	242.67	243.05	211.78	211.11
FEED	556.69	562.70	556.90	522.03	515.95
TR	893.69	895.71	891.20	847.15	836.72
IR	694.88	695.88	709.73	663.57	658.98
			Profit per ewe in the population (KSh)		
FLOCK	166.70	175.64	176.02	144.74	144.08
FEED	489.66	495.67	489.87	454.99	448.92
TR	826.66	828.68	824.17	780.12	769.68
IR	627.85	628.85	642.70	596.53	591.60

[a]See text for description of the breeding objectives.
[b]See text for the description of breeding systems.

An open nucleus breeding system is superior to 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). Returns and profit per ewe in the population were highest in CNSyre (a system that allowed for downward movement of dams from the nucleus to the commercial sector to breed sires and dams in this sector) under FEED and TR. Within each breeding objective, returns and profit per ewe were lowest in ONSore. In ONSyre, they were highest under FLOCK and IR.

3.3.2. Annual genetic gain in individual traits

The annual genetic gain in individual traits for different breeding systems and breeding objectives are shown in Table 13. The annual genetic gains in LS, PRWS, PWS and ES was small and similar in all breeding systems and objectives. These small changes reflect the generally low genetic correlations existing between these traits and the available criteria. A large increase in LS and LF was of course not desired under FLOCK because of the negative economic value of these traits (Table 6). It appears the amount of genetic variation for LS and LF need to be larger for changes in these traits to impact positively in meat sheep breeding programmes when there is limitation on the flock size.

Generally, in all breeding systems and objectives, the genetic responses in YW and CM were positive, because of the positive genetic correlations existing between these traits and most traits in the selection criteria. Heavier animals at yearling are normally associated with higher CM at slaughter (Kosgey et al., 2003). Increasing YW is desirable under all breeding objectives because it determines the profitability of the production system. Of interest is the comparison of the genetic gain in YW within each breeding system. The genetic gain in YW was higher under FLOCK and lowest under IR. This was also the trend in the genetic gain in ELW. The genetic gain in YW and ELW was higher under FLOCK than under FEED. Animals require energy for maintenance and production, and which cannot be supplied when feed resources are limiting.

Table 13. Annual genetic gains in individual traits for different breeding systems and breeding objectives addressing fixed flock size (FLOCK) and fixed feed resource (FEED) scenarios and accounting for tangible roles only (TR) or both tangible and intangible roles (IR) of sheep production

Breeding system[a]	Breeding objective[b]	Breeding objective trait[c]							
		LS	LF (%)	PRWS (%)	PWS (5)	ES (%)	YW (kg)	ELW (kg)	CM (%)
CNSyr	FLOCK	0.00	0.09	0.03	0.06	0.15	0.95	0.48	2.49
	FEED	0.01	7.41	0.02	0.06	0.14	0.74	0.10	2.30
	TR	0.01	8.02	0.02	0.06	0.14	0.67	0.05	2.19
	IR	0.01	8.74	0.02	0.05	0.13	0.63	-0.01	2.10
CNSyre	"	0.00	0.13	0.03	0.06	0.15	0.95	0.48	2.50
		0.01	7.20	0.02	0.06	0.14	0.75	0.11	2.32
		0.01	7.79	0.02	0.06	0.14	0.69	0.07	2.23
		0.01	8.56	0.02	0.06	0.14	0.64	0.01	2.14
ONSyre	"	0.01	0.10	0.03	0.06	0.16	1.00	0.50	2.64
		0.01	7.83	0.02	0.06	0.15	0.78	0.10	2.43
		0.02	8.47	0.02	0.06	0.15	0.71	0.05	2.33
		0.01	9.22	0.02	0.06	0.14	0.66	-0.01	2.23
CNSor	"	0.00	-0.19	0.02	0.04	0.11	0.84	0.42	1.95
		0.01	7.74	0.01	0.04	0.10	0.61	0.01	1.70
		0.02	8.35	0.01	0.04	0.10	0.54	-0.04	1.59
		0.01	9.01	0.00	0.04	0.09	0.50	-0.09	1.51
ONSore	"	0.00	-0.58	0.02	0.04	0.11	0.87	0.48	1.97
		0.01	8.21	0.01	0.04	0.10	0.60	-0.03	1.72
		0.02	8.82	0.01	0.04	0.10	0.53	-0.08	1.61
		0.01	9.50	0.00	0.04	0.09	0.49	-0.14	1.52

[a]See text for description of breeding systems.
[b]See text for description of breeding objectives.
[c]See text for description of the breeding objective traits.

3.4. Conclusions

This study demonstrated that two-tier nucleus breeding systems for meat sheep are profitable under the smallholder and pastoral production conditions in Kenya. It is evident that the open nucleus breeding systems with commercial-born ewes being introduced in the nucleus resulted in the highest annual genetic gains under all breeding objectives but profitability was highest under FLOCK and TR. These results suggest that, based on profitability, the optimal nucleus breeding system changes with the breeding objective and that no breeding system is universal. This is contrary to the general conclusion that open nucleus breeding systems are appropriate under all production systems and circumstances in developing countries; a recommendation arising from comparisons of these systems based on genetic gain without due regard to profitability. The success of open nucleus breeding system should focus on the logistics of establishing them. The introduction of commercial-born ewes in the nucleus is a major drawback to the systems. In this study, closed nucleus breeding systems (CNSyr and CNSyre) that utilised young rams ranked favourably in terms of annual genetic gains and profitability under all breeding objectives. Closed nucleus breeding systems are logistically attractive because they are simpler to establish and sustain given the already existing sheep production infrastructure in most developing countries. In such countries, it is important to establish systems that would improve performance from low to intermediate rather than systems that would improve performance from low to high but are not able to be sustained. Such established systems can later be upgraded after experience has been gained.

CHAPTER FOUR

ECONOMIC VALUES FOR RESISTANCE TO GASTROINTESTINAL HELMINTHS

4.1. Introduction

Development of a breeding objective forms the primary step in any genetic improvement programme (Harris et al., 1984; Ponzoni, 1986; 1992). In Kenya, a breeding objective was developed for meat sheep and economic values for different traits estimated (Kosgey et al., 2003). In that study, economic values for the different traits were estimated using profit functions. This method does not apply in the case of resistance to helminths because disease resistance has multifold influences on input and output which in turn affects the producer's profit. In meat sheep, RES and other traits in the breeding objective may not be of equal economic importance, but including RES in the breeding objective requires estimates of its economic values relative to the others included in the breeding objective. The objective of this chapter was to estimate the economic values for RES under four schemes that considered the roles sheep play in different production systems in Kenya.

4.2. Materials and methods

A method of estimating economic values for disease resistance described by Sivarajasingam (1995) was used. In this method, for a given set of assumptions, the breeding objective is matched to the expected responses in production traits and responses in these traits maximized relative to overall gains. The economic value for resistance to helminths was estimated relative to yearling weight (YW). Faecal egg count (FEC) was used as the indicator trait of resistance to helminths (Baker et al., 1999). Therefore, the assumption was that animals were selected for YW (kg) and low FEC (x 1000 eggs per gram, epg). The responses in YW and FEC were estimated using the selection index theory as described by Hazel (1943). The vector of selection index weight (b) is given by equation (5) which has been elaborated earlier (see page 28). The response in trait units (R_T) to selection per generation for each trait is given by:

$$R_T = \frac{b'G}{\sigma_I \times i} \qquad (6)$$

where σ_I is the standard deviation of the index and i the selection intensity. The selection intensity was assumed to be 1 throughout this chapter. Assuming the objective function is expressed in Kenya Shillings (KSh), response in each trait is given by:

$$R_{KSh} = \frac{b'GM}{\sigma_I \times i} \qquad (7)$$

where M is a matrix of economic weights in the diagonal with zeros on the off diagonals. The overall response is the sum of all elements of R_{KSh} and can also be expressed as $i\sqrt{(b'Pb)}$. As selection intensity was assumed to be 1, the overall response was the same as the standard deviation of the index (Sivarajasingam, 1995). The heritability estimate and phenotypic standard deviation for YW are shown in Table 10. The corresponding estimates for FEC were 0.31 and 2 x (1000 epg). The genetic and phenotypic correlations between YW and FEC were 0.30 and 0.08, respectively (Baker, 1995).

The economic values for resistance to helminths were estimated under four schemes that considered the roles sheep play in different production systems in Kenya. Scheme 1 accounted for tangible roles (i.e., meat from animals slaughtered for home consumption, cash income from animal sales and manure) only while considering individual records on YW and FEC for index calculation. This was the base scenario. Scheme 2 was similar to 1 except that there was additional information on YW and FEC on the sire and two male paternal half-sibs and on YW on the dam. Scheme 1 assumed a scenario where measurement of FEC has just begun while scheme 2 a scenario where previous selection had been under the same structure. This effectively assumed there had been measurement of FEC in previous generations. Schemes 3 and 4 were similar to schemes 1 and 2, respectively, only that they considered both tangible and intangible (i.e., financing and an insurance against emergencies) roles of sheep production. The economic values for YW were taken to be approximately KSh 70.00 (Kosgey et al., 2003) in schemes 1 and 2 and KSh 88.20 (Kosgey et al., 2004) in schemes 3 and 4. Within each scheme, economic values for resistance to helminths were estimated under five different breeding options: ($R_{IYW}=R_{SYW}$); when index response in YW is maximum (R_{IYW}=max); when the level of FEC is held constant ($R_{IFEC}=0$); when a predetermined arbitrary response of -0.22 (x 1000) epg is assumed ($R_{IFEC}=-0.22$); and when monetary value of response in FEC is minimum (R_{IFEC}^{KSh}=min). Responses in YW and FEC were calculated for a range of economic values for resistance to helminths.

Optimisation of breeding structures has to be based on calculations of the effectiveness of different critical parameters (Kinghorn et al., 2000). Accurate heritabilities and correlations among traits in the breeding objective and the selection criteria are required in order to design efficient selection programmes for livestock (Ponzoni, 1992). The heritability of FEC and the genetic correlation between YW and FEC used in the present study were based on the literature values. An overestimation of expected response from selection based on a selection index will arise from the sampling error of genetic parameters used in constructing an index (Hazel, 1943). Under scheme 1 which represented the lowest level of YW and FEC recording, sensitivity to changes in the heritability of FEC and genetic correlations between YW and FEC were investigated. In this case, the genetic variance was kept constant. The basis for this is that these parameters will likely change if estimated under different production systems found in Kenya. Three levels of each parameter (heritability and genetic correlation) were considered, representing the literature (base) values multiplied by a factor of 0.50, 0.75 or 1. The parameters were changed one at a time or together, providing eight variations in values from combinations of the two parameters.

