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STUDIES OF THE FLOCK MATING PERFORMANCE
OF
BOORoola MERINO CROSSBRED RAM LAMBS,
AND THE
FOOT "CONDITIONS" IN BOORoola MERINO CROSSBREDS
AND
PERENDALE SHEEP
GRAZED ON HILL COUNTRY

A THESIS PRESENTED IN PARTIAL
FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF AGRICULTURAL SCIENCE
IN ANIMAL SCIENCE AT
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MOHAMMED TAHA ALWAN
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MASSEY UNIVERSITY
PALMERSTON NORTH, NEW ZEALAND

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ABSTRACT

Two studies using the Booroola Merino crossbred animals were conducted. In the first, the flock mating performance of Booroola Merino-Romney crossbred ram lambs mated to Perendale ewes was examined. The second study comprised observations on the incidence of foot "conditions" in young Booroola Merino crossbreds and Perendale sheep grazed on hill country.

MATING PERFORMANCE

Eighteen Booroola Merino x Romney ram lambs^b (6 control, 12 mating group) were selected according to weaning weight, fleece characteristics and general body condition. Nine ram lambs were exposed to ewes prior to mating for two weeks (trained) and nine kept separate from any ewes (untrained). The ram lambs of the mating group (6 trained, 6 untrained) were allocated to six groups of ewes which were "single-sire" mated. Groups 1, 2, 3, 4 comprised 140 ewes each and Groups 5 and 6 comprised 100 ewes each. The ram lambs were changed after eight, eight, seven and seven days of mating, Periods P₁, P₂, P₃ and P₄ respectively, and a total of 12 "single-sire" mating groups generated. All ram lambs produced a satisfactory semen sample before joining with the flocks. Mating commenced on 30 March 1981.

The flock mating performance of each ram lamb was assessed by recording the percentage of ewes raddled, percentage of ewes returning to service, percentage of pregnant ewes, percentage of ewes lambing, docking rate and weaning rate. Differences among each of these parameters were attributed to various factors. Trained and un-

trained ram lambs were similar in most of the observed parameters of flock mating performance. There were no differences between individual ram lambs within each sire-group (trained or untrained) in mating performance. There were differences in the percentage of ewes raddled between first and second oestrous cycle of mating ($P < 0.001$).

Live weights of the ram lambs were measured from weaning (December 1980) until the end of the trial (December 1981), at weekly intervals during the mating periods and at monthly intervals during the post-mating and post-shearing periods. There was little loss in the mean live weight of the mating group ram lambs after P_1 . Overall the live weights of both groups increased consistently throughout the trial.

Semen samples (collected by electro-ejaculation) from the ram lambs of the mating group were microscopically examined for general motility after each mating period at least for three days. Recovery from mating exhaustion occurred four and six days after P_1 and P_2 respectively, while three and two days were required after P_3 and P_4 respectively.

Semen samples were also collected on two occasions from the rams (only 15) as two-tooths and examined for general motility, sperm concentration and percentage of live sperm. There were no differences in semen characteristics between rams of the mated and control groups.

The two-tooth rams were also subjected individually and randomly

on three occasions to pen-libido tests, each with two oestrous ewes. Mating ability was assessed by recording the number of mounts attempted on the oestrous ewes, the number of services, the reaction time to mount (in seconds) and the reaction time to service. There were no differences between the mating and control groups in the number of mounts and number of services performed on each occasion of the libido test. Significant differences were found between both groups in reaction time to mount ($P < 0.01$) and in reaction time to service ($P < 0.05$) but only at the first libido test.

It was concluded that the Booroola Merino x Romney ram lambs had achieved satisfactory levels of flock mating performance under the conditions of the trial. No adverse effects of mating on the post-mating body development of the ram lamb could be detected. Semen quality from the ram lambs deteriorated during mating but recovered shortly after mating. The use of ram lambs as sires had no adverse effects on their semen characteristics and libido performance at the two-tooth age.

FOOT "CONDITIONS"

The incidence of abnormal foot shape, foot scald and footrot was observed in Perendale and Booroola Merino crossbreds. The animals were generated in 1980 and 1981. Observations on foot "conditions" were made at the lamb, hogget and two-tooth ages for animals born in 1980, and at the lamb and hogget ages for those born in 1981. A scoring system was used to rank the various foot "conditions" (shape; scald; footrot) which were assessed separately.

