ESTIMATION OF GENETIC PARAMETERS AND ASSESSMENT OF GENETIC VARIATION FOR INTERNAL PARASITE RESISTANCE TRAITS IN RUMINANTS

A Dissertation

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ABSTRACT

Internal parasites are a major concern to the livestock industry leading to huge losses. Genetic enhancement of ruminants for resistance/tolerance to internal parasites may provide for a lasting solution to the problem of internal parasite infection in livestock. The objective of this study was to estimate heritability and permanent environmental variance for internal parasite resistance traits in sheep and to apply penalties on the records of treated animals, analyzing the effect of such penalties on the genetic parameters. Records from 1008 Dorper sheep in a private South African flock comprised 17,711 FAMACHA scores, 3,758 fecal egg counts (mostly *Haemonchus contortus*), and 4,209 hematocrit values that were collected from 1997 – 2000. Animal models were used to conduct single trait analyses. Data were analyzed in three sets: 1) untreated records only; 2) all records; no penalties; and 3) all records with treated records penalized. Heritability estimates of Fc (FAMACHA) ranged from 0.33 ± 0.03 to 0.37 ± 0.03; FEC (Fecal egg count) from 0.04 ± 0.02 to 0.05 ± 0.03 and hematocrit from 0.19 ± 0.04 to 0.20 ± 0.05. Permanent environmental variance as a proportion of phenotypic variance was 0.02 ± 0.02 to 0.03 ± 0.02 for Fc, 0.14 ± 0.04 to 0.18 ± 0.05 for Ht and 0.07 ± 0.02 to 0.08 ± 0.03 for FEC. The Inclusion of treated animal records in the analyses, with or without penalization did not change the estimates of heritability and permanent environmental variance as a proportion of phenotypic variance.

The objective of the second study was to assess genetic variation in fecal egg count and the associations of fecal egg count with other traits in growing crossbred Nelore-Angus cattle. Records of 201 F_2 and F_3 ½ Nelore ½ Angus steers in feedlot conditions in a genomics resource population in Central Texas were collected in 2012 and 2013. Helminth egg counts were determined from fecal samples before treatment with an anthelmintic product. The association of fecal egg count with other traits was assessed by modeling each in distinct analyses as a linear covariate. Year explained substantial variation in fecal egg count ($P = 0.001$). No other investigated covariate (birth weight, weaning weight, weaning temperament score, live weight, temperature, and exit velocity) was important in the different models ($P > 0.2$). Subsequently, sire (n = 13) was evaluated as a fixed effect (sires with less than 3 steers with records were excluded). Two sire families had significantly lower ($P < 0.05$) fecal egg counts (1.31 ± 0.28 and 1.57 ± 0.10) than the three sire families with the highest fecal egg counts (1.87 ± 0.10 - 2.06 ± 0.20). These results suggest the presence of additive genetic variation for fecal egg count, implying that selection can be carried out for the ability to suppress parasite worms in cattle.

DEDICATION

To my family for supporting my dream

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CHAPTER I

INTRODUCTION

Internal parasites are a major concern to the livestock industry worldwide resulting in great animal and economic losses. Huge direct (labor, cost of anthelmintics) and indirect (production losses) costs are associated with the prevalence of internal parasitism worldwide. Over $1 billion annual loss in Australia (McLeod, 1995), $192 million in Argentina (Entrocasso, 1988), £84 million in the British sheep industry (Nieuwhof and Bishop, 2005) and tens of billions worldwide (Roeber et al., 2013) are attributed to livestock internal parasitism. For a while, livestock producers have relied on the use of anthelmintic drugs to control parasite infestations in their herd for increased productivity and profitability (Sargison, 2008). Gastrointestinal nematodes, however, are known worldwide (Jackson and Coop, 2000; Vattaa and Lindberg, 2006; Gallidis et al., 2009; Kaplan and Vikdyashankar, 2012) to develop resistance to the anthelmintics used to kill them. Since quantitative trait loci for resistance to internal parasites have been identified in some ruminants (Marshall et al., 2013), genetic enhancement of ruminants for resistance/tolerance to internal parasites may provide

for a more sustainable long lasting solution to the problem of internal parasite infection in livestock.

Breeding livestock for resistance to parasites may help greatly in reducing animal losses and anthelmintic costs.

Resistance to internal parasites is a heritable trait of economic importance to the sheep industry. A problem with this trait however, is that it is difficult to measure and, therefore, evaluated through indicator traits such as fecal egg count, and hematocrit value (Bishop, 2012) and the FAMACHA (Van Wyk and Bath, 2002) score. Selection for resistance has been demonstrated (Vagenas et al., 2002; Karlsson and Greeff, 2006; Kemper et al., 2010) in small ruminants. Kemper et al. (2009) found no evidence of nematode adaptation to the resistant hosts, suggesting that selection for resistance could be sustainable. Genomic regions have been identified as QTL for nematode resistance in sheep with minimal overlap of those areas in different studies (Beraldi et al., 2007; Dominik et al., 2010; Silva et al., 2012; Marshall et al., 2013). This lack of consensus might be as a result of QTL for nematode resistance being of small effects, as a result of breed-specific loci or to genotype x environment combinations.

The objectives of this study, therefore, are:

1. To estimate heritability and permanent environmental variance for internal parasite resistance traits in sheep and to apply penalties on the records of treated animals, evaluating the effect of such penalties on the genetic parameters.
2. To assess genetic variation in fecal egg count for multiple species of internal parasites in growing crossbred *Bos indicus-Bos taurus* cattle.

CHAPTER II

LITERATURE REVIEW

2.1 Internal Parasites and the Livestock Industry

Internal parasites are a cause of great economic loss to the livestock industry. When livestock graze, they are exposed to internal parasites which pose a major threat to the health of the animals and the profitability and productivity of the industry. Parasites in livestock can result in major financial and agricultural losses (Roeber et al., 2013), not only causing diseases but also negatively impacting the socio-economic status of people. The annual cost associated with parasitic diseases in sheep and cattle in Australia has been estimated at 1 billion Australian dollars (McLeod, 1995). Roeber et al. (2013) further stated that these costs are proposed to be tens of billions of US dollars worldwide, according to the sales of anti-parasitic compounds by pharmaceutical companies, excluding production losses. Perry and Randolph (1999) described nematode parasite infections as one of the greatest causes of lost productivity of grazing livestock. They stated that in the developed world, the greatest component of impact is probably found in the costs of control while in the developing world the greatest impacts of parasitic diseases are in productivity losses in the form of lost potential. According to Ballweber (2006), based on overall numbers of worms, numbers of species present, general levels of pathogenicity, and widespread geographic distribution, the

gastrointestinal nematodes are considered to be the most important group of internal parasites.

2.2 Internal Parasites in Cattle

In cattle, internal parasite infections reduce appetite, leading to weight loss or slow growth, disease susceptibility, anemia, lowered reproductive performance, low feed conversion, diarrhea, blood loss and even death (Holmes, 1987). High costs are also incurred from buying medications and drugs. According to Entrocasso et al. (1986), internal parasitism may also affect carcass quality and quantity even following recovery and a feeding period. Similarly, Holmes (1987) stated that the quality and quantity of meat and milk can be decreased in parasitized cattle due to loss of protein (blood and plasma) into the gastro-intestinal tract and increased protein metabolism by the intestinal tract. Skeletal changes also can occur due to limited absorption of P caused by intestinal nematodes. Loss of K increases in parasitized calves, which can increase retention of body fluids. There is a decrease in lactose, fat content and protein milk from infected dairy cattle (Rinaldi et al., 2007).

Susceptibility to internal parasites is generally known to be higher in calves that are under one year of age than older ones because the older calves tend to develop some level of immunity as a result of frequent exposure. The abomasum and intestine of cattle contains nematodes which produce eggs, and these eggs are passed out in feces. When these eggs in the manure hatch and the larva from them become infective, they move

into the grass where cattle feed on them. Upon entry into the abomasum or intestine, they complete their development, feed in the stomach or on the animal's blood. Cattle are affected by different types of internal parasites, and greatest risk of infection is known to be in the late winter, spring, and fall. Dunn (1978) confirmed that the development from egg to the infective stage is temperature and humidity dependent. Sutherland and Leathwick (2011) listed various nematodes by their sites of action as:

1. Abomasum (fourth stomach): *Ostertagia ostertagi*, *Trichostrongylus axei* (mucosal browsers), *Haemonchus placei* (blood feeder).
2. Small intestine: *Cooperia oncophora*, *Cooperia pectinata*, *Cooperia punctata* (mucosal browsers).
3. Large intestine: *Oesophagostomum radiatum* (tissue feeders).

Sutherland and Scott (2010) listed *Ostertagia ostertagi* as the most important parasite of cattle in the temperate regions.

2.3 Internal Parasites in Sheep and Goats

In small ruminants (sheep and goats), huge losses are attributed to the prevalence of internal parasites. Sheep have been found to be more exposed to internal parasite infestations due to their grazing lifestyle than goats. The browsing habit of goats makes them less exposed to infective larvae which are on pasture. Mugambi et al. (1997) described gastroenteric verminosis as a disease with a great economic impact on sheep farms located in humid areas including tropical and subtropical regions of the world.