4.3. Results

The responses to selection in YW and FEC were evaluated under all schemes, but only curves for the base scenario are shown as the response curves were the same for all schemes. However, the actual responses to selection in YW and FEC in all the schemes are presented in Table 14. The responses to selection in YW and FEC in trait units and in KSh are presented in Figures 2a and 2b, respectively, under the base scenario (scheme 1). The responses increased as the economic values for resistance decreased from KSh 210.00 to KSh -420.00 (Figure 2a). The maximum response for YW was at a point where the economic value for resistance to helminths was KSh 0.00, i.e., no emphasis was placed on epg. Subsequently, the response in epg decreased as its emphasis was decreased (Figure 2a). Zero response in FEC was reached when the economic values for resistance to helminths were KSh -92.20, -87.56, -116.47 and -110.30 for schemes 1–4, respectively. The response in FEC was sigmoid (Figure 2a) when expressed in trait units and parabolic (Figure 2b) when expressed in monetary value (KSh).

Table 14. Economic values (EV) and response to selection under different breeding options when accounting for tangible and intangible roles in scheme 1, 2, 3 and 4

Breeding options[a]	EV (KSh)	R_{IYW} (kg)	R_{IFEC} (epg)	R_{OVER} (KSh)	r_{HI}
Accounting for tangible roles only					
Scheme 1					
1. $R_{IYW} = R_{SYW}$	-34.90	1.68	0.22	110.04	0.63
2. R_{IYW} = max	0.00	1.71	0.32	119.45	0.66
3. $R_{IFEC} = 0$	-92.20	1.48	0.00	103.65	0.58
4. R_{IFEC}=-0.22	-153.31	1.10	-0.22	110.32	0.53
5. R_{IFEC}^{KSh} = min.	-47.90	1.65	0.17	107.53	0.62
Scheme 2					
1. $R_{IYW} = R_{SYW}$	-83.70	1.68	0.12	116.24	0.65
2. R_{IYW} = max	0.00	1.87	0.32	131.14	0.72
3. $R_{IFEC} = 0$	-87.56	1.66	0.00	116.21	0.65
4. R_{IFEC}=-0.22	-143.50	1.30	-0.22	122.53	0.60
5. R_{IFEC}^{KSh} = min.	-45.50	1.82	0.17	111.82	0.69
Accounting for both tangible and intangible roles					
Scheme 3					
1. $R_{IYW} = R_{SYW}$	-44.00	1.68	0.22	138.65	0.63
2. R_{IYW} = max	0.00	1.71	0.32	150.51	0.66
3. $R_{IFEC} = 0$	-116.47	1.48	0.00	130.60	0.58
4. R_{IFEC}=-0.22	-190.70	1.10	-0.22	139.01	0.53
5. R_{IFEC}^{KSh} = min.	-60.28	1.65	0.17	135.5	0.62
Scheme 4					
1. $R_{IYW} = R_{SYW}$	-105.50	1.68	0.02	146.46	0.66
2. R_{IYW} = max	0.00	1.87	0.32	165.24	0.72
3. $R_{IFEC} = 0$	-110.30	1.66	0.00	146.43	0.65
4. R_{IFEC}=-0.22	-180.82	1.30	-0.22	154.39	0.60
5. R_{IFEC}^{KSh} = min.	-56.70	1.82	0.17	151.07	0.69

[a]See Figure 2 and text for description of variables, Scheme 1, records for YW and FEC available on the individual alone; Scheme 2, scheme 1 criteria plus records for YW and FEC available on the sire and two male paternal half-sibs and for YW available on the dam; Scheme 3 and 4, correspondingly similar to scheme 1 and 2 but include intangibles roles of sheep; R_{IFEC}^{KSh}, monetary index response in FEC; r_{HI}, accuracy of selection. 1USA dollar = KSh 70.00.

Table 14 presents the economic values, corresponding responses in each trait, overall response and accuracy of selection under different schemes and breeding objective options. From the response curves (e.g., Figure 2a, b), appropriate economic values for resistance to helminths were derived under different breeding objective options. Under $R_{IYW}=R_{SYW}$, the economic values for resistance were KSh -34.90, -83.70, -44.00 and -105.50, correspondingly, for schemes 1–4 (Table 14). This is just the left most point of intersection between line RSYW and curve RIYW (Figure 2b for scheme 1). Under R_{IYW}=max, the economic value for resistance was KSh 0.00 in all schemes (Table 14). In this case, no emphasis was being put on FEC despite the fact that this trait gave additional information on the animals. $R_{IYW}=R_{SYW}$ and R_{IYW}=max gave positive responses in FEC which is undesirable (Table 14).

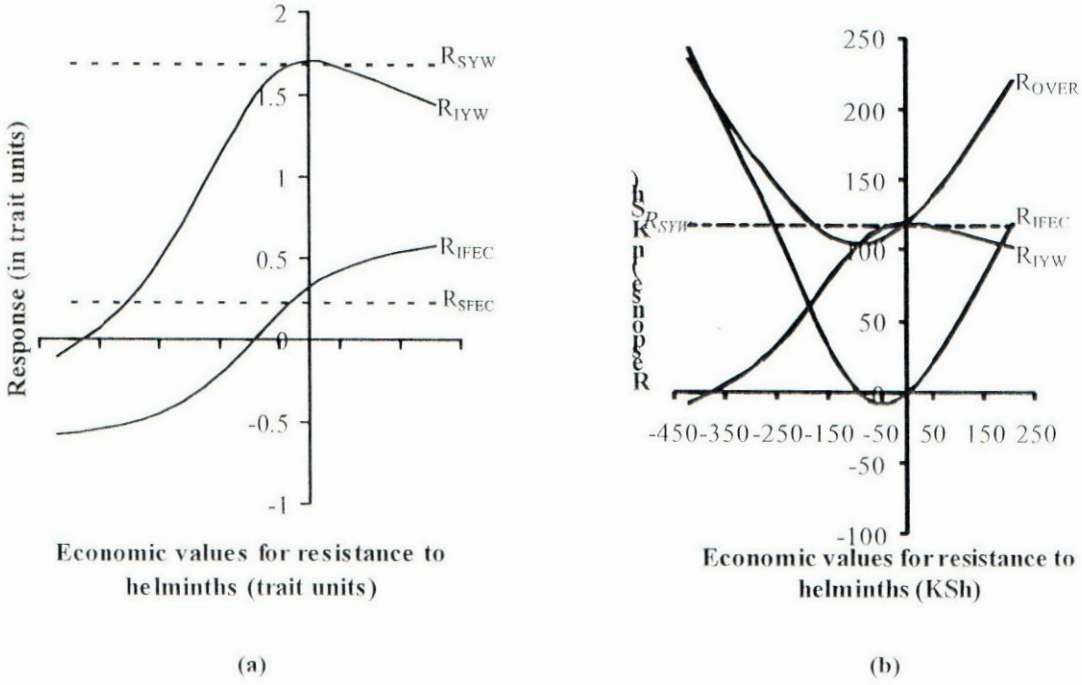


Figure 2 Response curves in trait units (a) and in KSh (b) over a range of economic values of resistance to helminths when accounting for tangible roles in scheme 1. [R_{IYW} and R_{IFEC}, index response in YW and FEC; R_{OVER}, overall index response in trait YW and FEC; R_{SYW}, single trait selection response for YW (= 1.68 kg and correlated response in FEC = 0.22 x1000 eggs per gram)]. 1USA dollar = KSh 70.00.

Under R_{IFEC}=0, the economic values for resistance were KSh -92.20, -87.56, -116.47 and -110.30 for schemes 1–4, respectively. This is the point of intersection between the RIFEC curve and the x-axis (Figure 2b for scheme 1). This corresponds to a situation where the level of resistance is tolerable but the breeder does not want any increase in susceptibility. When a predetermined arbitrary response of -0.22 (x1000) epg was assumed (R_{IFEC}=-0.22), the economic values became more negative (correspondingly, KSh -153.31, -143.50, -190.70 and -180.82 for the four schemes). This had a negative influence on the response to selection in YW and on the accuracy of selection (Table 14). When the objective was to maximise the value of production relative to gain, the economic values for resistance to helminths were KSh -47.90, -45.50, -60.28 and -56.70 for schemes 1–4, respectively. This is the lowest point of the parabolic curve in Figure 2b (for scheme 1). Under this option, the response to selection in both traits, overall response and the accuracy of selection are comparable to those obtained under R_{IYW}=R_{SYW}.

Table 15 indicates the sensitivity of economic values for resistance to helminths to changes in heritability of FEC and genetic correlation between YW and FEC under different breeding objective options when accounting for tangible roles in scheme 1. The economic values were responsive to changes in heritability of FEC and genetic correlation between YW and FEC. This suggests that the economic values are dependent on changes in genetic parameters when estimated under different production systems.

Table 15. Sensitivity of economic values for resistance to helminths to changes in heritability of FEC and genetic correlation between YW and FEC under different breeding objective options when accounting for tangible roles in scheme 1

Multiplier applied to the parameter[a]		Breeding objective Options			
h^2	r_g	$R_{1YW} = R_{SYW}$	$R_{1FEC} = 0$	R_{IFEC}=-0.22	$R_{IFEC}^{KSh} = min$
0.50	0.50	-10.00	-95.20	-449.70	-48.20
0.50	0.75	-23.00	-148.80	-459.00	-76.20
0.50	1.00	-40.00	-191.80	-448.10	-102.10
0.75	0.50	-10.00	-58.00	-188.00	-29.60
0.75	0.75	-23.00	-93.50	-123.00	-48.30
0.75	1.00	-37.00	-124.20	-229.50	-65.95
1.00	0.50	-10.00	-41.96	-111.60	-21.12
1.00	0.75	-22.00	-68.56	-133.70	-35.20
1.00	1.00	-34.90	-92.20	-153.31	-47.90

[a]Base values (multiplier 1) assumed for h^2 and r_g were 0.31 and 0.30, respectively. 1USA dollar = KSh 70.00.

4.4. Discussion

The methodology applied provided estimates of economic values for resistance to GI helminths in meat sheep under different breeding objective options. Under smallholder production circumstances in Kenya, where helminth infection is endemic, the objective is to reduce the cost of disease control. In the current study, the aim was to improve YW and minimise any positive response in FEC. Therefore, very large positive economic values for FEC are undesirable. The magnitudes of the estimated economic values found in the present study indicate that this could be achieved by using negative economic values for FEC. In practice, the level of disease prevalence determines the economic value to be applied in any breeding programme (Sivarajasingam, 1995). For example, in production systems where disease challenge is high (as is the case in most low-input systems), a large and negative economic value is desirable. This would lead to marginal loss in YW response and at the same time a negative response in FEC (Table 14). In such systems, both tangible and intangible roles of meat sheep are important (Kosgey et al., 2004). There are instances when the level of resistance is tolerable and the objective is to hold susceptibility constant. The

response in FEC should then be zero. This could arise in production systems that routinely drench their animals to control helminths. As shown in this chapter, the economic value for resistance to helminths to be used in a breeding programme targeting this production system would be KSh -87.56 or -92.20 as in these systems intangible roles are less important (Kosgey et al., 2004).