Booroola Merino crossbreds showed significantly a higher incidence of abnormal foot shape, foot scald and footrot than did Perendale sheep. Significant differences in foot "conditions" were also found between (Booroola x Romney) x Perendale and Booroola x Romney sheep. Sires of the progeny generated in 1980 and 1981 provided a major source for the variation in the incidence of these foot "conditions".

Estimates of heritability of each of the observed foot "conditions" were calculated at different ages (lamb, hogget and two-tooth).

Sex of the lamb caused significant effects on the incidence of abnormal foot shape ($P < 0.05$) and foot scald ($P < 0.001$) between ram lambs and ewe lambs, but not on the incidence of footrot.

Differences in the incidence of abnormal foot shape and foot scald occurred between 1980- and 1981-born sheep. These differences were attributed partly to the particular climatic conditions in each year (notably the annual rainfall).

It was concluded that under environmental conditions similar to that of the present trial, long-term selection programmes could be applied to enhance the natural resistance of sheep against foot diseases.

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CHAPTER ONE

GENERAL INTRODUCTION

The role of rams in the sheep industry directly affects both the number of progeny each year and the genetic make-up of the future breeding flock. Most of the rams used are two-tooth and older animals. In New Zealand the use of ram lambs as sires is becoming increasingly widespread as more farmers recognize the potential and unused capacity that exists in these young animals, especially if they are likely to be of high genetic merit. There seems to be no reason why this trend should not continue provided it can be shown that these animals can achieve satisfactory fertility. The reasons given by farmers for not mating immature rams at least until 18 months of age, appear to be the likelihood of an excessive weight loss during mating and also that the reproductive performance in future years would be adversely affected. Experimental data exists on some of these points, but it appears from farmer experience and trial work that there are no great disadvantages of mating ram lambs provided that not too high a ewe : ram ratio is used.

The recent use of Booroola Merino sires is being carried out mainly to increase the level of fecundity in some flocks by incorporating new "blood" into the local sheep. The Booroola Merino sheep (Turner, 1969) has high reproductive performance (see Cleverdon, 1980) and its performance when crossed with New Zealand sheep has yet to be assessed under a variety of conditions. While reproductive performance might be improved in the crossbred, it is also important to ensure that other characteristics of the sheep are not detrimentally

affected. Changes in wool production might be expected and may be acceptable. Even more important may be characteristics such as susceptibility to foot "problems" which might not be tolerated if considerable foot-paring and other husbandry procedures have to be adopted to achieve good productivity. It is evident that Booroola Merino crossbred animals should be evaluated for a range of characteristics in various environments.

At "Tuapaka" sheep farm, a long term trial to incorporate Booroola genes into part of the Perendale flock of ewes, has been established. The objectives of trial are:

- (i) to study the effect of an infusion of genes of Booroola Merino origin on the performance of sheep run on North Island hill country;
- (ii) to study the incidence of problems such as footrot, fleece rot and fly strike, traditionally associated with Merino-cross sheep grazed in damp conditions;
- (iii) to study whether the infusion of genes of Booroola Merino origin allows greater response to selection for fertility and higher fleece weight coupled with finer wool than can be achieved in a Perendale flock.

As part of the foregoing objectives, the present study was

undertaken to provide some information on the mating performance, libido and semen characteristics of Booroola cross ram lambs generated from the first matings of the Booroola sires and Romney ewes in 1980.

The second objective was to study the incidence of abnormal foot shape, foot scald and footrot in the Booroola cross offspring which were generated in the first two years of the programme.