Sutherland and Scott (2010) also stated that *Haemonchus contortus*, which causes parasitic gastroenteritis, is widely considered the most important, predominant, and prolific internal parasite of sheep. As confirmed by Balic et al. (2000), *H. contortus* is the most important gastroenteric nematode of sheep in many regions of the world due to its ubiquity and virulence. Although *H. contortus* can be found in cattle, its primary hosts are sheep and goats. When ruminants ingest worms from grazing infested grass, the worms find their way into the abomasum and subsequently the females shed their eggs into the abomasum. These eggs are then passed through feces on to pasture where they hatch; larvae feed on manure and again infect the small ruminants when consumed. *Haemonchus contortus* goes into a state of hypobiosis or arrested development in the host when conditions (such as winter) are not favorable for its development. Larvae development resumes when conditions become more favorable. *Haemonchus contortus* is hemophagic and therefore induces anemia in the host. Notter et al. (2003) listed the negative effects of *H. contortus* on the biological and economic efficiency of sheep herds to include malnutrition, low feed conversion, anemia, loss of appetite, low fertility indices, and in certain cases the death of young animals. Losses due to this disease as stated by Sackett et al. (2006) have been estimated at more than 400 million Australian dollars per year in Australia; treatments in Kenya, South Africa, and India cost up to 26, 46, and 103 million U.S. dollars respectively.

During the peripartum period of ewes or cows (late pregnancy to after delivery), fecal egg output is increased as a result of increased worm burden. This is often referred to as peri-parturient rise. Ewes or cows can therefore be said to be the major source of pasture contamination. Silva et al. (2011) and Huntley et al. (2004) explained that increase in fecal egg output during the peripartum phase is a result of a reduction in cellular immune response and systemic antibodies. Females are immunosuppressed during pregnancy and lactation therefore, maturing larvae survive longer in them than in non-pregnant, non-lactating females. Much attention should be given to the health and nutrition of pregnant and lactating females.

2.4 Control of Internal Parasites

Livestock producers typically have relied on the use of drugs (anthelmintics) to control internal parasites in their herds. Other names for anthelmintics include drenches, dewormers, and vermifuge. Vlassoff et al. (2001) explained that broad spectrum anthelmintics could be administered orally, through injection or topical application. Anthelmintics are more effective when administered discriminately and strategically, targeting the sick and the more susceptible animals in the herd/flock such as lambs, pregnant/lactating ewes and also administering the correct dosage (Craig, 2006).

Other approaches have been used in the control/reduction of internal parasites in herds/flocks to complement the use of anthelmintics. The use of management practices such as nutrition, good sanitation, type of grazing system and reduced stocking rate to

control or reduce the prevalence of internal parasites have been explored. Ensuring animals are kept in well sanitized environments, given clean water free from fecal material, fed high protein diets in troughs rather than on the ground, allowed to browse instead of graze, may all reduce exposure to internal parasites. According to Craig (2006), even if anthelmintics could eliminate all helminths, ignoring management practices such as nutrition and sanitation is not a good approach. The effectiveness of anthelmintics is enhanced when animals are not nutritionally deficient and are properly managed. Providing sufficient dietary protein during the growth and peripaturient periods is vital as this consequently makes the animals less susceptible to infections (Craig, 2006). Adult cattle are less susceptible to the helminths than sheep and goats. Allowing cattle to graze with sheep and goats (mixed grazing) may help in reducing the population of nematodes in the pasture. Cattle will ingest the sheep worm larvae thereby preventing them from affecting the sheep. To achieve maximum control while using anthelmintics, the right overall management practices should be put in place.

2.5 Nematode Resistance to Anthelmintics

In recent times, there have been cases of several nematode species showing resistance to different classes of anthelmintics. Abbott et al. (2009) defined anthelmintic resistance as 'the heritable ability of the parasite to tolerate a normally effective dose of the anthelmintic'. Populations of *Cooperia spp*., *H. contortus*, *H. placei*, and *Oesophagostomum* have been identified to be resistant to macrolytic lactones and

benzimidazoles (Fiel et al., 2009; Gasbarre et al., 2009). Some levels of resistance to the newly developed anthelmintics have also been identified in certain nematodes. Little et al. (2010) found STARTECT (Zoetis, Florham Park, NJ), the derquantel–abamectin combination to be 100% effective against *H. contortus*. However, according to Kaminsky et al. (2011), STARTECT was not effective against *H. contortus* (18.3%) suggesting that acquired resistance to the drug may be developing in *H. contortus*.

A major cause of anthelmintic resistance is the indiscriminate use of anthelmintics. Resistance has developed due to excessive applications of these drugs in small ruminants and in cattle. Fiel et al. (2009) reported that, in Brazil, increased anthelmintic resistance has been attributed to the availability of low-price macrolytic lactone products, resulting in their intense and indiscriminate use. Sutherland and Leathwick (2011) stated that anthelmintic resistance in gastrointestinal nematodes of cattle has now been detected in many countries, in many nematode species and against all of the currently available anthelmintic drug families. Given the increase in cases of rapid acquisition of resistance in recent years, it is proposed that anthelmintic resistance presents a significant threat to the sustainability of current worm control practices in grazing livestock.

Another problem with the use of anthelmintic drugs is with drug residues in meat or milk products. There is growing consumer concern about food contamination from the use of drugs in livestock management programs. In a study by Cooper et al. (2012), of 1,061 beef samples analyzed, 26 (2.45%) contained detectable residues of anthelminthic drugs (0.2 to 171 µg kg^{-1}), although none were above their European Union maximum residue limit or action level. Moreno et al. (2008) detected Stromectol (Merck and Co, Whitehouse Station, NJ) residues in all muscle locations in sheep carcasses. Anthelmintics cannot be solely depended upon to control internal parasites; therefore, a more sustainable long-term solution is needed to solve this problem.

2.6 Resistance to Internal Parasites

When an animal has the ability to stay unaffected by infection, toxins and pathogens, it is said to be resistant. Sheep that are resistant to the effects of internal parasites remain productive even when they are infected. Identification of sheep that show resistance to internal parasites may help in making selection decisions. The susceptible sheep can be removed while the resistant ones are retained in the herd. Genetic variation in internal parasite resistance has been found to exist between and within breeds of sheep.

Some sheep have been identified as showing higher resistance to internal parasites than others. Jilek and Bradley (1969) reported higher resistance to *H. contortus* in Florida Native Sheep (Spanish sheep introduced into Florida in the 1500s) than in Rambouillet. Zajac et al. (1988) and Courtney et al. (1985) also confirmed the higher resistance of Florida Native Sheep than the Dorset × Rambouillet and Barbados, respectively. Baker et al. (1994) and Preston and Allonby (1979) found Red Massai to be more resistant to *H. contortus* than Merino, Corriedale, Hampshire and Dorper.

The QTL that have been identified for internal parasite resistance appear to be different across breeds (Matika et al., 2011). Selection of animals based in part on the presence of markers associated with putative genes may be a promising alternative for improving resistance to or tolerance of internal parasites. Table 1 shows different QTL for sheep resistance to internal parasites as documented in various studies.

Table 1. Genomic regions with QTL identified for parasite resistance in sheep

BREED TYPE	CHROMOSOME[1]	REFERENCE
Blackface	OAR 3, 14, 20	Davis et al. (2006)
Outcross pedigrees	OAR 8, 23	Crawford et al. (2006)
Soay	OAR 3, X	Beraldi et al. (2007)
Spanish Churra	OAR 1, 6, 10, 14	Gutierrez-Gill et al. (2009)
½ Romney ½ Merino x Merino	OAR 22, 21, 3	Dominik et al. (2010)
½ Red Massai ½ Dorper x Red Massai , Dorper	OAR 3, 6, 14, 22	Silva et al. (2011)
½ Martinik Black-Belly ½ Romane x Romane	OAR 5,12, 13, 21	Sallé et al. (2012)
½ Red Massai ½ Dorper x ½ Red Massai ½ Dorper	OAR 2, 26	Marshall et al. (2013)

[1]**OAR-** ***Ovis aries***

2.7 Internal Parasite Resistance Traits in Sheep

In identifying sheep that are resistant to internal parasites, certain indicator traits are measured. These traits are used to monitor the severity and rate of parasite infection in the animals. Commonly measured internal parasite resistance traits include FAMACHA score, hematocrit count, and fecal egg count.

FAMACHA score

The FAMACHA system is the only tool well tested for use under practical farming conditions (Van Wyk and Bath, 2002) for the control of *H. contortus* in small ruminants, through the subjective evaluation of the color of the inner eye-lid. The FAMACHA system was developed in South Africa by Dr. Francois Faffa Malan along with other scientists and it classifies animals into categories based on their level of anemia for selective anthelmintic treatment (Bath et al., 1996). Cottle (1991) explained that the FAMACHA is comprised of categories 1 to 5, where higher numbers indicate increasingly pale color (healthy is red) of the conjunctiva.

According to Riley and Van Wyk (2009), FAMACHA scores are feasible, effective, less expensive and much more practical alternatives to analyses of hematocrit values or fecal egg worm counts, especially in the developing countries with relatively cheap labor and in resource-poor communities where most farmers own small numbers of animals and *H. contortus* is the primary parasite. Van Wyk and Bath (2002) also described the FAMACHA system as a method of clinical evaluation of anemia, used

primarily for selective anthelmintic treatment of only those individual animals which cannot manage unaided under field conditions of severe *H. contortus* challenge.

Selective treatment of animals is a strategy that could help in reducing incidences of parasite resistance to drugs. Through clinical identification and selective treatment of overly susceptible animals, while leaving the resistant and resilient ones (i.e., those which are, respectively, able either to eliminate parasites or to withstand their effect), use of anthelmintic drugs can considerably be reduced (Malan et al., 2001; Van Wyk and Bath, 2002; Mahieu et al., 2007; Molento et al., 2009). Van Wyk (2008) and Molento et al. (2009) stated that because FAMACHA only identifies individuals that are anemic, some production losses may have occurred before test results are obtained. Individuals that are infected with *H. contortus*, showing high levels of worm egg counts without signs of anemia would not be easily detected using the FAMACHA system.