In high-input systems where disease control measures are elaborate enough to handle positive responses in FEC, the main objective is to maximise returns. In these systems, intangible roles of sheep are not important. The economic value to use would then be that estimated when trait index response and single trait response are comparable (i.e. KSh -34.90 or -83.70). In instances where infection with helminths is not a significant constraint, the economic value for resistance to helminths could be assumed to be zero. In such cases, the response in production traits would be great (Table 14). In general, the economic values had significant effects on the response to selection in YW. A point to reckon is that scarcity of information is a constraint to estimation of economic values in developing livestock industries in the tropics (Kahi and Nitter, 2004). However, it is demonstrated here that economic values for resistance to helminths could be estimated even with limited information, which provides a starting point for future work. The magnitudes of the economic values estimated under different options emphasises the importance of inclusion of resistance to helminths in the breeding objective in different production systems. However, three issues must be tackled before inclusion. The first issue would be how to accurately and cheaply measure FEC under extensive management systems. FEC is relatively simple to measure although it has limitation because of low repeatability and the inability for the counting to be automated (McEwan et al., 1995). The method used to determine FEC is almost standard (Roberts and O'Sullivan, 1950). Recently, nematode antibody levels have been evaluated as indirect predictors of host resistance to helminths (Douch et al., 1995).

The second issue would be to determine the animals to which FEC are to be recorded. In this study, it was assumed that FEC was measured on the males. It is better to measure high-cost criteria only on candidates likely to have a high impact on the breeding population (Kahi and Graser, 2004). In most livestock species, the sires used in the nucleus have the greatest influence on the entire population. The last issue would be how to organise the recording protocol in a breeding programme. The protocol could be organised depending on when recording of FEC commences. Recording could either commence before or after weaning. Before weaning, FEC would be recorded on all lambs at one and two months of age. Any individual lambs would be drenched if FEC levels rises above a certain level. This

level is not universal but is determined by the environmental conditions. In Kenya, FEC levels of between 3 (·1000) epg and 4 (·1000) epg have been used (Baker et al., 1999). In New Zealand, levels of 0.8 (·1000) epg are considered critical (McEwan et al., 1995). All the lambs would then be drenched at weaning and grazed on pasture until a monitor group of lambs (from which samples are taken every week) reach the determined FEC levels. FEC would then be recorded and all lambs drenched thereafter. This procedure would be repeated until the lambs reach a year of age. Bishop et al. (1996) reported little or no detectable genetic variation in FEC of *Ostertagia circumcincta* in very young lambs (1–4 months). In that study, genetic variation in FEC was detectable only when animals were 6 months old. If this finding holds for other populations and parasite species, it would suggest that the measuring of FEC should be intense after the animals attain the age of 6 months.

If recording commence after weaning, two protocols are recommended: the standard or two field challenge and the brief protocols. In the standard protocols, animals would be drenched at weaning, grazed on contaminated pastures until FEC rises to a certain level and then individually sampled with FEC measured. The animals would then be drenched and subjected to a second challenge and a second FEC recorded. In the brief protocol, animals would be subjected to the same protocol as the standard, but sampled at the end of the second challenge, with two samples being collected on different days (McEwan et al., 1995). The choice of each of these protocols would be determined by the costs involved. The practical importance of a large increase in cost to the breeding programme should not be underestimated, however, as this can be a significant barrier to the adoption of any beneficial technology in breeding (Kahi et al., 2003).

4.5. Conclusions

The economic values were estimated relative to YW using an index that had only two information sources. It may be necessary to estimate economic values for resistance to helminths in situations where more information sources are included in the index. This chapter only considered the effect of economic values for resistance on YW based on a two-trait selection index. The results of the current study therefore need to be put in light of the effect of these economic values on selection response based on different selection criteria with more than two information sources. This is the subject of the next chapter.

CHAPTER FIVE

EFFICIENCY OF ALTERNATIVE SCHEMES BREEDING FOR RESISTANCE TO GASTROINTESTINAL HELMINTHS

5.1. Introduction

Breeding of meat sheep genotypes that are resistant to GI helminth requires efficient and sustainable breeding programmes that ensure rapid dissemination of genetics of superior animals. Breeding structures for the rapid dissemination of superior genes have been evaluated and their genetic and economic efficiencies determined in Chapter 3 but RES was not included in the breeding objective considered. In the long run, inclusion of RES in the breeding objective may cause undesirable correlated changes in the other sets of traits. Therefore, alternative breeding schemes need to be evaluated for their efficiencies for making genetic progress and for their return on investment in genetic selection. In most of the tropics, no attempts have been made to compare the efficiencies of schemes breeding for RES. The aim of this chapter was to compare the efficiency of alternative schemes breeding for RES in meat sheep in Kenya. Breeding schemes represent selection criteria, which consist of traits used in estimating breeding value of individual animals.

5.2. Material and methods

A theoretical basis of evaluating and optimising breeding schemes was established by Hazel (1943) who introduced the theory of selection indexes and later by Rendel and Robertson (1950) who defined selection pathways and derived the estimation of genetic gain per unit of time for the four pathway model. This chapter adopted this basis and used the computer programme ZPLAN (Karras et al., 1997) (see section 3.2).

5.2.1. Breeding objectives, population structure and selection groups

The breeding objectives used in this chapter represented the current and expected future objective for the sheep industry in Kenya and are presented in section 3.2.1. However, RES was included as an additional trait in the breeding objectives. The economic values for RES were KSh 92.20, 92.20, 153.31 and 190.70 in FLOCK, FEED, TR and IR, respectively. These values were based on the results presented in Chapter 4 (Table 14).

Since Chapter 3 showed that closed nucleus breeding systems are logistically attractive, the population structure consisted of a pyramid-breeding scheme with a nucleus flock disseminating genes down to the commercial sector. The closed nucleus breeding

system was similar to CNSor simulated in Chapter 3. However, in this case, a two-stage selection process was assumed in the selection of rams to be used in the nucleus. In the first selection stage, a proportion of young rams ($S_N^{YR}>S_N$) were selected based on their growing ability to weaning and information from relatives. Rams to be used in the nucleus for breeding of rams and ewes were selected from these young rams based on additional information on FEC and information from relatives. In Australia, Woolaston (1994) investigated several practical methods for selecting Merino sheep in a multi-trait breeding objective which included breeding for RES. In that study, a two-stage selection process involving selection for wool and production traits in the first stage and on FEC measures in the second stage was proposed as the most efficient selection strategy. Rams to be used in the commercial sector were selected directly from the young rams, effectively modelling a one-stage selection process. The assumed variable costs incurred in the breeding population were similar to those presented in Table 9 but additional costs for measuring RES were included. It was assumed that the cost of measuring FEC was KSh120 and it was measured when animals were 7.5 months and/or 9 months old depending on the breeding scheme under investigation as presented in the next section below.

5.2.3. Breeding schemes, selection criteria and index information

Breeding schemes were defined which differed on whether RES was included as a trait in the breeding objective or not and on the availability of information on FEC. In all breeding schemes, pedigree selection was assumed. When alternative breeding schemes are to be compared, a standard scheme also referred to as a conventional, traditional or established scheme, is usually the reference upon which other schemes are compared. Scheme 1 was considered as the traditional scheme (base scenario) upon which other schemes were compared. This scheme is similar to that used in Chapter 3 (section 3.2.1). The criteria included measurement of birth weight (BW), weaning weight (WW), YW, LS and lambing interval (LI). Scheme 2 was similar to scheme 1 but included RES in the breeding objective. This scheme examined the effect of concentrating selection for production traits in the presence of environmental stress of infection with helminths. Scheme 3 was similar to scheme 2 but included records on FEC measured in rams immediately after weaning using the standard protocol (McEwan et al., 1998). In this protocol, animals are drenched at weaning, grazed on contaminated pastures until FEC rises to a certain level and then individually sampled with FEC measured at 7.5 months of age. Resistance to GI helminths is an acquired immune response and therefore genetic differences in FEC will be far more

pronounced after the immune system has been triggered by the initial GI helminth infection during the pre-weaning period (Windon et al., 1987). Scheme 4 was similar to scheme 3 but after measuring FEC at 7.5 months of age, the animals were then drenched and subjected to a second challenge and a second FEC recorded at 9 months of age.

Selection was based on the best index of the available criteria in all breeding schemes. For the young rams (selection group $S_N^{YR}>S_N$)), information sources included available records of BW and WW on the individual, sire, dam, dams of the sire and dam, female paternal half-sibs and female paternal half-sibs of the sire and dam. For the other selection groups, additional information source included records of YW on the individual. For females, additional information sources included records of LS and LI. Depending on the breeding scheme under investigation, additional information source included measurement of FEC in males. The number of records used to select rams and ewes was calculated from figures for ram to ewe ratio, lambing rate and ewe and lamb survival, and culling rates at different stages.

5.2.4. Genetic and phenotypic parameters

Table 10 shows the genetic and phenotypic parameters used for growth, carcass, reproductive and survival traits. The heritability estimate and phenotypic standard deviation for FEC were 0.31 and 2 x (1000 epg), respectively. Estimates of phenotypic correlations between FEC and the traits in the selection criteria were -0.04 (for LS and LI) and -0.08 (for YW, BW and WW). The genetic correlations estimates between FEC and YW was -0.30. Information on (co)variances between FEC and other traits of economic importance in sheep is scarce. Therefore, traits for which correlations with FEC were unavailable were assumed to be -0.05 for reproductive and survival traits and -0.10 for growth and carcass traits (Baker, 1995). Faecal egg count was assumed to be highly correlated with RES with a genetic correlation of -0.99. Therefore the correlation between RES and the other traits were similar to those with FEC but had positive signs. The repeatability of FEC was 0.50 by assuming that the trait being expressed at various times is genetically the same (Bishop et al., 1996). Genetic and phenotypic (co)variance matrices were checked to ensure they were positive definite.

5.2.5. Variations and parameter sensitivity analyses

Variations of the nucleus size, usage level of rams from the nucleus in the commercial sector and proportion of young rams selected in the first selection stage for FEC measurement

were examined for all breeding schemes and objectives. In addition, under scheme 4 in all the breeding objectives, sensitivity to changes in the genetic correlations between FEC and LS, LF, YW and ELW were investigated. The impact on the overall profitability of a breeding programme of varying the nucleus size at a lower and higher level of usage of nucleus-born rams in the commercial sector was investigated, assuming the overhead costs of the breeding programme to be unaffected. The size of the nucleus was varied from 3.5% to 99.9% of the total population while the level of usage of nucleus-born rams in the commercial sector was varied from 20% to 99.9%. Also examined was the impact on genetic gain and profitability in scheme 4 of the proportion of young rams selected for FEC measurement. The proportion of young rams was varied from 3.5% to 99%. The aim here was to determine the optimal proportion of rams to initially select for FEC measurement.

The genetic correlations between FEC and LS, LF, YW and ELW were based on the literature values and assumptions because for some correlations estimates were unavailable. An overestimation of expected response from selection based on a selection index will arise from the sampling error of genetic parameters used in constructing an index (Hazel, 1943). Under schemes 3 and 4 of all breeding objectives considered, sensitivity of profitability to changes in the genetic correlations between FEC and LS, LF, YW and ELW were investigated. In this case, the genetic variance was kept constant. Alternative correlations were examined within the parameter space because larger variations in correlations would have resulted in a non-positive definite genetic covariance matrix. This would have necessitated bending of the matrix, making comparisons of sensitivity difficult. The basis for the sensitivity analysis is that correlations estimates will likely change if estimated under different production systems found in Kenya.