SECTION I

A STUDY
OF THE
FLOCK MATING PERFORMANCE
OF
BOORoola MERINO CROSSBRED
RAM LAMBS

* * * * *

CHAPTER TWO

REVIEW OF LITERATURE

A - PUBERTY IN THE RAM LAMB

1 - Introduction

Rams account for only about 3% of total flock numbers and the exploitation of early sexual maturity in ram lambs can not give the same economic advantages as breeding from ewe lambs. Nevertheless, the satisfactory attainment of puberty in ram lambs is important in husbandry practice for a very high proportion of ram lambs kept for breeding begin work in their first autumn. Moreover, where selected ram lambs are used in breeding programmes on performance and progeny testing, the generation interval is reduced and information is obtained on the ram at the earliest possible age, especially if his daughters are in turn bred as ewe lambs. Such a practice may facilitate the earlier selection and use of outstanding sires and consequently the rate of genetic improvement is likely to be accelerated (Terrill, 1938; Gjedrem, 1969; Joakimsen, 1969; Nearland, 1970; McDonald, 1974).

While there are many advantages in using ram lambs as sires, there are also some disadvantages. One disadvantage is that at an early age the assessment of wool characteristics is not as accurate and, therefore, farmers prefer to select rams for breeding purposes when the wool can be better described, such as after hogget shearing. The lower mating capacity of young rams compared to mature rams (Clarke *et al.*, 1966; Lightfoot, 1968; Lightfoot and Smith, 1968) is also a disadvantage. However, if ram lambs are mated singly or

in one age group, then it appears that their mating capacity is much better than when they are mixed with older rams (Dyrmundsson, 1973). The former system of mating would avoid the effects due to dominance and subordination of rams associated with mixed-age sires (Hulet *et al.*, 1962a; Hafez *et al.*, 1969).

Puberty in the male is often defined as the time at which reproduction first becomes possible, and spermatozoa are released (Dyrmundsson, 1973). At this stage the sexual organs have developed sufficiently to function. The animal will exhibit mating desire or sexual behaviour, and reproduction can occur. Puberty in the male is not easy to record precisely because it is the result of gradual changes related to body development, and involves responses affecting the Central Nervous System and reproductive system.

In the ram lamb puberty is associated with a marked increase in endocrine function, the onset of spermatogenesis and subsequently with the manifestation of full sexual behaviour. The developments are accompanied by certain anatomical changes in the reproductive organs as described by many workers (e.g. Watson *et al.*, 1956; Skinner *et al.*, 1968; Skinner and Rowson, 1968; Dyrmundsson and Lees, 1972a, b).

2 - Anatomical Changes

The attainment of puberty may be defined in several ways as follows:

- (i) Such as in terms of the stage of development when

mature and viable spermatozoa are first produced and released in the gonads (Dyrmundsson and Lees, 1972a, b). This could be done both by serialised castration and by semen collection by electro-ejaculation.

- (ii) Observation can be made on the development of the male reproductive organs. Certain anatomical changes must take place in external male reproductive organs before spermatozoa are released. Such developments proceed gradually under the control of the male hormone testosterone, which is secreted at an increasing rate prior to puberty (Skinner *et al.*, 1968). Normal development is that each testes must descend into the scrotum. The penis's adhesions gradually break down, so that it becomes freely movable. In the immature lamb, the glans penis and the processes urethrae are completely adherent to the prepuce, but at puberty these become detached. Most studies suggest that this freeing of the penis is more closely related to the growth rate of the animal than its age (Wiggins and Terrill, 1953; Dun, 1955; Watson *et al.*, 1956). Dun (1955) considered these anatomical changes to be sufficiently important in carrying out an assessment of the young ram by examination of the testes and penis. He stated that "A freely

movable penis combined with plump firm testes indicate that puberty has been reached".

- (iii) Sexual maturity is defined in terms of the lamb's willingness to mate with adult ewes known to be strongly oestrus. Sexual maturity or full reproductive capacity is reached at a later age. As such, puberty in the young ram is not synonymous with sexual maturity (Dyrmundsson, 1973).

These phenomena are not contemporaneous and physiological puberty preceded the first copulation often by several weeks. Thus the attainment of puberty in the ram cannot be measured as simply and as accurately as in the ewe lamb. Dyrmundsson (1973) has emphasized the importance when comparing reports of considering the criteria on which the definition of puberty may have been based.

In summary, therefore, puberty marks that time in an animal's life when it attains breeding capability. At this stage, the androgens are produced, sperm are, and the reproductive organs have matured so that the penis is free of its sheath, permitting the ram lamb to serve and impregnate the ewes.