The use of the FAMACHA system is being optimized in different production systems and countries (Malan et al., 2001; Vatta et al., 2001; Kaplan et al., 2004; Ejlertsen et al., 2006; Di Loria et al., 2009; Riley and Van Wyk, 2009; Scheuerle et al., 2010).

Hematocrit value

Hematocrit (also called packed cell volume) count represents the ratio of the volume of red blood cells to the total volume of blood expressed as a percentage. Because *H. contortus* is hemophagic, its presence often leads to depletion of the red

blood cells in infected animals. Hematocrit count therefore gives an indication of the level of infection, lower scores suggesting higher levels of infection. Normal ranges for hematocrit values of sheep, goat and cattle are 27 to 45, 22 to 38 and 24 to 46 respectively (Smith, 1996). An average of 21 was reported by Riley and Van Wyk (2009) in a Merino flock under heavy worm challenge (this was determined by the number of sheep that were treated for worm infection based on level of anemia). At 8 wk of age, the hematocrit value of *H. contortus* infected goats was 25 and uninfected at the same age was 28 in a study by Pralomkarn et al. (1997). Pam et al. (2013) reported that the mean hematocrit value of 35.13 ± 5.2 for cattle with one or more parasites (*Eimeria species*, *Oesophagostuma radiatum*, *Strongyloides*, *Syngamus laryngeus*, *Babesia bigemina*) and 35.02 ± 4.9 for cattle with no parasites were not different ($P < 0.5$).

Fecal egg count

Fecal egg count represents the number of eggs per g of feces as an indication of worm burden in animals. A common method for detecting anthelmintic resistance in nematodes is by the Fecal Egg Count Reduction Test (Calvete and Uriarte, 2013). This technique helps to know the rate of contamination on pasture, identify animals for selective deworming and measure the effect of anthelmintics. According to Smith (2014), fecal egg counts of above 500 eggs per g are considered high, between 100 and 500 eggs per g are considered moderate and below 100 eggs per g are low. Since only the adult worms lay eggs, fecal egg count is an indication of adult worm burden and not

necessarily the total worm burden. Fecal egg counts are generally known to be higher in sheep than in cattle.

2.8 Heritability Estimates

Resistance to internal parasites in small ruminants has been found to be heritable. Riley and Van Wyk (2009) reported low estimates of heritability for FAMACHA score ranging from 0.06 ± 0.04 to 0.24 ± 0.05 in a study of 1,671 Merino lambs. Snyman (2007) reported a heritability estimate of 0.17 for FAMACHA and 0.19 for both fecal egg count and hematocrit value in 2,751 Afrino lambs. One hundred and nineteen Santa Inês lambs exposed to two natural *Haemonchus contortus* challenges had fecal egg count heritability estimates varying from 0.04 to 0.27 and 0.01 to 0.52 in two distinct challenges; heritability estimates for hematocrit value were 0.31 and 0.12 in the two challenges (Lobo et al., 2009). The heritability estimate for fecal egg count was 0.11 ± 0.61 in the Appenninica sheep breed (Macchioni et al., 2007). Vanimisetti et al. (2004) reported heritability estimates for hematocrit and fecal egg count of 0.15 and 0.31 respectively in ewes of 50% Dorset, 25% Rambouillet, and 25% Finnsheep ancestry. Prince et al. (2010) reported 0.15 ± 0.10 heritability for fecal egg count in a study of 433 Avikalin sheep in India. These are in the same range with the findings of Gauly and Erhardt (2001) in sheep. In an artificial challenge of Merinoland sheep to *Haemonchus contortus*, heritability estimates for fecal egg count ranged from 0.07 ± 0.07 to 0.17 ± 0.07 and hematocrit from 0.51 ± 0.27 to 0.56 ± 0.20 (Gauly et al., 2002). However, Van

Wyk and Bath (2002) reported high heritability estimates for FAMACHA values of 0.55 ± 0.17 in a Merino study with 550 young rams and ewes which were progeny of 21 sires.

In a study on 11,970 Creola goats, Gunia et al. (2011) reported 0.13 ± 0.05 and 0.18 ± 0.04 heritability estimates for hematocrit value and fecal egg count respectively. Mandal et al. (2012) reported direct heritability estimates of 0.11 to 0.16 for fecal egg count in Jamunapari goats which were similar to the findings of Woolaston et al. (1992) in adult meat-type goats (0.08).

Riley and Van Wyk (2009) reported strong estimates of genetic and phenotypic correlation for FAMACHA and hematocrit values (–0.98 ± 0.05; –0.96 ± 0.09), hematocrit values and fecal egg count (–0.80 ± 0.11; –0.83 ± 0.09) and a strong positive correlation between FAMACHA and fecal egg count (0.85 ± 0.12; 0.73 ± 0.12). In a study of sheep from 29 farms in Canada, Mederos et al. (2014) reported simple correlations between hematocrit count and fecal egg count (−0.25), hematocrit and FAMACHA (−0.31); and fecal egg count and FAMACHA (0.178). The phenotypic correlation coefficient between hematocrit value and fecal egg count was –0.67 while that between fecal egg count and log transformed total worm count was 0.72 (Mugambi et al., 2005) in Dorper × Red Massai backcross lambs. In a study on Merinoland and Rhon sheep infected with *Haemonchus contortus*, Gauly et al. (2002) reported negative phenotypic correlations between fecal egg count and hematocrit, −0.41 and −0.33 for Merinoland and −0.21 and −0.34 for Rhon. Also, low estimates of genetic and

phenotypic correlations (–0.21 ± 0.22 and –0.07 ± 0.11) between hematocrit and fecal egg count were reported by Gunia et al. (2011).

Genetic variation in cattle for fecal egg count has been reported in a few studies. Leighton et al. (1989) reported sire differences in fecal egg count in purebred Angus calves. Fecal egg count heritability estimate (0.32 ± 0.16) for Angus cattle was reported by Morris et al. (2003). Gasbarre et al. (1990) also found genetic variation for fecal egg count due to sire ($P < 0.05$) in Angus cattle.

CHAPTER III

MATERIALS AND METHODS

3.1 Objective 1 – Sheep

Animals

One thousand and eight Dorper sheep consisting of 351 lambs and 657 adults were used. These sheep were raised in a private flock in Witibank, Mpumalanga, South Africa. They were sired by 39 rams and out of 264 ewes. Lambs were weaned at approximately 3 mo. Six hundred and seventy–two of these sheep were treated with anthelmintic at least once. Any animal with a FAMACHA score of 3 was immediately treated.

Data collection and description

Data from sheep were collected from 1997 through 2000. The main traits measured were FAMACHA (n = 17,711), hematocrit value (n = 4,209), and fecal egg count (n = 3,759). FAMACHA scores were assigned to individual animals on a scale of 1 to 5, where higher numbers indicate increasingly pale color (healthy is red) of the conjunctiva. Samples of blood were collected from the jugular vein of each animal to determine hematocrit values. Fecal samples, about 5 g, were taken from each animal through the rectum and stored in a sealed plastic bag for fecal egg count analysis. The fecal egg count was log transformed to the tenth base before analyses as an attempt to

normalize the distribution. Table 2 is a summary of data for treated and untreated records.

Table 2. Number of records, and means (SD) for traits by treatment status

	FAMACHA		Hematocrit		Fecal egg count		
Status	n	Mean	n	Mean	n	Mean	Log_{10} (Mean)
Treated	5,169	2.08 (0.77)	1,828	26.59 (4.89)	1,312	2,325.98 (4,741.64)	2.94 (0.55)
Untreated	1,2542	1.83 (0.75)	2,381	27.18 (5.52)	2,447	3,376.44 (6,219.92)	3.12 (0.59)
Total	17,711		4,209		3,759		

Penalization of treated records

Animals with a FAMACHA score of 3 and above were treated with anthelmintics. Since treatment alters the phenotypes of the animals, records of treated animals might be advantaged over those of untreated animals. Where the average of treated records was not better than the average of untreated records, no penalty was applied. Penalties were applied to treated records where their average improved over the

average of the untreated records. For both FAMACHA score and hematocrit values, the average of the treated records was not better than the average of the untreated records (i.e., average untreated record of FAMACHA score was lower and hematocrit value was higher than average of treated records). The treated records were not penalized in this case. However, the average fecal egg count for treated animals was lower than those of untreated animals for all age categories. To apply penalties to treated fecal egg count records, per age category, the difference between treated and untreated averages was calculated, divided by the untreated average and then expressed as a percentage. This percentage decrease was then added as a penalty to treated records in the corresponding age category. Table 3 shows the penalties applied to the fecal egg count records.

Table 3. Penalties for treated fecal egg count records

Age category	Untreated mean	Treated mean	Penalty (%)
Lambs	2,150.54	1,341.50	37.62
Yearlings	1,784.61	1,255.83	29.63
2-yr-olds	1,819.15	497.72	72.64
3-yr-olds	1,539.38	501.87	67.40
4-yr-olds	3,178.18	474.00	85.09
5-yr-olds or older	2,170.42	1,062.92	51.03

Statistical analyses

Single trait animal models were employed using the ASReml (Gilmour et al., 2009) statistical package in order to estimate genetic parameters under alternative parameterizations of the effect of treatment. Fixed effects investigated were year, month (12 levels), sex, age (6 categories, lambs, yearlings, 2-yr-olds, 3-yr-olds, 4-yr-olds, and 5-yr-olds and older), treat (2 levels, treated and untreated) and their interactions while random effects were animal and permanent environment. Data were analyzed in 3 sets: 1) untreated records only; 2) all records, no penalties; and 3) all records, treated records with better averages than untreated penalized by adding the percentage difference (unique to age categories) to the record. After initial analyses, an alternative parameterization of the time effect was evaluated with time grouped into 2 seasons corresponding to the warm (October through March) and cool (April through September) season. Probability values of pairwise comparisons were corrected with Bonferroni adjustments.