5.3. Results and discussion

5.3.1. Annual monetary genetic gains, returns and profits

The annual monetary genetic gains, returns and profits per ewe of alternative breeding schemes and objectives considered are shown in Table 16. The annual monetary genetic gains, returns and profits per ewe varied amongst and within breeding schemes and objectives evaluated. They were higher for TR than for the other breeding objectives since this objective had the highest economic values for most breeding objective traits, and therefore the importance of considering the appropriate economic values in the design of any breeding programme. For all the breeding objectives, scheme 1 had the lowest and scheme 4 the

highest annual monetary genetic gains, returns and profits per ewe. This was expected because scheme 1 represented the lowest and scheme 4 the highest level of investment in performance recording. When schemes 1 and 2 are compared, additional genetic gain and profitability in all breeding objectives was realised when RES was included as a trait in the breeding objective, even without including an indicator trait for RES in the selection criteria. Scheme 2 assessed the impact of a non-zero economic value for RES on genetic gain and profitability. When the economic value of RES is zero, the assumption is that infection with helminths is not a significant constraint. In such cases, the response in production traits would be great.

Inclusion of FEC in the selection criteria and RES as a trait in the breeding objective in scheme 4 resulted in higher annual monetary genetic gain, returns and profit per ewe than inclusion of RES in the breeding objective in scheme 2. This emphasises the importance of accompanying inclusion of a trait in the breeding objective with a correlated trait in the selection criteria. Selecting rams on the basis of FEC measured twice after weaning is a desirable strategy both genetically and economically. Taking two measurements of FEC is expensive but these high costs were offset by the benefits accrued from the breeding programme. However, large increases in cost to the breeding scheme should not be underestimated because they could be a significant barrier to the adoption of any beneficial technology in breeding (Kahi et al., 2003).

There were only small differences in annual monetary genetic gains, returns and profits per ewe between schemes 3 and 4 for all breeding objectives investigated. The differences ranged from 2.0% to 5.1% for the annual monetary genetic gains, 2.7% to 5.2% for returns and 1.3% to 3.7% for profit per ewe, indicating that there is little benefit taking a second measurement of FEC. Therefore, as a recommendation towards the establishment of effective and sustainable programmes breeding for resistance to helminths in meat sheep, one measurement of FEC after weaning is adequate and would be a sufficient indicator of RES. This will allow for selection and use of rams when they are young, and consequently a faster dissemination of their genes in the population. Gains obtained in the early years of a genetic improvement programme as is the case with programmes utilising young animals, provide more rapid return to invested capital than gains of similar magnitude obtained later as seen in of programmes utilising old animals. In the tropics where helminthosis is endemic in smallholder and pastoral production systems, a breeding programme that ensures a faster rate of dissemination of genes responsible for RES is more desirable.

Table 16. Annual monetary genetic gains, returns and profits per ewe of the alternative breeding schemes and objectives studied

Breeding scheme[a]	Breeding Objective[b]	Annual monetary genetic gain (KSh)	Total returns per ewe (KSh)	Profit per ewe (KSh)
1	FLOCK	38.77	211.78	144.74
	FEED	111.03	522.03	454.99
	TR	188.77	847.15	780.12
	IR	148.16	663.57	596.53
2	"	53.20	290.32	223.29
		123.84	598.08	531.05
		208.30	967.48	900.45
		172.11	811.14	744.11
3	"	61.72	330.14	255.31
		128.45	622.35	547.52
		215.45	1,007.48	932.65
		183.68	874.97	800.14
4	"	64.84	347.34	264.68
		131.19	639.55	554.88
		219.67	1,034.80	949.45
		189.68	910.75	823.73

[a]See text for description of the breeding schemes.
[b]See text for description of the breeding objective.

5.3.2. Annual genetic gain in individual traits

The annual genetic gain in individual traits for different breeding schemes and breeding objectives studied are shown in Table 17. It should be noted that a positive value of the response in RES indicates an improvement in resistance because the values reflect a reduction in FEC given the negative relationship between RES and FEC (Table 10). Notable was the small genetic responses in LS, PRWS, PWS and ES in all breeding schemes and objectives as a result of low genetic correlations between these traits and the selection criteria (Table 10). A large response in LS was definitely not desired in the case of FLOCK as it had a negative economic value. Further, increasing LS under feed constraints would be undesirable (Kosgey et al., 2003). In scheme 1, there were instances of negative responses in LF and ELW. This was as a result of the negative economic values for these traits (Table 6). A large increase in these traits was therefore not favourable under this scheme.

Table 17. Annual genetic gain in individual traits in all breeding schemes and breeding objectives

Breeding scheme[a]	Breeding objective[b]	Traits[c]								
		LS	LF (%)	PRWS (%)	PWS (%)	ES (%)	YW (kg)	ELW (kg)	CM (%)	RES (epg x 1000)
1	FLOCK	0.00	-0.19	0.02	0.04	0.11	0.84	0.42	1.95	
	FEED	0.01	7.74	0.01	0.04	0.10	0.61	0.01	1.70	
	TR	0.02	8.35	0.00	0.04	0.10	0.54	-0.04	1.59	
	IR	0.02	9.01	0.00	0.04	0.09	0.50	-0.09	1.51	
2	"	0.00	0.42	0.02	0.05	0.12	0.84	0.40	2.12	0.16
		0.01	7.07	0.01	0.05	0.11	0.65	0.06	1.86	0.14
		0.01	7.65	0.01	0.04	0.11	0.60	0.02	1.78	0.13
		0.01	7.90	0.01	0.05	0.11	0.60	0.00	1.81	0.13
3	"	0.00	0.43	0.04	0.09	0.21	0.76	0.40	2.17	0.29
		0.01	7.35	0.03	0.07	0.17	0.61	0.05	1.91	0.23
		0.01	7.90	0.02	0.07	0.17	0.55	0.01	1.82	0.22
		0.01	7.79	0.03	0.08	0.19	0.53	0.00	1.86	0.24
4	"	0.00	0.54	0.05	0.10	0.24	0.75	0.39	2.22	0.33
		0.01	6.67	0.03	0.08	0.20	0.64	0.10	2.03	0.27
		0.01	7.17	0.03	0.08	0.20	0.59	0.06	1.96	0.27
		0.01	7.05	0.04	0.09	0.22	0.56	0.05	1.98	0.29

[a]See text for description of breeding schemes.
[b]See text for description of breeding objectives.
[c]See text for description for the breeding objective traits.

In all breeding schemes and objectives responses for YW, CM and RES were positive (Table 17). These resulted from positive genetic correlations between these traits and the selection criteria. Large responses in these traits are desirable since they would translate to increased profitability. For instance, increasing the responses in YW and CM will lead to an increase in saleable meat because in most tropics meat is sold in terms of weight (Kosgey et al., 2003). At the same time increasing an animal's RES is desirable because infection with GI helminths is associated with delayed and reduced productivity, increased cost of production and increased susceptibility to other infections (Baker, 1995). Of interest is the comparison of the magnitudes of genetic gain in YW, CM and RES in the different schemes. A comparison of schemes 2 and 4 showed that utilisation of extra criteria will lead to lower gains in YW and higher gains in CM and RES in scheme 2 than in scheme 4. For RES, the difference in genetic gain between scheme 3 and 4 was small but the gain in scheme 4 was almost double that in scheme 2. Inclusion of measurement of FEC on rams improves the accuracy of selection which consequently leads to an increase in genetic response. This is in agreement with the results of Piper and Barger (1988) and Kominakis and Theodoropoulos (1999) who reported significant additional responses in RES when FEC was included in the selection index.

5.3.3. Impact of varying the nucleus size and usage level of nucleus-born rams in the commercial sector

Figure 3 shows the impact on annual monetary genetic gain of varying the size of nucleus at the assumed usage level of nucleus-born rams in the commercial sector (i.e., 70%). The trend was similar for all other breeding schemes and objectives and therefore only the result for scheme 4 of FLOCK is presented. An increase in the size of the nucleus resulted in an increase in monetary genetic gain, the effect initially increasing fast and then gradually after a nucleus size of 25% of the population, eventually levelling off after about 45% of the population. Figure 4 presents results for the impact on profitability of varying the nucleus size under scheme 4 of all breeding objectives. Increasing the nucleus size resulted in similar trends in all schemes but the optimal size was different for the alternative breeding objectives. For example, for FLOCK the nucleus size was optimal at 10% of the total population, whereas this was so at 45% of the population for TR. The size of the nucleus is an indirect measure of the amount of recording. Consequently, recording the whole population would result in negative profitability in FLOCK.

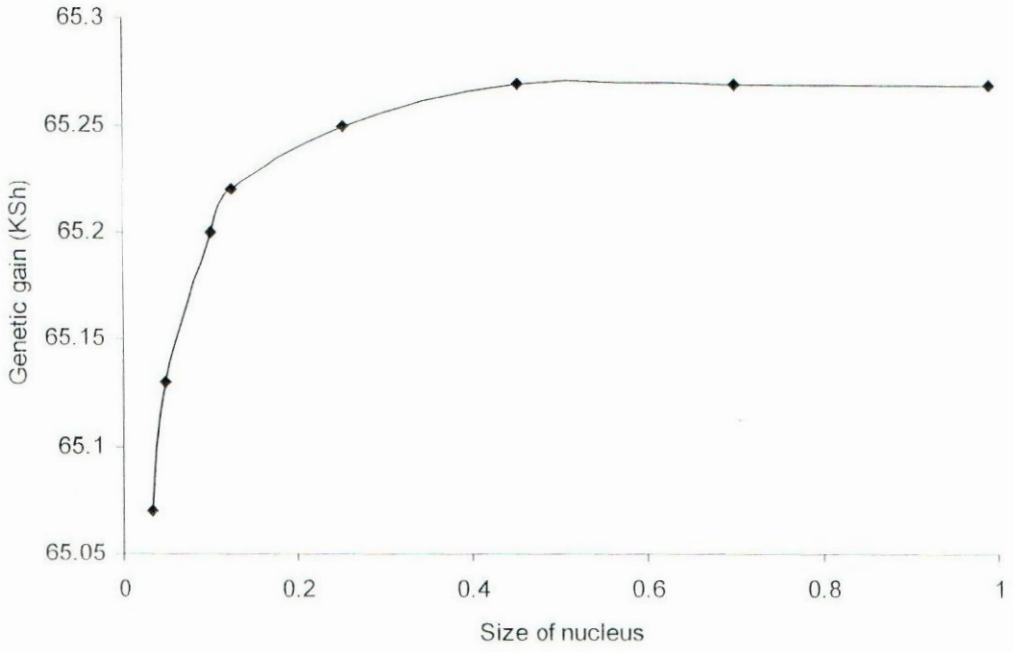


Figure 3. Impact on annual monetary genetic gain (KSh) of varying the size of the nucleus under scheme 4 of FLOCK.