3 - Factors Affecting the Attainment of Puberty

The initial hormonal stimulus for puberty begins in the hypothalamus where the gonadotropic releasing hormone (GNRH) is produced. This stimulates the anterior pituitary gland to secrete

follicle stimulating hormone (FSH), which then acts to sensitize the testes to interstitial cell stimulating hormone (ICSH). Androgens in turn are produced by the testes. These hormone interplay results in puberty (Kragt and Masken, 1972; Ortavant *et al.*, 1977; Mattner, 1980). Androgens and gonadotropins initiate spermatogenesis, androgens stimulate growth of the penis and accessory glands and finally libido occurs. Secondary sex characteristics appear rapidly as puberty approaches and the androgen level rises. Other factors which may affect between animal variation in attainment of puberty are reviewed below.

(a) Age and body weight

It is generally accepted that body weight is the most important parameter in determining sexual development of ram lambs. The development of a ram lamb as reflected in its growth rate and subsequently body weight is usually a better guide to puberty than its age (Dun, 1955; Watson *et al.*, 1956; Symington, 1961; Pretorius and Marincowitz, 1968; Dyrmondsson and Lees, 1972b; Ortavan^t *et al.*, 1977; Sorensen, Jr., 1979; Lees, 1979).

The volume and the weight of the testes as well as the volume and diameter of the seminiferous tubules also show a closer relationship with body weight than with age (Carmon and Green, 1952; Watson *et al.*, 1956; Skinner *et al.*, 1968; Colyer, 1971). The freeing of the penis was found to be more dependent on the growth rate than on the advancement in the age (Johnstone, 1948; Wiggins and Terrill, 1953; Dun, 1955; Watson *et al.*, 1956; Belonje, 1965; Skinner and Rowson, 1968; Pretorius and Marincowitz, 1968; Dyrmondsson, 1972).

Singles are likely to attain puberty earlier than twins in all above aspects (Lees, 1979).

Dyrmundsson and Lees (1972b) studied the effect of early and late born Clun Forest ram lambs on attainment of puberty. Table 2.1 and Figure 2.1 show the parameters involved in their study. Marked variation was shown in the age and body weight at which spermatozoa were found in the epididymis at castration. While the majority of lambs reached this stage of development at $4\frac{1}{2}$ - 5 months, the age range for 52 ram lambs was 99 - 176 days. The mean body weight at puberty was 32.5 kg with a range of 24.5 to 38 kg or 35 - 45% of adult body weight.

Courot (1961) has reported that, while at birth the seminiferous tubules occupied only 50% of the testicular volume in the ram lamb, this increased to 80% at puberty. A close relationship was found between testes weight increase and both weight and contents of accessory glands (Skinner *et al.*, 1968). The weight of the epididymis is highly correlated with testicular weight and body weight (Watson *et al.*, 1956; Dyrmundsson and Lees, 1972b). Lees (1978) concluded that correlation coefficients between various parameters of anatomical sexual development and both age and body weight showed such development to be more closely related to body growth than to age.

The effect of age on puberty attainment cannot be ignored although it seems less important than body weight. Lees (1979) reported that, in some cases ram lambs which had grown at a fast rate and had well developed testes, had no spermatozoa present in the