3.2 Objective 2 - Steers

Animals

Two hundred and one F_2 and F_3 ½ *Bos indicus* (Nellore) ½ *Bos taurus* (Angus) yearling steers born in 2011 and 2012 at the Texas A&M AgriLife Research Center in McGregor were used. These steers were progeny or grandprogeny of females produced in 14 embryo transfer families, from 4 F_1 Nellore-Angus bulls and 14 cows in a genomics resource population (Hanna et al., 2014). Steers were weaned at approximately 7 months of age and kept on pasture until 12 months of age. As yearlings, steers were transported to a feedlot and kept in 4 different pens. The steers were sired by 18 sires and were not treated for parasites before the study began.

Data collection and description

Records from steers were collected in 2012 and 2013. Some sires had steers in a single year while others had progeny in both years. The simple averages of the traits are presented in Table 4. The traits measured were fecal egg count, birth weight, weaning temperament score, Bovine Viral Diarrhea Virus (BVDV) antibody titer, live weight, and exit velocity. Temperament scores were assigned by 4 evaluators on a scale of 1 through 9 where lower values represented more docile and calm animals and higher values represented more temperamental or bad disposition. Exit velocity (Burrow et al., 1998) was measured in m/s as the rate at which the animals exited the squeeze chute. Samples of blood were collected from the jugular vein of each animal to determine

hematocrit values. Fecal samples, about 5 g were taken from each animal through the rectum and stored in a sealed plastic bag for fecal egg count analysis. Helminth egg counts were determined from fecal samples before treatment with an anthelmintic product to assess inherent differences among individuals. Subsequent to fecal egg count determination, antibody titers in response to BVDV challenge were collected on the yearling steers following vaccination to bovine respiratory disease viral pathogens.

Trait 4. Numbers of records, means (SD) of traits of steers

Trait	N	Mean	SD
Fecal egg count	198	99.50	129.67
Birth weight, kg	199	37.39	7.02
Weaning weight, kg	201	209.78	40.46
Weaning temperament score[1]	195	4.65	1.92
Live weight, kg	201	315.60	37.28
Temperature, °C	199	39.64	0.55
Exit velocity, m/s	196	0.71	3.26
BVDV Antibody titer (log_2)	175	7.65	2.83

[1] Weaning temperament score was recorded by 4 evaluators on a scale of 1-9; 1 representing steers that are docile and 9 for those with bad disposition.

Fecal egg count analyses

The number of fecal eggs per gram (EPG) was determined by the modified McMaster's method (Herd, 1992), with a sensitivity of 25 EPG. Twenty–eight ml of saturated NaCl solution with specific gravity of 1.20 were mixed with 2 g of feces. The mixture was emulsified and then added to specifically designed counting slides with four grids being counted under 100 × magnification. Total number of eggs was multiplied by 25 to achieve EPG. A 5-g Wisconsin double centrifugation test was performed on the sample, with a sensitivity of 0.2 EPG of feces. Five g of feces was mixed with 30 ml of tap water, strained through a single layer of cheese cloth, then centrifuged for 5 min at 1,100 rpm to sediment the eggs and other undigested material. The sediment was then mixed into a sucrose solution with a specific gravity 1.26 in a 15 ml centrifuge tube filled to a positive meniscus; a cover slip was applied then was spun by centrifugation for 10 min at 1500 rpm (Todd et al., 1975).

Statistical analyses

The association of fecal egg count with birth weight, weaning weight, weaning temperament score, live weight, exit velocity, and BVDV antibody titer was assessed by modeling each in distinct analyses as a linear covariate. Year was considered to be a fixed effect and animal was considered to be a random effect. Subsequently, sire was evaluated as a fixed effect to assess genetic variation between sires for fecal egg count. In this analysis, animal was not modeled as a random effect. Sires with less than 3 steers

with records were excluded from the analyses. Fecal egg counts were log transformed to the tenth base before analyses in an attempt to normalize the distribution.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Objective 1 - Sheep

These data contain records of sheep that were considered to be under the influence of anthelmintics for 90 d after treatment. Treatment of animals alters their phenotypes and this may result in analyses with unreliable estimates of genetic parameters. Data were analyzed as 3 sets: 1) records of sheep that were not under the influence of treatment, 2) all records (both treated and untreated) with treatment status modeled as a fixed effect, and 3) all records, but with records of sheep under the influence of treatment with better averages than untreated penalized by adding the percentage difference (unique to age categories) to the record.

Analysis 1 - Records of treated sheep excluded

In these data, there were 12,542 records of FAMACHA score, 2,381 records of hematocrit value and 2,447 records of fecal egg counts.

The effect of time in months was investigated and there were numerous differences for the many levels of this effect, especially in interactions with other main effects. Inspection of simple means suggested that an efficient construction of time would correspond to the conditions that favored or did not favor the proliferation of worm populations. In order to better evaluate the effect of time, time was parameterized

into 2 seasons (warm and cool). The warm season corresponded to October to March while the cool season corresponded to April to September.

Year was a significant fixed effect in all analyses. Two-way interactions of sex, season and age category were significant model components.

An interaction of sex with age category was detected in the analyses of FAMACHA score ($P < 0.001$), hematocrit value ($P < 0.001$) and fecal egg count ($P = 0.041$) (Table 5). Comparisons were limited to sex differences within age categories and age differences within sex. Male lambs and yearlings had lower ($P < 0.001$) FAMACHA score than females of the same age categories. All other age categories did not differ ($P > 0.08$) by sex. There were no differences ($P > 0.09$) found between age categories for males for FAMACHA score. In females, all age categories were different ($P < 0.001$) except lambs, 2-yr-olds, and 3-yr-olds. This suggests that, when sheep are young, their low FAMACHA score may be the result of maternal influence in the form of immunity. Among females, 4-yr-olds had the lowest ($P < 0.001$) FAMACHA score and they were different ($P < 0.001$) from 5-yr-olds or older who had the highest score. Yearlings had higher ($P < 0.001$) FAMACHA score than 2, 3, and 4-yr-olds. There were no FAMACHA records for 4-yr-old males.

Sex differences were not found ($P > 0.01$ after Bonferroni correction) within age categories for hematocrit value. Male yearlings had higher ($P = 0.0007$) hematocrit value than male lambs but no other differences ($P > 0.08$) among males were detected. Three-yr-old and 4-yr-old females had the highest hematocrit values and were different ($P <$

0.001) from female lambs, yearlings and 5-yr-olds or older. Four-yr-olds were also different ($P < 0.001$) from 2-yr-olds. There were no hematocrit records for 3-yr-old and 4-yr-old males.

Sex differences were not found ($P > 0.40$) within age categories for fecal egg count, and there were no differences ($P > 0.18$) found between males. Three-yr-old females had lower ($P < 0.001$) fecal egg count than female lambs. The differences seen in the females could be a result of different physiological stages which impact their response to internal parasites. There were no differences ($P > 0.005$ after Bonferroni correction) for fecal egg count between yearlings, 2-yr-olds, 4-yr-olds, and 5-yr-olds or older. There were no fecal egg count records for 4-yr-olds and males that were 5 yr of age or older.

The higher standard errors in the older males are a result of very few numbers of records. Hence, most significant differences for males are among the younger age categories.

Table 5. Sex-age category means for FAMACHA score, hematocrit value and fecal egg count when treated records were excluded[1]

	n	FAMACHA	n	Hematocrit	n	$\log_{10}$(Fecal egg count)
Male						
Lambs	2,574	1.49 ± 0.06[x]	463	25.97± 0.47[f]	423	3.20 ± 0.04
Yearlings	439	1.43 ± 0.07[x]	85	27.95± 0.69[g]	34	3.06 ± 0.1
2-yr-olds	19	1.36 ± 0.19	3	26.82± 2.94	3	3.33 ± 0.34
3-yr-olds	2	0.88 ± 0.45			1	3.40 ± 0.58
5-yr-olds or older	2	1.54 ± 0.49	1	35.58± 5.39		
Female						
Lambs	2,960	1.62 ± 0.06[ay]	572	27.18 ± 0.41[a]	452	3.17 ± 0.04[a]
Yearlings	1,507	1.81 ± 0.06[by]	315	26.61 ± 0.46[a]	374	3.11 ± 0.04
2-yr-olds	1,037	1.68 ± 0.06[a]	201	27.73 ± 0.54[ab]	210	3.11 ± 0.05
3-yr-olds	513	1.49 ± 0.07[a]	86	29.78 ± 0.75[bc]	89	2.90 ± 0.07[b]
4-yr-olds	196	1.29 ± 0.08[c]	27	31.52 ± 1.14[c]	35	3.00 ± 0.11
5-yr-olds or older	3,293	2.00 ± 0.05[d]	628	26.03 ± 0.34[a]	826	3.11 ± 0.03

[a, b, c, d] Where superscripts are present, age category means for females within a column that do not share a superscript differ ($P < 0.001$).
[f, g] Where superscripts are present, age category means for males within a column that do not share a superscript differ ($P < 0.001$).
[x, y] Sex differences: where superscripts are present, means within age categories that do not share a superscript differ ($P < 0.001$).
[1] Absence of a mean in a cell indicates there were no records.

An interaction of season with sex was detected in analyses of FAMACHA score and hematocrit value ($P < 0.001$), but not in fecal egg count ($P = 0.162$) (Table 6). For FAMACHA score, males were better ($P < 0.001$) than females in both the warm and cool seasons. Both males and females had better ($P < 0.001$) FAMACHA scores in the cool season than in the warm season. This is expected as the warm season corresponds to high worm season and the impact of internal parasites is higher on the animals than in the low worm season.