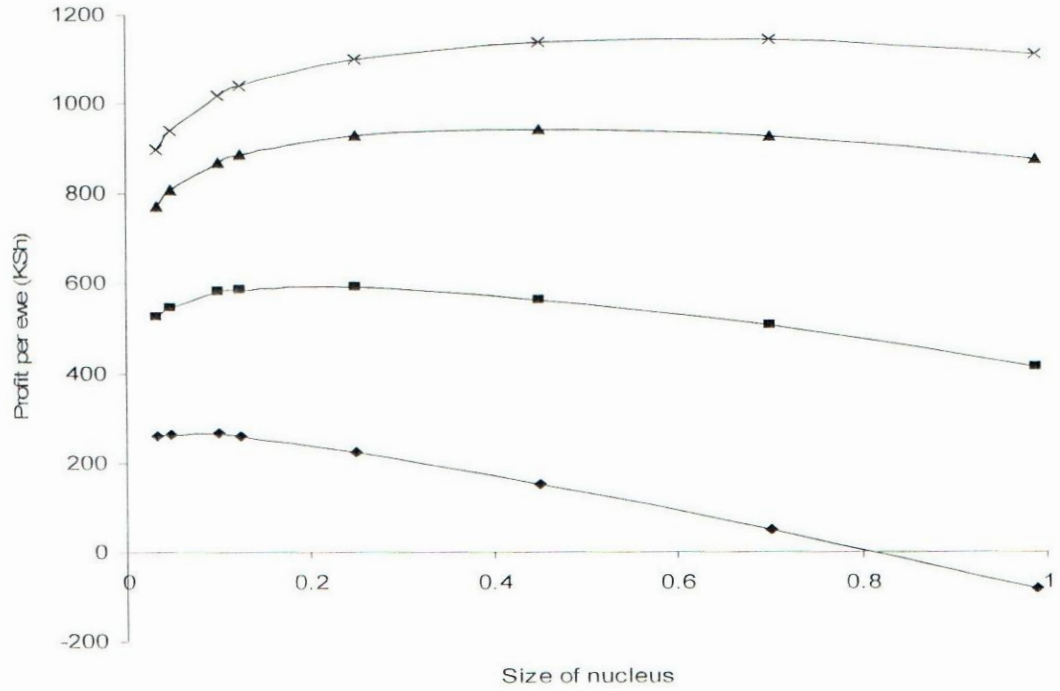


Figure 4. Impact on profit per ewe (KSh) of varying the size of the nucleus under scheme 4 of all breeding objectives considered (Breeding objectives: ♦ = FLOCK; ■ = FEED; ▲ = IR; x = TR).

The results indicate that the optimal size of nucleus is dependent on the breeding objective. This may reflect the fact that it is more profitable to measure FEC on a large proportion of animals when the genetic improvement achieved has a higher value and when the objective addresses a system with higher economic values for RES. A large nucleus size would provide the whole programmes with rams of superior genetic merit through a high intensity of selecting elite ewes, a large number of young rams for FEC measurement and minimal inbreeding rates. In breeding programmes that are beginning, larger nucleus sizes might be limited by the associated high costs.

Figure 5 presents results for the impact on profit per ewe of varying the nucleus size under different levels of usage of nucleus-born rams in commercial sector under scheme 4 of FLOCK and IR. Profit per ewe in the population increased tremendously with an increase in the usage level, the effect initially increasing with nucleus size then decreasing as the nucleus approached whole population recording. When the whole population is recorded and sires are sourced from within this population, the intensity of selection of these sires decreases because of the need for more rams to service the population. The optimal size of the nucleus was determined by both the breeding objectives and the usage levels of nucleus born rams. In FLOCK, the optimal nucleus size was 5% and 10% at lower (20, 40 and 60%) and higher (80% and 99.9%) usage levels, respectively. In this case, increasing the usage level of nucleus-born rams in the commercial sector would increase the needed size of the nucleus. In IR, the converse would be true because the optimal size of the nucleus reduced with increased usage level of nucleus-born rams in the commercial sector.

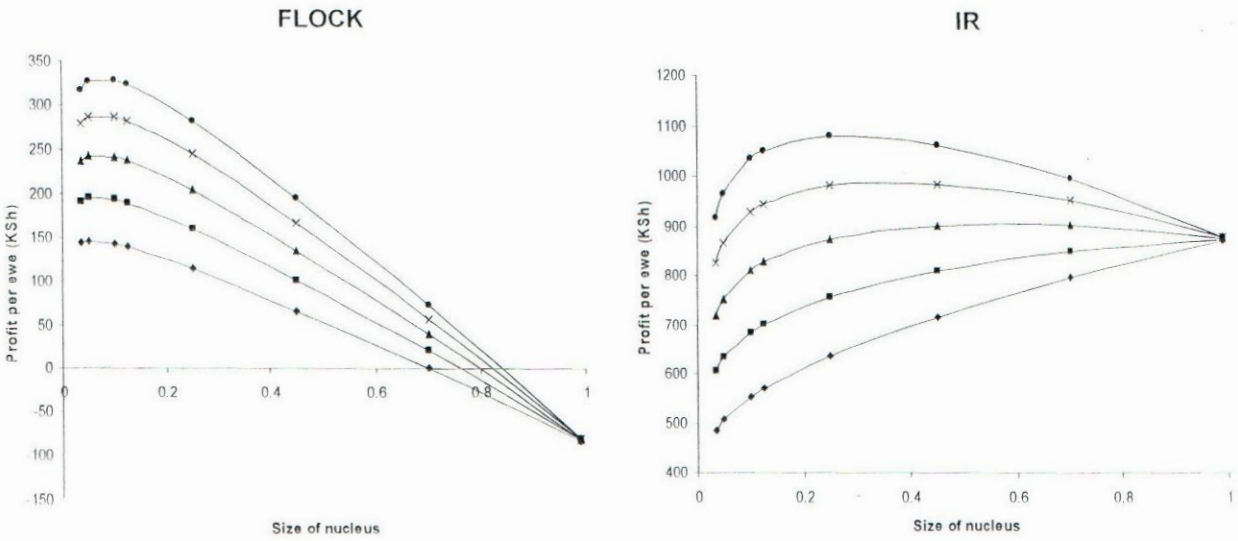
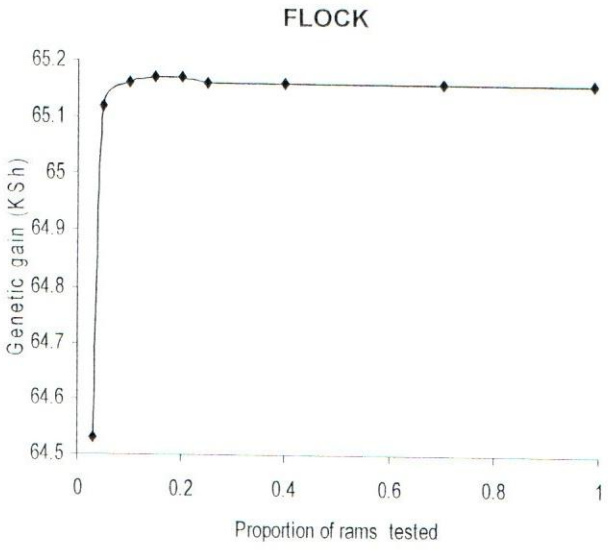


Figure 5. Impact on profit per ewe (KSh) of varying the size of the nucleus under different levels of usage of improved sires in the commercial sector under scheme 4 of FLOCK and IR (Level of usage of sires: ♦ = 20%; ■ = 40%; ▲ = 60%; x = 80% and ● = 99.9%).

5.3.4. Impact of varying the proportion of rams tested for FEC

The impact on monetary genetic gain and profit per ewe of varying the proportion of rams tested for FEC in scheme 4 of FLOCK and IR are shown in Figures 6 and 7, respectively. Increasing the proportion of rams tested for FEC resulted in a rapid increase and then a flat response in genetic gain in both objectives (Figure 6). As the proportion measured increased (Figure 7), profitability increased sharply and then gradually declined. Based on profitability, the optimal proportions of rams to select for FEC measurement was 5% for FLOCK and 10% for IR. The optimal proportion of rams to test for FEC in FLOCK and IR was similar to that observed in FEED and TR, respectively. The effect of varying the proportion of rams tested for FEC measurement is in the number of rams selected in the first selection stage and the number available for the second selection stage. Increasing the proportion selected for FEC measurement reduces the selection intensity in the first selection stage. However, the selection intensity in the second selection stage is increased. Reduction in profitability came from an increase in the number of animals on which FEC was measured. These results have important consequences for sheep programmes breeding for resistance to helminths. They indicate that measuring of high-cost criteria like FEC on 5-10% of the rams will likely have a high impact in the whole population.



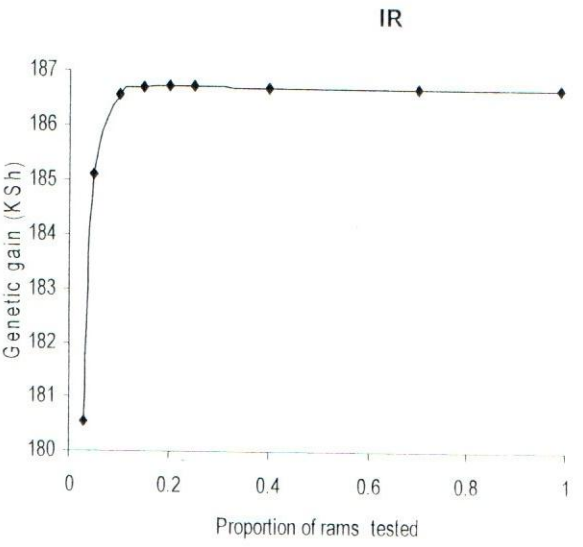
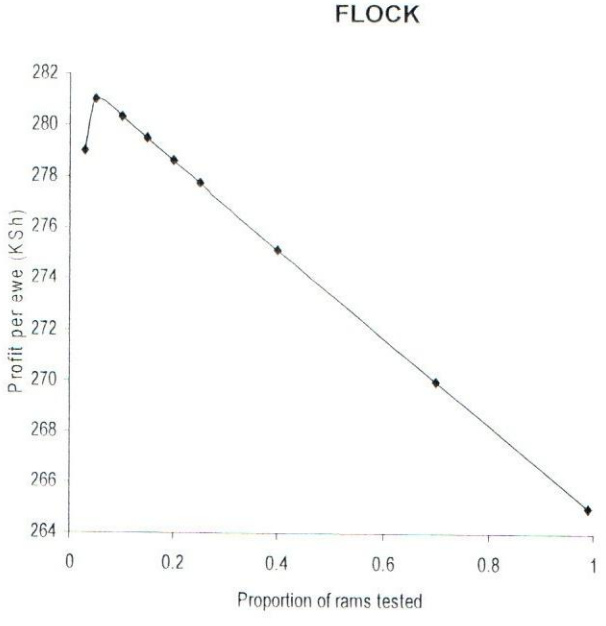


Figure 6. Impact on annual monetary genetic gain (KSh) of varying the proportion of rams tested for FEC scheme 4 of FLOCK and IR.