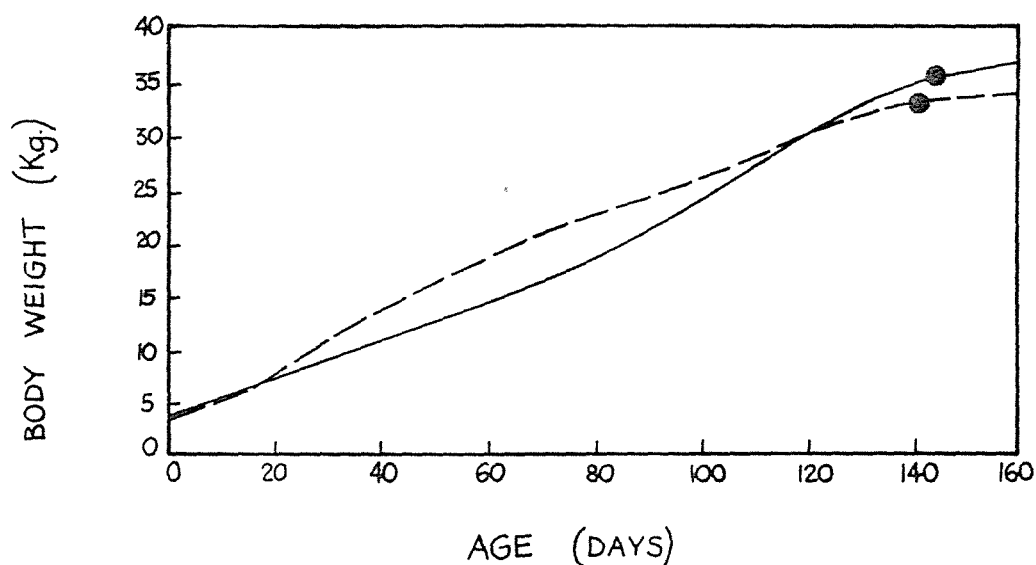


FIG 2.1 MEAN GROWTH RATES OF EARLY AND LATE-BORN RAM LAMBS FROM BIRTH TO 160 DAYS OF AGE. —, EARLY-BORN; ---, LATE-BORN; ● MEAN AGE AND BODY WEIGHT AT PUBERTY. (ADAPTED FROM DYRMUNDSSON AND LEES, 1972b).

TABLE 2.1 A COMPARISON BETWEEN 28 EARLY AND 26 LATE-BORN RAM LAMBS (MEAN DATA) (Adapted from Dyrmundsson and Lees, 1972b).

PARAMETER	EARLY BORN	LATE BORN
Birth date	14 January	3 April
Date of puberty	9 June	23 August
Age	145 days	142 days
Body weight	33.7 kg	31.1 kg
Testes weight	149.1 g	175.9 g
Epididymis weight	20.6 g	20.9 g

epididymis when castration took place at heavy body weight but early ages. Thus, Lees (1979) suggested that "...a certain limit of chronological age below which puberty is not attained, irrespective of body and testicular weights etc."

A description of the weight and other characteristics of ram lambs at puberty can be given in relation to the body or size of mature rams. Thus, as an example, 168-day Suffolk rams which had reached puberty were 65% of mature body weight and the testes were 81% of mature size (Skinner and Rowson, 1968). McDonald (1974) stated that, after puberty the growth rate of testes decreases while the increase in the size and volume of the accessory organs is related to increased semen production and the animal eventually became sexually mature.

(b) Genetic

Genetic differences may play an important role in attainment of puberty in ram lambs through hormone production and release (Sorensen, Jr, 1979).

The literature which was summarised and tabulated by Dyrmondsson (1973) clearly shows that there are marked differences in puberal age and body weight between ram lambs of various breeds, and genetic factors may account for some of these variations. The youngest quoted age at which puberty occurred was 99 days, this being for a Clun Forest ram lamb. The oldest age recorded was 456 days for a ram lamb of the Rahmani breed, in Egypt. The most commonly quoted ages fall between 150 - 200 days. So, in general, in most breeds of

sheep, male puberty is reached during the fifth, sixth or seventh month of age. McDonald (1974) stated that, some observations suggest that in prolific breeds, the ram lambs exhibit vigorous mating activity at an early age and that testes weights and diameters are greater than in animals of less prolific breeds.

It was shown that penis development tended to be retarded by inbreeding (Wiggins and Terrill, 1953). Genetic factors may also account for some of the variation within breed. Great differences among Clun Forest ram lambs were reported in age and in both testicular and epididymal weights at puberty, even where birth dates and growth rates were carefully standardised (Dyrmundsson and Lees, 1972b).

No literature exists concerning the use of early attainment of puberty in ram lambs in a direct selection programme in order to increase flock fertility. But selection for increased testes size or sperm production leads to an increase in the flock fertility (Land, 1973). Conversely, recent work with a New Zealand Romney flock shows that selection for fertility and fecundity has increased the ram lambs' testes diameters and weights (Knight, 1982). Also, there was an increase in the number of sperm in the testes and epididymides of the ram lambs.