In the warm season, males and females did not differ ($P = 0.48$) for hematocrit value. However, in the cool season, females had better ($P = 0.026$) hematocrit values than males. The reason for this unexpected result may be associated with the fewer numbers of male hematocrit records than female records. For hematocrit value, both sexes had higher ($P < 0.001$) values in the cool season than in the warm season.

Table 6. Season-sex means for FAMACHA score and hematocrit value when treated records were excluded

Season	Sex	n	FAMACHA	n	Hematocrit
Warm	Male	1,663	1.65 ± 0.06^{ax}	309	26.56 ± 0.56^{x}
	Female	5,772	1.77 ± 0.05^{bx}	1,016	26.90 ± 0.41
Cool	Male	1,373	1.27 ± 0.06^{ay}	243	28.54 ± 0.59^{ay}
	Female	3,734	1.52 ± 0.05^{by}	813	29.74 ± 0.43^{b}

[a, b] Within seasons, means in a column that do not share a common superscript differ ($P < 0.001$).
[x, y] Between seasons, means in a column that do not share a common superscript differ ($P < 0.001$).

An interaction of season by age category was detected in the analyses of all traits ($P < 0.001$) (Table 7). All age categories except 4-yr-olds ($P = 0.49$) had better ($P < 0.001$) FAMACHA score in the cool season than in the warm season. All warm season FAMACHA means differed ($P < 0.001$) except lambs, yearlings and 2-yr-olds ($P > 0.008$ after Bonferroni correction); 4-yr-olds had the best and 5-yr-olds or older had the worst scores. In the cool season, FAMACHA scores were best in the 4-yr-olds and they differed ($P < 0.001$) from yearlings, 2-yr-olds, and 5-yr-olds or older. The 5-yr-olds or older had the worst ($P < 0.001$) scores. Yearlings and 2-yr-olds differed ($P < 0.001$) from lambs and from 3-yr-olds.

Lambs, yearlings and sheep 5 yr age or older had better ($P < 0.001$) hematocrit value in the cool season than in the warm season (Table 7). In the warm season, hematocrit value was best ($P < 0.001$) in the 4-yr-olds which did not differ ($P > 0.003$ after Bonferroni correction) from 2-yr-olds and 3-yr-olds. The 5-yr-olds and older had the worst ($P < 0.001$) hematocrit value but they were not different ($P > 0.01$ after Bonferroni correction) from lambs and yearlings. There were no differences ($P > 0.1$) across all age categories in the cool season.

Two-yr-olds had better ($P < 0.001$) fecal egg count in the warm season than in the cool season. All other age categories did not differ ($P > 0.004$ after Bonferroni correction) between seasons. In the warm season, fecal egg count was best in the 3-yr-olds and worst in the lambs, no probability values met significance criteria after application of the Bonferroni correction. In the cool season, fecal egg count was lowest

($P < 0.001$) in 3-yr-olds and they differed ($P = 0.001$) from 2-yr-olds with the highest ($P < 0.001$) fecal egg count.

Table 7. Season-age category means for FAMACHA score, hematocrit value, and fecal egg count when treated records were excluded

	n	FAMACHA	n	Hematocrit	n	Log_{10} (Fecal egg count)
Warm						
Lambs	3,407	1.75 ± 0.06^{ax}	638	25.18 ± 0.39^{bcx}	678	3.19 ± 0.03
Yearlings	1,143	1.77 ± 0.06^{ax}	211	25.69 ± 0.50^{bcx}	243	3.10 ± 0.05
2-yr-olds	595	1.68 ± 0.06^{ax}	100	26.72 ± 0.65^{ab}	116	2.99 ± 0.06^{x}
3-yr-olds	210	1.50 ± 0.07^{bx}	72	28.51 ± 0.77^{ab}	70	2.94 ± 0.08
4-yr-olds	125	1.27 ± 0.08^{c}	24	30.12 ± 1.17^{a}	21	3.16 ± 0.13
5-yr-olds or older	1,955	2.03 ± 0.05^{dx}	280	24.14 ± 0.46^{cx}	526	3.17 ± 0.04
Cool						
Lambs	2,127	1.32 ± 0.06^{ay}	397	27.98 ± 0.43^{y}	197	3.20 ± 0.05
Yearlings	803	1.61 ± 0.06^{by}	189	27.85 ± 0.50^{y}	165	3.15 ± 0.05
2-yr-olds	461	1.51 ± 0.06^{by}	104	28.39 ± 0.66	97	3.28 ± 0.07^{ay}
3-yr-olds	305	1.29 ± 0.07^{ay}	14	29.13 ± 1.58	20	2.80 ± 0.14^{b}
4-yr-olds	71	1.21 ± 0.09^{a}	3	29.22 ± 2.85	14	2.80 ± 0.16
5-yr-olds or older	1,340	1.82 ± 0.05^{cy}	349	27.25 ± 0.45^{y}	300	3.05 ± 0.04

[a, b, c, d] Within seasons, means within a column that do not share a common superscript differ ($P < 0.001$).
[x, y] Between seasons means within a column that do not share a common superscript differ ($P < 0.001$)

Estimates of genetic parameters

Estimates of heritability and permanent environmental variance as a proportion of phenotypic variance for FAMACHA score, hematocrit value and fecal egg count are shown in Table 8. The estimate of heritability for FAMACHA score was higher than

0.19 ± 0.05 reported by Riley and Van Wyk (2009, 2011) in peak worm challenge conditions in Merino lambs when treated records were excluded. The heritability estimate for hematocrit value was consistent with those reported by Snyman (2007), and Vanimisetti et al. (2004). Fecal egg count had a low heritability estimate which falls within the range of 0.04 to 0.27 reported by Lobo et al. (2009).

Table 8. Estimates of genetic parameters for FAMACHA score, hematocrit value and fecal egg count when treated records were excluded

	h^2	c^2
FAMACHA	0.37 ± 0.03	0.02 ± 0.02
Hematocrit	0.20 ± 0.05	0.18 ± 0.05
Log fecal egg count	0.05 ± 0.03	0.08 ± 0.03

Analysis 2 - Records of treated sheep included

In these data, there were 17,711 records of FAMACHA score, 4,209 of hematocrit value and 3,759 of fecal egg count.

In this set of analyses, treatment status was modeled as a fixed effect. Records within 90 d of treatment for internal parasites were considered to be under the influence of that treatment event. A treatment by sex interaction was detected in the analyses of all traits ($P < 0.001$) (Table 9). FAMACHA score was lower ($P = 0.002$) in treated males than in untreated males, but higher ($P < 0.001$) in treated females than untreated females. Males had lower ($P < 0.001$) FAMACHA score than females in both treatment statuses. The lower male scores are expected as females are known to be more susceptible to infections than males (Silva et al., 2011). Females go through different physiological stages such as pregnancy and lactation, and at such times, the immunity is lowered making them more susceptible to infections.

For hematocrit value, treated males did not differ ($P = 0.5$) from untreated males. In females, treatment did not improve ($P < 0.001$) hematocrit value over untreated records. There was no difference ($P = 0.65$) between treated males and females. Also, untreated males did not differ from untreated females ($P = 0.13$).

Treated males did not differ ($P = 0.22$) from untreated males for fecal egg count while treated females had lower ($P < 0.001$) fecal egg count than untreated females. Treated males had higher ($P < 0.001$) fecal egg count than treated females but no difference ($P = 0.3$) was seen between untreated males and females.

Table 9. Treatment status-sex means for FAMACHA score, hematocrit value, and fecal egg count

	N	FAMACHA	N	Hematocrit	n	Log_{10} (Fecal egg count)
Treated						
Male	1,042	1.39 ± 0.06^{ax}	242	27.00 ± 0.54	197	3.03 ± 0.06^{a}
Female	4,127	1.69 ± 0.05^{bx}	1,586	26.78 ± 0.36^{x}	1,115	2.84 ± 0.03^{bx}
Untreated						
Male	3,036	1.47 ± 0.06^{ay}	552	27.29 ± 0.47	461	3.09 ± 0.04
Female	9,506	1.64 ± 0.05^{by}	1,829	27.90 ± 0.35^{y}	1,986	3.05 ± 0.03^{y}

[a, b] Within treatment status, means in a column that do not share a common superscript differ ($P < 0.001$).
[x, y] Between treatment status, means in a column that do not share a common superscript differ ($P < 0.001$).

An interaction of treatment by season was detected in the analyses of all traits ($P < 0.001$) (Table 10). Regardless of treatment status, as expected, cool season FAMACHA means were lower ($P < 0.001$) than warm season means. Warm season means did not differ ($P = 0.4$) by treatment status. However, untreated cool season records were better ($P = 0.002$) than treated cool season records.

Cool season hematocrit value means were higher ($P < 0.001$) than warm season in both treated and untreated animals. Untreated warm season means were higher ($P < 0.001$) than treated means. In the cool season, untreated hematocrit values were higher ($P < 0.001$) than treated.

Warm season fecal egg count was higher ($P < 0.001$) than cool season. There

was no difference ($P = 0.80$) between seasons in untreated records. Warm season treated records did not differ ($P = 0.80$) from untreated records. In the cool season, treated records were lower ($P < 0.001$) than untreated records.

Table 10. Treatment status-season means for FAMACHA score, hematocrit value, and fecal egg count

	N	FAMACHA	N	Hematocrit	n	Log_{10} (Fecal egg count)
Treated						
Warm	2,346	1.69 ± 0.05^{a}	762	25.72 ± 0.40^{ax}	572	3.11 ± 0.04^{a}
Cool	2,823	1.46 ± 0.05^{bx}	1,066	27.72 ± 0.40^{bx}	740	2.70 ± 0.04^{bx}
Untreated						
Warm	7,435	1.68 ± 0.05^{a}	1,325	26.46 ± 0.36^{ay}	1,654	3.10 ± 0.03
Cool	5,107	1.41 ± 0.05^{by}	1,056	28.97 ± 0.38^{by}	793	3.10 ± 0.03^{y}

[a, b] Within treatment status, means for seasons in a column that do not share a common superscript differ ($P < 0.001$).
[x, y] Between treatment status, means in a column that do not share a common superscript differ ($P < 0.002$).