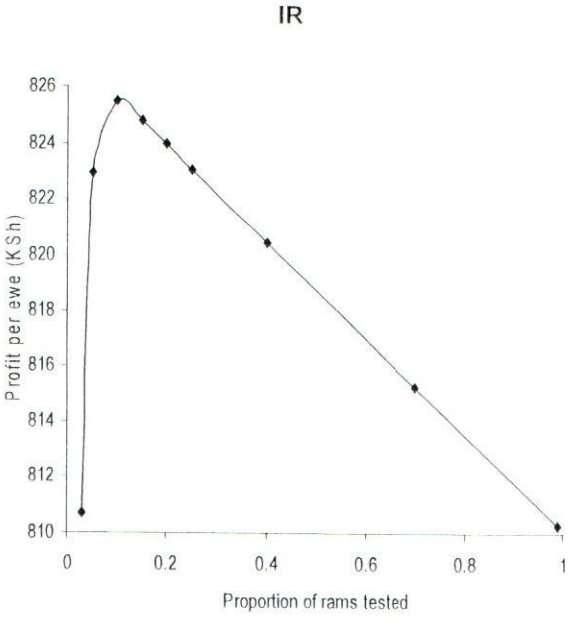


Figure 7. Impact of varying on profit per ewe (KSh) of varying the proportion of rams tested for FEC under scheme 4 of FLOCK and IR.

5.3.5. Sensitivity to changes in genetic correlations

Table 18 shows the sensitivity of profit per ewe to changes in genetic correlations between FEC and YW and ELW for schemes 3 and 4 of all the breeding objectives. The sensitivity of profit per ewe to change in correlation between FEC and LS and LF was also

modelled but the change was small and is therefore not presented. As expected, the profit per ewe was sensitive to changes in the genetic correlations. The TR objective was relatively more sensitive to the variation in the correlation between FEC and YW and ELW. An increase in the genetic correlations resulted in an increase in the profit per ewe. Profit per ewe was more sensitive to changes in the genetic correlations with YW than with ELW. This indicates that genetic correlation estimates between FEC and YW are more important than correlations between FEC and other traits included in the breeding objective. Therefore, use of reliable estimates of this correlation is important to avoid over or underestimating the expected response from selection.

Table 18. Sensitivity of profits per ewe (KSh) to changes in genetic correlations between FEC and YW and ELW under schemes 3 and 4 of all breeding objectives[a]

Correlation with FEC		Scheme 3				Scheme 4			
YW	ELW	FLOCK	FEED	TR	IR	FLOCK	FEED	TR	IR
-0.30	-0.05	255.48	547.07	930.65	799.40	264.90	554.26	946.68	822.74
-0.30	-0.10	255.31	547.52	932.65	800.14	264.68	554.88	949.45	823.73
-0.30	-0.15	255.15	547.98	934.70	800.88	264.47	555.51	952.27	824.72
-0.25	-0.05	243.58	536.66	915.38	781.55	252.73	543.35	930.97	804.68
-0.25	-0.10	243.41	537.12	917.42	782.30	252.52	543.97	933.76	805.70
-0.25	-0.15	243.25	537.57	919.50	783.07	252.30	544.60	936.61	806.71
-0.20	-0.05	231.85	526.41	900.43	764.28	240.70	532.57	915.53	740.86
-0.20	-0.10	231.68	526.87	902.50	765.05	240.48	533.20	918.35	741.16
-0.20	-0.15	231.50	527.33	904.62	765.83	240.26	533.82	921.23	741.46
-0.15	-0.05	220.30	516.33	885.81	747.62	228.82	521.94	876.80	739.78
-0.15	-0.10	220.12	516.78	887.91	748.41	228.59	522.56	891.31	740.08
-0.15	-0.15	219.94	517.24	890.05	749.20	228.37	523.19	906.13	740.38

[a]See text for description of traits and breeding schemes and objectives.

5.4. Conclusions

This study has demonstrated the possibility of breeding meat sheep for RES using FEC as the selection criterion. Inclusion of RES in the breeding objective and FEC as the selection criterion resulted in an improvement in genetic gain and profitability. Measuring FEC once was as efficient genetically and economically as measuring it twice. This has important consequences in production systems with inadequate financial resources and indicates that RES can be improved with minimal costs. Genetic gain and profit per ewe were sensitive to changes in genetic correlations between FEC and traits in the breeding objectives. This stresses the importance of using reliable estimates of genetic and phenotypic parameters in implementation of effective breeding programmes and also in assessment of the progress of ongoing programmes.

CHAPTER SIX
GENERAL DISCUSSION AND CONCLUSIONS

6.1. Rationale for the study

Gastro-intestinal (GI) helminths remain a major constraint to improved productivity and profitability of sheep under low-input production systems in Kenya and other tropical countries (Baker, 1995). The GI helminth infection reduces productivity, increase cost of production, increase susceptibility to other infections and increase use of antihelminthics. One effective option to addressing this problem under low-input production systems is raising sheep that are resistant to GI helminths. This requires developing efficient and sustainable breeding systems and schemes incorporating resistance to GI helminths (RES) in the breeding objective to ensure rapid dissemination of genetics of superior animals to sheep producers. The design of efficient breeding strategies involves definition of the breeding system and identification of schemes, but these are presently lacking in Kenya for undertaking systematic breeding of sheep for RES. As a prerequisite for successful establishment of a breeding programme that incorporates RES for meat sheep in Kenya, this study evaluated the genetic and economic efficiencies of alternative two-tier nucleus breeding systems and schemes when incorporating RES in the meat sheep breeding objective. The evaluation undertaken tested three hypotheses: (i) that there are no differences in the genetic and economic efficiencies of alternative two-tier nucleus breeding systems for meat sheep. (ii) that in meat sheep RES and other traits in the breeding objective are of equal economic importance and (iii) that the alternative schemes breeding for RES in meat sheep have equal genetic and economic efficiencies for making genetic progress and return on investment in genetic selection.

6.2. Methodological approach

6.2.1. Efficiency of alternative two-tier breeding systems

The model calculations in evaluation of the genetic and economic efficiency of alternative two-tier nucleus breeding systems designed for the improvement of meat sheep in Kenya were performed using the computer programme ZPLAN (Karras et al., 1997). Five alternative two-tier nucleus breeding systems that would fit Kenya's meat sheep production circumstances were evaluated. The breeding systems differed in whether a system was open or closed, the type of animals used in dissemination of genetic improvement and the number

of selection groups in each of the five systems (Table 7). In all the systems, the nucleus generated genetic gain and ram selection was the main activity. Performance and pedigree recording exclusively occurred in the nucleus and the breeding objective traits in all the five systems included litter size (LS), lambing frequency (LF), pre-weaning survival (PRWS), post-weaning survival (PWS), ewe survival (ES), yearling weight (YW), ewe liveweight (ELW) and consumable meat (CM). Selection criteria included measurement of birth weight (BW), weaning weight (WW), yearling weight (YW), litter size (LS) and lambing interval (LI). The breeding systems were compared using similar genetic, biological and economic variables (Table 8). In this case, no sensitivity analysis to changes in these variables was done since it was expected that a change in a variable will have similar effects in all breeding systems. Only the economic values were varied and this was represented with four breeding objectives characteristic of Kenya's meat sheep production systems. The production systems were either identified by their respective constraints (fixed flock size, FLOCK, and fixed feed resource, FEED) or by the role played by sheep (tangible roles, TR, and both tangible and intangible roles, IR). The returns were discounted at 5% and costs at 3%. An investment period of 15 years was assumed for all the systems.

6.2.2. Estimation of economic values

A method of estimating economic values for disease resistance described by Sivarajasingam (1995) was adopted in estimating economic values for RES in meat sheep in Kenya. In this method and for a given set of assumptions, which in this study was that animals were selected for YW (kg) and low FEC (x 1000 epg), the breeding objective is matched to the expected responses in production traits and responses maximised relative to overall gains. The economic value for RES was estimated relative to YW. The FEC was used as the indicator trait of RES (Baker et al., 1999). The responses in YW and FEC were estimated using the selection index theory as described by Hazel (1943).

6.2.3. Efficiency of schemes for RES

In evaluation and optimisation of genetic and economic efficiencies of alternative schemes breeding for RES in meat sheep in Kenya ZPLAN (Karras et al., 1997) was used. Four alternative breeding schemes were considered. The schemes differed on whether RES was included as a trait in the breeding objective or not and on availability of information on FEC. A two-tier nucleus breeding system was considered. Breeding objectives and traits were similar to the ones considered in the evaluation of efficiencies of alternative two-tier nucleus

breeding systems except for the inclusion of RES. A two stage selection was assumed in the selection of rams to be used in the nucleus, with the first selection stage involving use of information on FEC in young rams. Selection was based on the index of the available criteria in all the breeding schemes. Variation of the nucleus size, usage level of rams from the nucleus in the commercial sector, proportion of young rams selected in the first stage for FEC measurement (for all breeding schemes and objectives) and sensitivity to changes in genetic correlations between FEC and LS, LF, YW and ELW were investigated.

6.2.4. Limitation of methods used

Generally, methods of evaluating the efficiency of alternative breeding strategies can either be deterministic or stochastic. In this study, a deterministic approach was used. The programme ZPLAN was used which calculates the annual genetic gains for the aggregate breeding value and for each selection and correlated trait, the returns from investment of a breeding system or scheme and the profit per female animal by subtracting breeding costs from returns. The results in the study are completely determined by the input parameters (i.e., genetic, biological and economic input variables). A requirement is that the input variables in the parameter file in the programme are changed based on the breed, production system and production circumstances in question. The calculations assume unchanged selection strategies and constant genetic, biological and technical parameters during the investment period. Only the effects of one round of selection on the performances of succeeding generations are taken into consideration. This is a major weakness with the programme since parameters cannot be held constant in a changing production environment. Where systematic selection is applied, it is expected that there will be reduction in variance (Bulmer, 1980) and an increase in inbreeding due to the tendency to select members with a common ancestry.

Estimating economic values for disease resistance using the method described by Sivarajasingam (1995) has a major limitation in that the breeding objective is matched to the expected responses in production traits and responses in these traits maximised relative to overall gains. Increasing the index traits (e.g., considering all traits in the breeding criteria) would be complex. This study considered only two traits (YW and FEC) with the economic value for RES being estimated relative to YW.

6.3. Establishment of nucleus breeding systems

This study showed that well-organised two-tier nucleus breeding systems are profitable and will result in the overall improvement of meat sheep in Kenya. The question

would be on how to establish these systems without severe organisational problems. In Africa, there are very some examples of nucleus breeding systems for sheep from which lessons can be learnt during the establishment of these systems in Kenya (Kosgey et al., 2005). This is important to avoid repeating the same mistakes that led to the failure of other systems elsewhere (Kahi et al., 2004). In Ivory Coast for example, a two-tier open nucleus breeding programme is being operated for the Djallonké sheep (Yapi-Gnaoré et al., 1997). In this system, there is a central performance testing station for rams while farmers' flocks are the commercial population. This system is different from the open nucleus breeding system modelled in this study in that there is no movement of ewes born in the commercial population to the nucleus. Upward movement of animals is restricted to males, which are subsequently selected in the nucleus and later used for mating in the commercial population.