(c) Nutrition

In general, nutrition is important and may even be the major factor leading to the onset of puberty. Overfeeding hastens puberty, while underfeeding delays it. Nutrition influences hormonal

initiation and therefore may bring about the various phenomena previously discussed. The effects of nutrition on endocrine function and sexual development are fully discussed by Rattray (1977).

Nutritional effects have been studied in relation to total digestible nutrients, energy, protein and numerous other components. Most researchers have used a high level and a low level of nutrients to compare with the recommended nutrient needs for normal growth and development.

An adequate plane of nutrition is clearly important for the early sexual development of the ram lamb. Many workers have concluded that in the young and growing male, nutritive deficiency (notably, low energy intake) will retard sexual development and lead to some delay in the onset of puberty (Marshall and Hammond, 1952; Mann, 1964; Donovan and Ten Bosch, 1965; Rattray, 1977). Ragab *et al.* (1966) and Pretorius and Marincowitz (1968) working with animals under controlled feeding conditions, found that ram lambs fed at a higher level were heavier and reached puberty earlier than those on a lower level of feeding. Other studies have demonstrated the effect of fluctuations in nutritional conditions during rearing, mainly as a result of variation in pasture growth and quality (see review of Moule, 1970). Some authors have, therefore, pointed out that, this would appear likely to influence sexual development in ram lambs (Skinner and Rowson, 1968; Dyrmondsson and Lees, 1972b), through the relationship between date or season of birth and grazing conditions.

It was found that under conditions of inadequate or poor nutrition there was a lack of gonadotrophin from the hypophysis, though the testes will usually continue to produce testosterone (Mann, 1964), thus the androgenic function is retarded more markedly than is spermatogenesis (Mann *et al.*, 1967; Skinner and Rowson, 1968). Conversely, in very well fed and rapidly growing lambs, it appears that androgenic function is preferentially advanced (Dyrmundsson and Lees, 1972b).

Dyrmundsson (1973) and Rattray (1977) reviewed some of the early work on nutritional deficiency as it influences sexual development in ram lambs. Besides the influences of lower levels of energy and protein intake, there is evidence that deficiency of certain vitamins and minerals may adversely affect the reproductive process, e.g. Vitamin A and Zinc deficiencies are known to severely impair sexual maturation in ram lambs. Underwood and Somers (1969) showed that low levels of zinc (c. 15 ppm) fed to rams resulted in testes that were about half the size of those of rams fed more zinc (c. 30 ppm). However, the lower level of zinc had no detectable effect on body growth and development.

(d) Date of birth

Table 2.1 shows that late-born ram lambs had a much heavier mean testes weight at puberty than early-born ram lambs despite their lower mean age and body weight at this stage of development. After correction for age and body weight at puberty, month of birth was still a highly significant factor (Lees, 1979). Moreover, Skinner and Rowson (1968) have noted a greater accessory gland development in

late-born (summer) than in early-born (spring) ram lambs. This was suggestive of a seasonal influence on sexual development, but the number of lambs studied was small.

(e) Daylight and temperature

There appears to be no direct evidence of a relationship between photoperiodism and onset of puberty in ram lambs. Skinner and Rowson (1968) have suggested that such a relationship may exist and the results obtained by Dyrmondsson (1972) and Dyrmondsson and Lees (1972a, b) do not preclude the possibility that apart from seasonal fluctuations in nutritional conditions during rearing, other factors such as the natural light environment might have influenced the sexual development and libido of ram lambs. Furthermore, there is also work which indicates that a decline in the hours of light generally appears to enhance sexual performance in ram lambs (Dyrmondsson, 1973).

No information has been recorded regarding a possible relationship between environmental temperature and puberty attainment in ram lambs. But, Hafez (1964) reported that breeds from Tropical and Sub-tropical regions attain puberty later than breeds of Temperate regions. However, it should be borne in mind that such a delay in attainment of puberty is not only a function of high environmental temperature but rather a combination of many factors (e.g. genetic, nutrition, hormonal).

It seems that in mature rams daylight and temperature have some effect on semen production as well as on libido and consequently

cause a reduction in the flock fertility (see review of Holmes, 1979). Moule (1950) observed that rams confined in a darkened room during spring became much more interested and active in mating than rams in normal light. McFarlane (1963) pointed out that, in spite of some defects in sperm resulting from high temperatures, the libido of rams is not as dependent on temperature as on the influence of photo period. More details will be given later in the relevant section.