A treatment by age category interaction was detected in the analyses of all traits ($P < 0.001$) (Table 11). Untreated FAMACHA score of 5-yr-olds or older was lower ($P < 0.001$) than that of treated records. No other age category differences were detected ($P > 0.03$) by treatment status. In the untreated status, lambs did not differ ($P = 0.5$) from 2-

yr-olds but all other age categories differed ($P < 0.001$). The best FAMACHA score in the untreated status was seen in the 4-yr-olds while the worst was in 5-yr-olds or older. In the treated records, 3-yr-olds had the best ($P < 0.001$) FAMACHA score while 5-yr-olds or older had the worst ($P < 0.001$). There were no differences between lambs, yearlings and 2-yr-olds ($P > 0.003$ after Bonferroni correction). There were no treated 4-yr-old records.

Yearlings and 5-yr-olds or older that had not been treated had higher ($P < 0.001$) hematocrit values than those that were treated. Other age categories did not differ ($P > 0.001$ after Bonferroni correction) by treatment status. In the untreated records, 4-yr-olds had the highest ($P < 0.001$) hematocrit value but they were not different ($P = 0.02$ after Bonferroni correction) from the 3-yr-olds. Five-yr-olds and older had the lowest ($P < 0.001$) value but they did not differ ($P > 0.01$ after Bonferroni correction) from lambs, yearlings and 2- yr-olds. Among treated animals, lambs had higher ($P < 0.001$) hematocrit values than yearlings and sheep 5 yr or older; the mean for 5-yr-olds or older was also lower ($P = 0.001$) than 3-yr-old hematocrit value. There were no treated 4-yr-old records.

Lambs, yearlings, 2-yr-olds and 5-yr-olds or older had that were treated had lower ($P < 0.001$) fecal egg count than those that were untreated. There were no treatment status differences for 3- or 4-yr-olds ($P = 0.7$). In the untreated records, 3-yr-olds had the lowest ($P < 0.001$) fecal egg count and they were different from all except 4-yr-olds ($P = 0.41$). The highest ($P < 0.001$) fecal egg count was in the 5-yr-olds and

older and they differed ($P < 0.001$) only from 3-yr-olds. In the treated records, there were no differences ($P > 0.01$ after Bonferroni correction) in age categories.

Table 11. Treatment status-age category means for FAMACHA score, hematocrit value, and fecal egg count

	n	FAMACHA	n	Hematocrit	n	Log_{10} (Fecal egg count)
Untreated						
Lambs	5,534	1.58 ± 0.06^{a}	1,035	26.54 ± 0.33^{a}	875	3.17 ± 0.03^{ax}
Yearlings	1,946	1.68 ± 0.06^{b}	400	26.53 ± 0.39^{ax}	408	3.15 ± 0.04^{ax}
2-yr-olds	1,056	1.56 ± 0.06^{a}	204	27.07 ± 0.49^{ab}	213	3.15 ± 0.05^{ax}
3-yr-olds	515	1.39 ± 0.06^{c}	86	29.02 ± 0.65^{bc}	90	2.90 ± 0.07^{b}
4-yr-olds	196	1.17 ± 0.07^{d}	27	31.38 ± 1.04^{c}	35	2.99 ± 0.10^{ab}
5-yr-olds or older	3,295	1.91 ± 0.05^{ex}	629	25.73 ± 0.36^{ax}	826	3.15 ± 0.03^{ax}
Treated						
Lambs	1,621	1.57 ± 0.06^{a}	558	26.42 ± 0.37^{a}	380	2.98 ± 0.04^{y}
Yearlings	908	1.65 ± 0.06^{a}	393	25.06 ± 0.41^{bcy}	315	3.01 ± 0.04^{y}
2-yr-olds	686	1.60 ± 0.06^{a}	300	25.77 ± 0.47^{abc}	187	2.84 ± 0.05^{y}
3-yr-olds	169	1.27 ± 0.07^{b}	52	27.58 ± 0.80^{ab}	22	2.85 ± 0.12
4-yr-olds					28	2.73 ± 0.12
5-yr-olds or older	1,785	2.02 ± 0.05yc	525	24.30 ± 0.38cy	380	2.97 ± 0.04y

[a, b, ,c, d, e] Means within a column with the same treatment status that do not share a common superscript differ ($P < 0.001$).

[x, y] Means within a column with different treatment status that do not share a common superscript differ ($P < 0.001$).

An interaction of sex by age category was detected in the analyses of all traits ($P < 0.001$). In FAMACHA score, males did not differ ($P > 0.4$) by age category. Male lambs and yearlings had better ($P < 0.001$) FAMACHA scores than ewe lambs and yearlings. No other age categories differed ($P > 0.1$) by sex. All females were different ($P < 0.001$) except lambs and 2-yr-olds ($P = 0.07$). The lowest mean ($P < 0.001$) was for 4-yr-olds and the highest score ($P < 0.001$) was in the 5-yr-olds and older.

Hematocrit values were not different ($P > 0.08$) in males. In the females, 4-yr-olds had the highest ($P < 0.001$) hematocrit value and they differed ($P < 0.001$) from all age categories except the 3-yr-olds ($P = 0.02$ after Bonferroni correction). The lowest ($P < 0.001$) hematocrit value was in the 5-yr-olds or older but they did not differ ($P > 0.004$ after Bonferroni correction) from yearlings and 2-yr-olds. Between the sexes, there were no differences ($P > 0.05$) within age categories.

Males did not differ ($P > 0.6$) by age category for fecal egg count. The major differences are those of younger age categories because the older ones do not have sufficient records. In females, fecal egg count was lowest ($P < 0.001$) in 3-yr-olds and they differed ($P < 0.001$) from lambs, yearlings and 5-yr-olds or older but they did not differ ($P = 0.6$) from 4-yr-olds. The highest ($P < 0.001$) fecal egg count was seen in the lambs but they only differed ($P < 0.001$) from 3-yr-olds. Between the sexes, there were no differences ($P > 0.05$) within age categories.

Table 12. Sex-age category means for FAMACHA score, hematocrit value and fecal egg count when treated records were included

	n	FAMACHA	n	Hematocrit	n	Log_{10} (Fecal egg count)
Male						
Lambs	3,397	1.49 ± 0.06^{x}	686	26.09 ± 0.40	592	3.11 ± 0.03
Yearlings	654	1.47 ± 0.06^{x}	104	26.28 ± 0.60	62	3.14 ± 0.08
2-yr-olds	22	1.41 ± 0.19	3	26.40 ± 2.80	3	3.23 ± 0.33
3-yr-olds	3	1.28 ± 0.37			1	3.35 ± 0.56
5-yr-olds or older	2	1.53 ± 0.49	1	35.00 ± 5.13		
Female						
Lambs	3,758	1.65 ± 0.06^{ay}	907	26.65 ± 0.36^{a}	663	3.04 ± 0.03^{a}
Yearlings	2,200	1.80 ± 0.06^{by}	689	25.94 ± 0.38^{ac}	661	3.03 ± 0.03^{a}
2-yr-olds	1,720	1.70 ± 0.06^{a}	501	26.60 ± 0.42^{ac}	397	2.96 ± 0.04
3-yr-olds	681	1.50 ± 0.06^{c}	138	28.51 ± 0.59^{b}	111	2.78 ± 0.06^{b}
4-yr-olds	196	1.32 ± 0.07^{d}	27	30.94 ± 1.04^{b}	63	2.82 ± 0.08
5-yr-olds or older	5,078	2.05 ± 0.05^{e}	1,153	25.23 ± 0.28^{c}	1,206	3.01 ± 0.02^{a}

[a, b, c, d, e] Means within a column and sex that do not share a common superscript differ ($P < 0.002$).
[x, y] Between sexes, means within a column that do not share a common superscript differ ($P < 0.001$).

The interaction of season and sex was important ($P < 0.001$) in the analyses of all traits (Table 13). For FAMACHA score, males were lower ($P < 0.001$) than females in both seasons, buy they were much better ($P < 0.001$) than females in the cool season than in the warm season.

For hematocrit values, females in the warm season were higher ($P < 0.001$) than males in that season. In the cool season, there was no difference ($P = 0.4$) between males

and females. Both males and females had higher ($P < 0.001$) hematocrit values in the cool season than in the warm season.

In the warm season, males and females did not differ ($P = 0.88$) for fecal egg count but, they were different ($P < 0.001$) in the cool season. Between the seasons, males did not differ ($P = 0.19$) but females had lower ($P < 0.001$) fecal egg count in the cool season than they did in the warm season.

Table 13. Season-sex means for FAMACHA score, hematocrit value and fecal egg count when treated records were included

Season	Sex	n	FAMACHA		Hematocrit	n	Log_{10} (Fecal egg count)
Warm	Male	2,095	1.65 ± 0.06^{ax}	444	25.27 ± 0.49^{ax}	456	3.04 ± 0.04
	Female	7,686	1.78 ± 0.05^{bx}	1,643	26.31 ± 0.35^{bx}	1,770	3.03 ± 0.03^{x}
Cool	Male	1,983	1.28 ± 0.06^{ay}	350	28.75 ± 0.50^{y}	202	3.10 ± 0.05^{a}
	Female	5,947	1.55 ± 0.05^{by}	1,772	28.37 ± 0.37^{y}	1,331	2.86 ± 0.03^{by}

[a, b] Means within a column, within a season that do not share a common superscript differ ($P < 0.001$).
[x, y] Means within a column, between seasons that do not share a common superscript differ ($P < 0.001$).