The open nucleus breeding systems utilising young rams and with commercial ewes being introduced in the nucleus (ONSyre) had the highest annual genetic gains under the four breeding objectives. However, profitability was highest under FLOCK and IR (Table 12). Under conditions in developing countries, maximising profitability rather than genetic gain might be of major interest for establishing livestock breeding programmes (Nitter, 1998). Nonetheless, it is not only sufficient to base the choice of breeding system on genetic gain and profitability but also on other factors that might be important in ensuring its successful implementation and sustainability. Most of these other factors are logistic in nature. The type of open nucleus system modelled in this study allows commercial sector ewes to be introduced in the nucleus. This would mean farmers parting with their best animals, which in most cases is not possible. The ewes might be incorporated in the nucleus on a temporary basis or on lease, although disease prevention may be prohibitive (Roden, 1995). It has been suggested that nucleus mating could be introduced in the nucleus with migration of semen to this sector (Kahi et al., 2004). This is not possible because use of AI in sheep breeding in Kenya and in most of the tropics is none-existent. Introducing nucleus-born males for natural mating in the commercial sector will be cumbersome and would require good pedigree recording. An alternative could be to introduce selected commercial sector ewes to the nucleus only for natural mating and thereafter return the ewes to the farmers. However, the distance from farmers' flock to the nucleus flock could be prohibitive.

The closed nucleus breeding systems are logistically simpler to establish than open nucleus breeding systems in meat sheep breeding. In Kenya, smallholder farmers and pastoralists are the main producers of meat sheep and in most cases source their breeding rams from farms that they consider to have genetically superior animals to theirs. In other words, a

closed nucleus breeding system is being operated in Kenya, although unconsciously. The challenge would be to organize this system by identifying large flocks that could be used as nuclei. Kahi et al. (2004) recommended several approaches that can be used to encourage large flocks to serve as nucleus farms. These include good extension work aimed at boosting the experience and skills of owners of these flocks and other farmers. Provision of incentives such as less taxation, long-term contracts for the supply of rams to farmers, discounts on electronic data processing and breeding advice would also motivate large flocks to actively participate in the breeding programme. Most of these large flocks aim to maximise profits therefore a cost-benefit analysis should be able to convince them to play an active role in the success of the breeding programme. There are usually many unplanned benefits from participation in a breeding programme in that farmers learn much more about the genetic potential and actual performance of their animals and use that to boost their technical expertise and profits (Kahi et al., 2004). These large flocks would, however, reach a compromise with other farmers on what would be the cost of rams leaving the nucleus. As clients, farmers determine the economic efficiency of a breeding programme.

To avoid the problem of inbreeding within the closed nucleus flocks, these flocks should be encouraged to co-operate with one another through exchange of ewes. With time and as experience is gained, such an arrangement can easily be changed to an open nucleus breeding system that would allow for upward movement to the nucleus of rams born in the commercial sector (Yapi-Gnaoré et al., 1997). However, due to high fecundity, migrating rams to the nucleus from the commercial sector after lag is established will not give any significant genetic gains, unless there is some degree of measurement on rams or their close relatives in this sector. Recording is difficult in this sector but such rams might be selected by physical appraisal on their growth and body condition as well as on their dams. This system would be similar to the CNSyr or CNSor modelled in this study but with a certain usage level of rams from the commercial sector to produce both rams and ewes for the nucleus flock. In such an arrangement, a two-stage selection process would have to be adopted. The first stage would involve performance testing and the second stage progeny testing, depending on the costs involved. Costs can be a significant barrier to adoption of any beneficial technology in breeding (Kahi et al., 2003).

Simple selection criteria that can be used to improve the breeding objective traits were assumed in this study. Under the production conditions of smallholder farmers and pastoralists, resistance to disease is very important. Diseases and parasites are a major constraint on the productivity and cost of production of meat sheep (Kosgey et al., 2004).

Gastro-intestinal helminths are the most important parasites (Baker et al., 1999). Infection with GI helminths is associated with delayed and reduced productivity, increased cost of production, increased susceptibility to other infections and increased use of antihelminthics (Baker, 1995). Therefore, inclusion of RES in the breeding objective is a worthwhile endeavour.

6.4. Practical implication of inclusion of RES in the breeding objective

This study showed that inclusion of RES in the breeding objective and of FEC in the selection criteria resulted in increased profit per ewe for all the breeding objectives assessed. The importance of FEC measurements indicated the importance of RES to the overall profitability of a sheep flock. This study assumed optimal management in the nucleus and trait measurement for all selection criterion traits. As a result, implementation of a programme incorporating RES could have fewer benefits in practice than those predicted in this study in a situation where management is suboptimal. The selection schemes modelled in this study did not account for the interaction between genetic resistance of the host population and the epidemiology of GI helminths. This interaction may affect the genetic relationships between resistance and productivity, as well as selection response since decreased FEC reduces subsequent re-infection rates in the flock (Bishop and Stear, 1999; MacKenzie and Bishop, 1999).

The study has contributed to demonstrating the economic and genetic benefits of breeding for resistance to GI helminths in meat sheep for both smallholder and pastoral production systems in Kenya. The benefits increases when information on FEC measured on rams after weaning is used in the selection criteria, implying the need to invest on measuring and recording FEC. Because of the costs involved in measuring FEC and the little added benefits of additional measurement of FEC post-weaning; only one measurement need to be planned for. This has important consequences towards the establishment of effective and sustainable breeding programmes for meat sheep since improvement in RES is possible with limited investment in FEC measurement.

Measurements for FEC can effectively be undertaken in the nucleus flock where special technical attention can be paid to accurate measures of FEC together with estimation of accurate genetic and phenotypic parameters of selection criteria and breeding objective traits. However, a compromise is needed between reducing measurement costs and increasing accuracy of selection. Increasing the number of FEC measurements is expected to positively affect the accuracy of selection since this reduces the measurement error and increases the

heritability of FEC. Further studies, are however, required to examine the relationship between cost and accuracy of selection, and the overall effect on response to selection. The sensitivity of profit per ewe to changes in genetic correlations between FEC and traits in the breeding objective stress the importance of using reliable estimates of genetic and phenotypic parameters in the implementation of effective breeding programmes and assessment of the progress of on-going programmes.

This study has shown that pursuing different breeding objectives may require operating with varying nucleus population size. Of interest is the fact that a nucleus size of 10% could result in optimal profitability in some breeding objectives. A small nucleus is always advantageous in breeding programmes that are beginning and those in which costs are more crucial than genetic gain. This study demonstrated that the optimal proportion of rams to test for FEC is determined by the breeding objective. The optimal proportion was higher in breeding objectives with higher economic values for traits. It may reflect the fact that it is more profitable to measure FEC on a larger proportion of rams when the genetic improvement achieved has a higher value and the production system addressed has higher risks.

Results presented here provide encouragement for the establishment of programmes breeding for RES in meat sheep in the tropics. Breeding programmes in Australia and New Zealand have been successful in improving resistance of sheep to infection with various parasitic nematodes such as *Haemonchus contortus, Trichostrongylus colubriformis* and to mixed natural infections (Baker et al., 1991; Eady et al., 1994; Morris et al., 1997; Piper and Barger, 1988; Woolaston, 1994; Woolaston and Baker, 1996; Woolaston and Piper, 1996). Breeding for RES is an achievable goal, but it is just one step in a journey which needs to be carefully considered, monitored and actively pursued (Bell and Eady, 2001). In Kenya presently, private large scale flocks or flocks owned by parastatal or research organisations have the necessary infrastructure to maintain nucleus flocks of sheep. These organisations need to take the lead in implementing the suggested programme of breeding meat sheep for RES to benefit the sheep industry in Kenya. It should, however, be noted that breeding for RES may not necessarily lead to more productive sheep, but should produce sheep that can survive and keep GI helminths burden at a level where their productivity is not compromised (Eady and Smith, 2001).

This study assumed the use of conventional breeding methods with selection based on the use of phenotypic information. Breeding operations involving the use of molecular genetics techniques aimed at locating and exploiting gene loci which have a major effect on

quantitative traits were not considered. Although the transfer of RES capacity is very interesting, there are still very few applications of these techniques for sheep. However, identification of genetic markers linked to genes responsible for RES holds potential for marker-assisted selection. In addition, this would form an avenue to enable introgression of genes to incorporate RES in other susceptible meat sheep breeds. There is an urgent need to develop acceptable alternative breeding schemes that incorporate genetic markers linked to genes responsible for RES.

6.5. Effects of breeding for RES

Baker (1995) noted that incentives to apply genetic principles to disease traits result from (1) a realisation that the breeding objective is often incomplete without a disease resistance trait(s), (2) the increasing cost or the decreasing availability of effective management strategies and drug therapies, (3) ethical concerns about continuing to treat animals with drugs, although with perhaps equal ethical concerns to minimise the suffering experienced by diseased animals and (4) increasing consumer preferences for food products from animals maintained in 'chemical free' or minimal drug environments. A further increase especially in RES has been due to increased interest in parasite resistance and recording of FEC.

Many studies have reported improved production in sheep selected (within breed) for worm resistance when under similar worm challenges to unselected sheep contrasting that of Morris et al. (2000) who reported a lower productivity in sheep selected for worm resistance. One hypothesis that was forwarded by Baker et al. (1999) on this observation was that the immune response mounted against worms by resistant sheep carries some cost to the animal. Other studies (Albers et al., 1987; Piper, 1987; Woolaston et al., 1991) have shown that genetic correlations between FEC and the traits of wool production and fibre diameter appear to be close to zero. This implies that selection for increased production should do little to improve sheep's genetic resistance to parasites. If production is measured in an environment in which worms are not controlled, animals which are more resistant to worms will tend to have high fleece weights, body weight, resistance to other diseases and reproductive traits because of physiological effects worms have on these traits. Selection on production in an environment where worms are prevalent may lead to genetic change in resistance. Given the current knowledge of genetic correlations between production and FEC, selection for RES is unlikely to compromise progress in other economically important traits.

Infection with helminths affects feed intake, digestibility and the utilisation of absorbed nutrients (Dargie, 1980). The interaction between parasites and feed intake and utilisation has raised many unanswered questions in animal production. The net effect results in nutritional stress. This has led to an increased focus on the nutritional physiology of the parasitised animal in an attempt to explain the deleterious effects or exonerate the potential of genetic resistance to endo-sparasites of small ruminants. For example, the impaired productivity during ovine fasciolosis is thought to be as a result of reduced feed intake due to infection with internal parasites resulting in poor feed utilisation (Dargie et al., 1979). Reduced feed intake and subsequent poor utilisation leads to lowered immunity levels in the affected host (Berry and Dargie, 1976). By extension, selecting for RES could lead to positive response in most other diseases. It has been frequently suggested that the nutritional status of the host (usually affected negatively by infection with GI helminths) can influence the pathogenesis of an infection and that well-nourished animals withstand infection better than those that are less adequately fed (Whitlock, 1949; Berry and Dargie, 1976).