An interaction of season by age category was detected ($P < 0.001$) in the analyses of all traits (Table 14). For FAMACHA scores, in the warm season, lambs and yearlings were different ($P < 0.001$) from all other age categories. In both seasons, the lowest ($P < 0.001$) and highest ($P < 0.001$) FAMACHA scores were in the 4-yr-olds and 5-yr-olds or older, respectively. Four-yr-olds did not differ ($P > 0.1$) from 3-yr-olds and lambs in the

cool season and, in the warm season, they did not differ ($P > 0.005$ after Bonferroni correction) from 3-yr-olds. Within each age category, there were differences ($P < 0.001$) across the seasons but 3-yr-olds and 4-yr-olds in the warm season did not differ ($P > 0.006$ after Bonferroni correction) from those in the cool season.

For hematocrit value, in the warm season, lambs were not different ($P > 0.5$) from 1-yr-olds and 5-yr-olds and older. The highest hematocrit value was in the 4-yr-olds and they were different ($P < 0.001$) from all age categories except 3-yr-olds ($P = 0.14$). The lowest was in the 5-yr-olds and older but they were not different ($P > 0.006$ after Bonferroni correction) from lambs and 1-yr-olds. In the cool season also, 4-yr-olds had the highest hematocrit value but no probability values met significance criteria after application of the Bonferroni correction. Five-yr-olds and older had the lowest but they only differed ($P < 0.001$) from lambs. Within age categories, lambs, yearlings and 5-yr-olds and older are different ($P < 0.001$) between the seasons but 2-yr-olds, 3-yr-olds and 4-yr-olds did not differ between the seasons ($P > 0.07$).

Warm season fecal egg count of yearlings was different ($P < 0.001$) from 2-yr-olds and 3-yr-olds. The lowest ($P < 0.001$) fecal egg count was in 3-yr-olds while the highest ($P < 0.001$) was in 5-yr-olds or older but they only differed ($P > 0.001$) from 3-yr-olds. In the cool season, there were no differences ($P > 0.002$ after Bonferroni correction) between age categories. Within age categories, only yearlings and 5-yr-olds or older were different ($P < 0.001$) between seasons.

Table 14. Season-age category means for FAMACHA score, hematocrit value and fecal egg count when treated records were included

	n	FAMACHA	n	Hematocrit	n	Log_{10} (Fecal egg count)
Warm						
Lambs	3,956	1.78 ± 0.06^{ax}	916	24.61 ± 0.35^{ax}	889	3.13 ± 0.03^{abc}
Yearlings	1,577	1.77 ± 0.06^{ax}	402	25.25 ± 0.41^{abx}	371	3.18 ± 0.04^{ax}
2-yr-olds	914	1.66 ± 0.06^{bx}	191	26.23 ± 0.50^{b}	170	2.98 ± 0.05^{b}
3-yr-olds	303	1.45 ± 0.07^{cd}	102	28.33 ± 0.64^{cd}	77	2.89 ± 0.07^{c}
4-yr-olds	125	1.27 ± 0.08^{d}	24	29.88 ± 1.07^{d}	23	3.08 ± 0.12^{abc}
5-yr-olds or older	2,906	2.06 ± 0.05^{ex}	452	23.91 ± 0.38^{ax}	696	3.15 ± 0.03^{abx}
Cool						
Lambs	3,199	1.35 ± 0.06^{ay}	677	28.15 ± 0.36^{ay}	366	3.05 ± 0.04
Yearlings	1,277	1.60 ± 0.06^{bcy}	391	26.64 ± 0.41^{bcy}	352	2.98 ± 0.04^{y}
2-yr-olds	828	1.54 ± 0.06^{cy}	313	27.04 ± 0.48^{abc}	230	3.02 ± 0.05
3-yr-olds	381	1.33 ± 0.07^{a}	36	26.74 ± 0.90^{abc}	35	2.78 ± 0.10
4-yr-olds	71	1.24 ± 0.09^{a}	3	28.53 ± 2.70^{abc}	40	2.74 ± 0.10
5-yr-olds or older	2,174	1.87 ± 0.05^{dy}	702	26.12 ± 0.37^{cy}	510	2.96 ± 0.04^{y}

[a, b, c, d, e] Within seasons, means within a column that do not share a common superscript are different ($P < 0.001$).

[x, y] Between seasons, within age category, means within a column that do not share a common superscript are different ($P < 0.001$).

Genetic estimates

Including treated records and modeling treatment as a fixed effect resulted in similar estimates of heritability and permanent environmental variance as a proportion of phenotypic variance (Table 15). In a similar study by Riley and Van Wyk (2009), inclusion of treated records and modeling treatment status as a fixed effect did not

change estimates of heritability. Modeling treatment status as a fixed effect may not be an effective way of handling records of treated animal for the estimation of genetic parameters.

Table 15. Estimates of genetic parameters for FAMACHA score, hematocrit value and fecal egg count when treated records were included

	h^2	c^2
FAMACHA	0.33 ± 0.03	0.03 ± 0.02
Hematocrit	0.19 ± 0.04	0.14 ± 0.04
Log fecal egg count	0.04 ± 0.02	0.07 ± 0.02

Analysis 3 - Records of treated sheep penalized

For both FAMACHA score and hematocrit values, the average of the treated records was not better than the average of the untreated records (i.e., average untreated record of FAMACHA score was lower and hematocrit value was higher than average of treated records). Therefore, only the treated fecal egg count records were penalized by applying the percentage decrease (the difference between treated and untreated averages, divided by the untreated average and then expressed as a percentage) as a penalty to treated records in the corresponding age category.

The effect of treatment by sex interaction on penalized fecal egg count records (Table 16) was similar to when records were not penalized. Males did not differ (P = 0.15) by treatment status. While females did not differ (P = 0.05 after Bonferroni correction) by treatment status in the penalized records, they differed ($P < 0.0001$) when the records were not penalized (Table 9). Treated males had higher (P = 0.002) fecal egg count than treated females but untreated males did not differ (P = 0.19) from untreated females.

Table 16. Treatment status-sex means for penalized fecal egg count records

	n	Log_{10} (Penalized fecal egg count)
Treated		
Male	197	3.18 ± 0.06^{a}
Female	1,115	3.01 ± 0.03^{b}
Untreated		
Male	461	3.11 ± 0.04
Female	1,986	3.06 ± 0.03

[a, b] Within treatment status, means in a column that do not share a common superscript differ ($P < 0.001$).

Warm season records differed ($P < 0.0001$) by treatment status (Table 17) but they did not differ ($P = 0.76$) when fecal egg count records were included without penalization. All other effects of treatment by season interaction were similar to those in the analysis when fecal egg count records were not modified (Table 10).

Table 17. Treatment status-season means for penalized fecal egg count records

Season	n	Log_{10} (Penalized fecal egg count)
Treated		
Warm	572	3.28 ± 0.04^{ax}
Cool	740	2.88 ± 0.04^{bx}
Untreated		
Warm	1,654	3.11 ± 0.03^{y}
Cool	793	3.11 ± 0.03^{y}

[a, b] Within treatment status, means for seasons in a column that do not share a common superscript differ ($P < 0.001$).
[x, y] Between treatment status, means in a column that do not share a common superscript differ ($P < 0.002$).

In the interaction of treatment status by age category ($P < 0.05$), results were similar to when records were included without penalization (Table 11). However, there were no differences ($P > 0.1$) within age categories between treatment statuses (Table 18).

Table 18. Treatment status-age category means for penalized fecal egg count records

	Age category	n	Log_{10} (Penalized fecal egg count)
Untreated	Lambs	875	3.17 ± 0.03^{a}
	Yearlings	408	3.15 ± 0.04^{a}
	2-yr-olds	213	3.15 ± 0.05^{a}
	3-yr-olds	90	2.90 ± 0.07^{b}
	4-yr-olds	35	2.99 ± 0.10^{ab}
	5-yr-olds or older	826	3.15 ± 0.03^{a}
Treated	Lambs	380	3.12 ± 0.04
	Yearlings	315	3.12 ± 0.04
	2-yr-olds	187	3.07 ± 0.05
	3-yr-olds	22	3.07 ± 0.12
	4-yr-olds	28	2.99 ± 0.12
	5-yr-olds or older	380	3.15 ± 0.04

[a, b,] Means within a column with the same treatment status that do not share a common superscript differ ($P < 0.001$).

Similar to when records were included without penalization (Table 12), males did not differ ($P > 0.6$) by age category and there were no differences ($P > 0.05$) between sexes for age categories (Table 19). Three-yr-old ewes had the lowest ($P < 0.0001$) fecal egg count and were different ($P < 0.002$) from lambs, yearlings, and 5-yr-olds or older but not different ($P > 0.002$ after correction) from 2-yr-olds and 4-yr-olds.

Table 19. Sex-age category means for penalized fecal egg count records

Sex	Age categories	n	Log_{10} (Penalized fecal egg count)
Male	Lambs	592	3.19 ± 0.03
	Yearlings	62	3.20 ± 0.08
	2-yr-olds	3	3.31 ± 0.33
	3-yr-olds	1	3.42 ± 0.56
Female	Lambs	663	3.11 ± 0.03[a]
	Yearlings	661	3.09 ± 0.03[a]
	2-yr-olds	397	3.07 ± 0.04
	3-yr-olds	111	2.88 ± 0.06[b]
	4-yr-olds	63	2.95 ± 0.08
	5-yr-olds or older	1,206	3.10 ± 0.02[a]

[a, b] Means within a column that do not share a common superscript differ ($P < 0.002$).

There was a difference ($P < 0.0001$) between sexes in the cool season but no sex difference ($P = 0.8$) was seen in the warm season (Table 20). Males in the warm season did not differ ($P = 0.20$) from those in the cool season. Warm season females were different ($P < 0.0001$) from females in the cool season. These results are similar to those when treated fecal egg count records were included without penalization (Table 13).

Table 20. Season-sex means for penalized fecal egg count records

Season	Sex	n	Log_{10} (Penalized fecal egg count)
Warm	Male	456	3.13 ± 0.04
	Female	1,770	3.12 ± 0.03^{x}
Cool	Male	202	3.19 ± 0.05^{a}
	Female	1,331	2.95 ± 0.03^{by}

[a, b] Means within a column, within a season that do not share a common superscript differ ($P < 0.001$).
[x, y] Means within a column, between seasons that do not share a common superscript differ ($P < 0.001$).

There was an interaction between season and age category ($P < 0.001$). In the warm season, yearlings did not differ ($P = 0.005$ after Bonferroni correction) from 2-yr-olds (Table 21) but they differed ($P < 0.001$) when fecal egg count records were included without penalization. All other comparisons were similar to those in Table 14.

Table 21. Season-age category means for penalized fecal egg count records

Season	Age category	n	Log_{10} (Penalized fecal egg count)
Warm	Lambs	889	3.20 ± 0.03^{abc}
	Yearlings	371	3.24 ± 0.04^{ax}
	2-yr-olds	170	3.08 ± 0.05^{a}
	3-yr-olds	77	2.98 ± 0.07^{c}
	4-yr-olds	23	3.17 ± 0.12^{abc}
	5-yr-olds or older	696	3.24 ± 0.03^{abx}
Cool	Lambs	366	3.12 ± 0.04
	Yearlings	352	3.04 ± 0.04^{y}
	2-yr-olds	230	3.14 ± 0.05
	3-yr-olds	35	2.89 ± 0.10
	4-yr-olds	40	2.88 ± 0.10
	5-yr-olds or older	510	3.05 ± 0.04^{y}

[a, b, c, d, e] Within month, means within a column that do not share a common superscript are different ($P < 0.001$).

[x, y] Between months, within age category, means within a column that do not share a common superscript are different ($P < 0.001$).

Estimates of genetic parameters

Estimates of heritability and permanent environmental variance as a proportion of phenotypic variance for fecal egg count when treated records were penalized were 0.04 ± 0.02 and 0.07 ± 0.02 respectively. These are not different from the estimates when treated fecal egg count records were included in the analysis without any penalties (Table 15). In a similar study by Riley and Van Wyk (2009), penalization of treated fecal egg count records increased the estimate of heritability. This difference in the effect of penalization may be as a result of the unique nature of these data as it includes all age categories. Also, Dorper sheep may be better adapted to the environment so the effect of treatment and penalization may not be as high as in less adapted breeds.

4.2 Objective 2 - Steers

Nematode population

In both years, gastrointestinal nematodes found were predominantly *Cooperia spp*. (64%). Other nematodes included *Haemonchus spp*. (19%), and *Oesophagostomum spp*. (9%). No liver flukes were found. The most predominant, most important cattle internal parasite is *Ostertagia* (Sutherland and Scott, 2010), accounting for most of the losses due to internal parasites in cattle. However, only a small proportion of *Ostertagia spp*. (8%) was found in these steers.

In most herds, it is rare to see infections with only one parasite as there are mostly mixed parasite infections. Levels of parasites in cattle vary from pasture to pasture. Treating the steers with an anthelmintic drug led to a 100% reduction in egg count indicating that there was no anthelmintic resistance in the parasites.

The relationship of fecal egg count with birth weight, weaning weight, weaning temperament score, live weight, exit velocity, and BVDV antibody titer were assessed. Each trait was modeled as a linear covariate in distinct analyses. Year was considered to be a fixed effect and animal was considered to be a random effect. Regression coefficient estimates of modeled covariates are presented in Table 22. None of the covariates were found ($P > 0.2$) to be associated with fecal egg count. Only year explained substantial variation ($P < 0.001$) in fecal egg count.

Table 22. Estimates of regression coefficient and *P*-values for modeled covariates[1, 2]

Trait	Estimate	*P*-value
Birth weight, kg	0.001 ± 0.002	0.555
Weaning weight, kg	0.001 ± 0.001	0.353
Weaning temperament score	–0.007 ± 0.017	0.690
Live weight, kg	0.0002 ± 0.017	0.676
Temperature, °C	0.002 ± 0.017	0.576
Exit velocity, m/s	0.014 ± 0.011	0.209
BVDV antibody titer	0.006 ± 0.013	0.636

[1] Weaning temperament score was recorded by 4 evaluators on a scale of 1-9; 1 representing steers that are docile and 9 for those with bad disposition.
[2] Rectal temperature was recorded at the same time with live weight.

Sire family

After removing sires that had less than 3 progeny with records in the data, the remaining 13 sire families were analyzed for their effect on fecal egg count (Table 23). Two sire families (461T and 032T) had the lowest fecal egg count and were not significantly different from each other. Three families (158U, 539S, and 673S) had the highest fecal egg count means.

The mean for steers sired by 461T (20 EPG) was significantly different from 158U (115 EPG) but not different from any other half-sibling family. The mean for steers sired by 032T (37 EPG) was significantly lower than means for the 3 sire families with the highest EPG.

This result suggests that there is genetic variation for fecal egg count in these crossbred steers. The establishment of fewer worms in 461T and 032T as compared to others is an indication of their ability to suppress the worms. Based on this result, the two sire families are more desirable and would be selected for resistance to internal parasites. Similar results were reported by Leighton et al. (1989) and Gasbarre et al. (1990) who found differences ($P < 0.0002$ and $P < 0.05$ respectively) in fecal egg count as a result of sire in purebred Angus calves. Morris et al. (2003) found genetic variation in Angus cattle for fecal egg count with a heritability estimate of 0.32 ± 0.16.

Table 23. Means of half-sibling families for fecal egg count

Sire	Log transformed	Back transformed (eggs per g)		
	Mean	Mean	.95% C.I. Lower	Upper
128S	1.82 ± 0.10	66	42	104
174U	1.67 ± 0.27	48	14	158
229T	1.67 ± 0.11	48	28	77
297J	1.67 ± 0.18	48	21	105
482T	1.82 ± 0.11	66	40	109
494S	1.83 ± 0.13	68	38	122
497S	1.85 ± 0.14	71	38	133
604S	1.69 ± 0.17	49	23	105
461T	1.31 ± 0.28[ab]	20	6	72
032T	1.57 ± 0.10[a]	37	24	58
158U	2.06 ± 0.20[c]	115	47	283
539S	1.87 ± 0.09[bc]	74	49	111
673S	1.89 ± 0.10[bc]	78	49	122

[a, b, c] Means without a common superscript differ ($P < 0.05$).
Means without superscripts do not differ ($P < 0.05$).

The introduction of non-native cattle with high growth potential in less challenging environments has failed in many instances because of susceptibility to parasites and/or infectious diseases. Studies have been done on variation for fecal egg count in *Bos taurus* but no other study on genetic variation for fecal egg count has been carried out in *Bos indicus* crosses.

CHAPTER V

SUMMARY AND CONCLUSION

5.1 Objective 1 - Estimation of Genetic Parameters for Parasite Resistance in Dorper Sheep

In the three analyses, all interactions between the fixed effects were significant for all traits. Estimates of heritability for FAMACHA score, hematocrit value and fecal egg count when treated records were excluded from the analyses were 0.37 ± 0.03, 0.20 ± 0.05, 0.05 ± 0.03 respectively. Permanent environmental variance as a proportion of phenotypic variance was 0.02 ± 0.02 for FAMACHA score, 0.18 ± 0.05 for hematocrit value and 0.08 ± 0.03 for fecal egg count. Including treated records in the analyses resulted in heritability estimates of 0.33 ± 0.03, 0.19 ± 0.04, 0.04 ± 0.02 for FAMACHA score, hematocrit value and fecal egg counts respectively and permanent environmental variance as a proportion of phenotypic variance was 0.03 ± 0.02 for FAMACHA score, 0.14 ± 0.04 hematocrit value , and 0.07 ± 0.02 for fecal egg count. Penalization of treated fecal egg count records did not change the estimates of heritability and permanent environmental variance as a proportion of phenotypic variance.

The inclusion of young and mature animals with records in this data and the repeated records structure across the year makes it different from other studies. Also, Dorper sheep may be relatively more adapted to this environment suggesting that

variation also exists in more adapted sheep breeds and selection for resistance to internal parasites can be carried out in such breeds.

5.2 Objective 2 - Genetic Variation for Fecal Egg Count in *Bos indicus-Bos taurus* Cattle

In the steers, no association was found between fecal egg count and birth weight, weaning weight, weaning temperament score, live weight, temperature and exit velocity. A lack of detection of relationship between fecal egg count and other traits may be as a result of the small data set. The only significant explanatory variable was year. Two sire families had lower ($P < 0.05$) fecal egg count (1.31 ± 0.28 and 1.57 ± 0.10) than the three sire families with the highest fecal egg count (1.87 ± 0.10 - 2.06 ± 0.20) suggesting the presence of additive genetic variation for fecal egg count. This implies that selection can be carried out for the ability to suppress parasite worms in cattle. Studies on the additive genetic variation in cattle for fecal egg count have been done in *Bos taurus* but no other study has been done in *Bos* indicus crosses. More studies will be needed to investigate the additive genetic variation for resistance to internal parasites especially in *Bos taurus* – *Bos indicus* crosses.

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