6.6. Design of sustainable breeding programme for a large-scale sheep flock

In the initial stages of a breeding programme, return on investment is more important than the levels of genetic gain expected. The objective is to develop a programme that will be sustainable within the constraints of the local farming conditions. Design of breeding programmes involves integration of the four main components of a breeding programme - the breeding objective, methods for evaluation of potential breeding stock, including generation and collection of data, methods for selection, and mating strategies - into a strategy that maximises the overall objective of the programmes. From a technical perspective, the programme's objective is frequently formulated in terms of the rate of genetic gain, often with some consideration of inbreeding. In today's competitive market for breeding stock, it is however, crucial that breeding programmes are evaluated in relation to the objectives and factors that drive the decision making process. This often means evaluation of not only rates of genetic gains and inbreeding but also economic aspects, the use of resources, and the marketability and competitiveness of the resulting product. Variables under control of the breeder include, among others, size of the breeding population, number of tiers and size of each tier, the extent of use of technology, selection intensities, selection criteria, mating strategies. Generally, in the design and implementation of breeding systems and schemes uncertainty about genetic parameters, establishment logistics and practical limitations in infrastructure in the tropics are inevitable. This leads to the need for *a priori* evaluation of

alternative breeding systems and schemes putting in mind the existing infrastructure and technical support in alternative production systems.

An important area for research on the design of breeding programmes has been, and continues to be incorporation of new technology, including developments in data collection and genetic evaluation, reproductive technology, and molecular genetics. This role will gain increasing importance in the future, with the rapid rate of technological development in these areas. Most studies on evaluation and optimisation of breeding programmes are conducted under idealised conditions. Practical implementation of new technology is, nevertheless, often faced with a degree of unreliability of information, parameters, and technical results, which can limit benefits derived from technology and could impact on optimum strategies for use of technology in breeding programmes. In addition, implementation of technology can be hampered and affected by existing inefficiencies of operational breeding programmes and by practical restrictions. It is therefore important to consider all these factors and their interplay in the design of a breeding programme for large-scale sheep flocks. It is vital at the design level to consider factors that have led to success or failure of small ruminants breeding programme in the tropics and where possible plan to shun the problems at the design level. More importantly is to consider the breeding objectives for small ruminants under smallholder and pastoral production systems in the tropics (Kosgey et al., 2004).

6.6.1. Current status of large-scale sheep farming in Kenya

In Kenya, sheep is raised mainly for meat and skins (MLFD, 2002), but also to a smaller extent for wool. Large-scale sheep farming in Kenya is found mainly in the medium to low potential areas where crop production is difficult due to low rainfall and high evapotranspiration. The animals are raised under extensive or communal grazing and management. Highly specialised commercial large-scale sheep production systems are generally lacking (MLFD, 2002). Indigenous genotypes are predominant among large-scale producers (pastoral communities). The few existing large-scale sheep farms in Kenya are either run traditionally in accordance with the available resources (skilled and unskilled labour, feed supplements, inputs for animal health, etc.). Ranching systems consist of labour-extensive enterprises specialising in one or more livestock species and producing mainly live animals for slaughter (for meat and skins). Management is characterised by grazing within the fixed boundaries that delimit tenure. Ranches are generally commercial enterprises, with generation of a cash income as the primary function of the livestock raised on them. Ranching systems can either hold both breeding and growing stock or specialise in rearing or

fattening animals, according to environmental and economic conditions (Jahnke et al., 1988). Ranching systems are commonest in the arid and semi-arid zones of Kenya. Ranching differs from traditional pastoralism in supporting fewer people per land area, since tenure is generally individual (although not necessarily private), and providing options for intensifying water and pasture supplies.

6.6.2. Choice of breeding structure

A breeding programme involves two main activities (van Arendok and Bijma, 2003). These are the generation of genetic improvement by selection and mating, and the subsequent dissemination of the superior genes to the whole population. Breeding structures define systems for gathering information necessary in assessing animals in a production system and conditions that allow selection of parents of future progeny and desirable mating systems of these animals (Rege et al., 2001). Kinghorn (2000) proposed closed nucleus breeding structures for genetic improvement in developing countries in the tropics so as to minimise measurement and recording costs. All traits recording and genetic evaluation is done in the nucleus and none in the commercial flocks. Small ruminant interventions with increased input costs by smallholder farmers and/or pastoralists are rarely adopted (Makokha, 2002). Proper management of the nucleus is crucial for its success. Good husbandry to reduce mortality would help in obtaining higher genetic gain as a result of increased selection intensity and accuracy of selection.

This study has proposed a two-tier closed nucleus system as a good starting point. It is worth noting that decision on the choice of this system was based on costs and logistics of establishing a closed system versus open system under smallholder and pastoralists farming conditions. It is not only sufficient to base the choice of breeding system on genetic gains and profitability but also on other factors that might be important in ensuring its successful implementation and sustainability. As experience is gained, the nucleus could be opened (Roden, 1995. Opening the nucleus to allow in the best animals from the commercial flocks results in more sustained genetic returns. This is due to higher selection intensity, and therefore more certainty that the best females are selected as a result of increased genetic variation in the next generation (Kinghorn et al., 2000). Open nucleus systems provide approximately 10% more genetic gain than closed nucleus systems because there are more animals which are potential candidates for selection.

6.6.3. Choice of breeding objective and selection criteria

Breeding objectives are developed to provide a clear statement of direction in animal improvement programmes. In general terms, the purpose of a breeding objective is to identify the traits that affect some production goal and to allow selection of animals that will increase the frequency of alleles with favourable effects on these traits. In livestock production, animal productivity is commonly measured by income generated from the enterprise. For this reason, goals of selection usually include genetic change in traits that are more beneficial (profitable) for the livestock programme. In the development of a breeding programme, it is important to distinguish the traits in the breeding objective from the selection criteria. While the choice of the traits in the breeding objective is based on their economic importance, selection criteria are the traits used in assessing the breeding value of individuals to be used as parents for the next generation. By identifying traits of economic importance, a breeding objective clarifies the role of genetics in defining profitability and facilitates development of selection strategies. Decisions on the selection criteria should be made after the breeding objective has been defined. The traits considered in the breeding objective in this study could be a good starting point for any attempts at establishing a breeding programme for meat sheep.

Traits used as selection criteria in a breeding programme can be seen as a means to maximise the aggregate breeding value. In this study, selection criteria in all five nucleus breeding systems considered included BW, WW, YW, LS, LI and FEC. Initially, the selection criteria to be used should be very simple. The selection criteria used in this study are usually measured in most sheep farms in Kenya. Inclusion of FEC might be tricky because this would mean involvement of other organisations (e.g., KARI and Universities) and necessary infrastructure for FEC determination. This study has however shown that inclusion of FEC in the selection criteria is profitable, indicating that the costs associated with FEC measurement will simply be offset by the profits that accrue from the breeding programme. The most important issue farmers need to face during measurement of FEC is the requirement of withholding dewormers from animals so that genetic variation for host resistance can be manifested. But since research has shown that genetic resistance of sheep to internal parasites is not able to develop until 5 months of age (Gray, 1991), young lambs (1 to 6 months of age) would need to be dewormed. Moreover, since the natural resistance of ewes decreases when they are pregnant, they should be given a deworming treatment about 2 weeks before lambing. This practice will prevent placing very young lambs in a dangerous

parasite environment resulting from the natural peri-parturient (pre-lambing) rise in faecal eggs.

6.6.4. Demonstration of the benefits of breeding for resistance to GI helminths

Breeding for resistance to GI helminths can well be demonstrated by considering a two-tier closed nucleus system with a total of 300 (5% of the population) and 5,700 ewes in the nucleus and commercial sector, respectively. The number in the nucleus is considered bearing in mind the flock sizes of most large-scale meat sheep farms. Screening of the animals for the nucleus is based on the selection criteria considered in schemes 1 and 3 (see section 5.2.3) for FLOCK. The superior animals selected are expected to contribute to the improvement of the gene pool of a whole population of animals in the nucleus. Animals in the nucleus are ordered according to performance using the available performance measurements and identification systems.

The large-scale producer could be a government institution such a KARI's NAHRC with a station like Ol' Magogo in Naivasha being considered as the nucleus or privately owned farms. Input parameters used in the demonstration are as described in Chapter 5 (sections 5.2.1 – 4). Table 19 shows the annual genetic gains, returns and profits per ewe in the nucleus. A profit per ewe of KSh 82.33 is expected when RES is incorporated in the breeding objectives for meat sheep.

Table 19. Annual monetary genetic gains, returns and profits per ewe in the nucleus of 300 ewes for schemes 1 and 3 under FLOCK[a]

	Scheme[b]	
	1	3
Annual monetary genetic gains (KSh)	38.60	53.08
Returns per ewe in the population (KSh)	210.92	285.75
Profits per ewe in the population (KSh)	23.07	82.33

[a]See text for description of the breeding objectives.
[b]See text for the description of breeding schemes.

These results show that even with a nucleus of 300 ewes, which is the average flock size under large-scale production system (Kosgey et al., 2003), it is profitable to breed sheep for RES. Further benefits in terms of annual monetary genetic gains, returns and profit per ewe are anticipated with an increase in the population size. This demonstration could serve as an incentive for private large-scale flocks or flocks owned by parastatal or research organisations to implement the suggested programme of breeding meat sheep for RES.

6.7. Conclusions

This study provided vital information on the most appropriate breeding systems and schemes (strategies) to be adopted in the establishment of a breeding programme in meat sheep under smallholder and pastoral production systems in Kenya. The two-tier nucleus breeding systems were profitable and closed nucleus breeding systems were logistically more attractive, being more simpler than open nucleus breeding systems to establish. In addition to genetic gain and profitability, it is vital to pay attention to factors that might be important in ensuring its successful implementation and sustainability when choosing a breeding system. Under smallholder and pastoral production circumstances in Kenya, where helminth infection is endemic, the objective is to reduce the cost of disease control. In the current study, improving YW while minimising any positive response in FEC meant that very large positive economic values for FEC were undesirable. The magnitudes of the economic values for FEC indicate that this could be achieved by using negative economic values for FEC, but in practice, the level of disease prevalence determines the economic value to be applied in any breeding programme.

The economic and genetic benefits of breeding for RES in meat sheep in both smallholder and pastoral production systems increased when information on FEC measured on rams after weaning was used in the selection criteria, implying the need to invest on measuring and recording FEC. Measuring FEC is costly and because additional measurements yielded no substantial additional benefits, only one measurement needs to be planned for under resource constrained smallholder and pastoral systems. This will be effective and sustainable in the long run for meat sheep since it is possible to achieve desirable improvement in RES with limited investment in FEC measurement. Generally, a two-tier closed nucleus scheme considering one FEC measurement in rams immediately after weaning was shown to be the most appropriate strategy for the improvement of meat sheep in Kenya in smallholder and pastoral production systems.

There is need to consider results from this study in the light of modern and current breeding techniques such as MOET, progeny testing, AI, MAS, among others with regard to their influence on genetic and economic efficiency of a breeding strategy.

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