4 - Semen Production

The quantity and quality of spermatozoa ejaculated by pubescent ram lambs in general are relatively poor as compared to that of mature rams (Terrill, 1938; Dyrmondsson and Lees, 1972b). The latter authors have shown that, the concentration of sperm in smears taken at puberty from epididymides after castration is very low, and even lower in the ejaculates collected by electro-ejaculation.

Symington (1961), Louw and Joubert (1964) and Skinner and Rowson (1968) have demonstrated marked increases in ejaculate volume, concentration of spermatozoa, percentage of normal sperm and percentage of live sperm of ram lamb semen after puberty is attained. Thus, there is a rapid improvement in the fertilizing potential of the semen with advancing age and more mature body development (Terrill, 1938; Dun, 1955; Watson *et al.*, 1956; Symington, 1961; Louw and Joubert, 1964; Skinner and Rowson, 1968; Alwan, 1980).

Ejaculates may be collected by electro-ejaculation before adhesions between the penis and the prepuce have completely broken down. Dyrmondsson (1973) suggested it is possible to study the same

animal repeatedly for extended periods. The secretions from the accessory glands and the testes can be examined chemically and the results related to endocrine function and sexual development (Skinner and Rowson, 1968; Skinner *et al.*, 1968).

5 - Mating Behaviour

Pre-puberal mounting of both a hetero- and homosexual nature occurs commonly among ram lambs (Symington, 1961; Banks, 1964; Louw and Joubert, 1964; Ragab *et al.*, 1966; Dyrmondsson, 1972). Scott (1945) termed these attempts as "play activity". Occasionally the orientation of the ram lamb during the mount is not normal, such as the ram mounting the side or head end of its flock mate (Banks, 1964). "Nudge", "Nuzzle" and "Nose" displays are also shown by the ram lamb when introduced to the oestrous ewes. Nosing of the udder region and even nuzzling of the teats are other displays sometimes observed (Banks, 1964; Dyrmondsson and Lees, 1972a).

Dyrmondsson and Lees (1972a) studied the mating behaviour of Clun Forest ram lambs from 140 days of age and introduced individually at 14 day intervals to adult oestrous Clun Forest ewes. They noted that at each introduction to ewes in oestrus, the ram lambs exhibited widely varying degrees of libido ranging from a total lack of heterosexual interest to intense mounting activity resulting eventually in successful mating. Even so, these ram lambs were rarely able to copulate successfully on first introduction to an oestrous ewe, but mating dexterity of the ram lambs improved gradually with experience as the number of sexual encounters increased. This was emphasized in a study of three breeds of ram lambs (Romney, Perendale and

Drysdale), which showed that mating ability was enhanced with advancement in the age and experience (Alwan, 1980).

Also, Dyrmondsson and Lees (1972a) have reported that puberty in Clun Forest ram lambs was attained at 35 - 45% of adult body weight, while the majority of ram lambs copulated when they reached approximately 40 - 50% of adult body weight.

When introduced to ewes in oestrus, ram lambs showed preference for individual ewes and the most sexually^{active} ram lambs were the most selective (Rouger, 1969). However, Dyrmondsson (1972) observed that ram lambs being relatively small in stature, may sometimes experience difficulty in mating with mature ewes.

Studies concerning the homosexual activity amongst rams have shown that such activity seems common among ram lambs and there is some evidence to suggest that it may interfere with the establishment of normal heterosexual mating behaviour, especially when the ram lambs are reared in large groups (Hulet *et al.*, 1964; Banks, 1964; Hulet, 1966; Marincowitz *et al.*, 1966; Pretorius, 1967; Mattner *et al.*, 1971). Furthermore, Dyrmondsson and Lees (1972a) noted that homosexual behaviour was common among the very well grown and early-born ram lambs, but it did not interfere with the establishment of normal heterosexual mating.

The effect of dominance among rams on their mating behaviour has been studied extensively by many workers (Lambourne, 1956; Lindsay and Robinson, 1961a, b; Hulet *et al.*, 1962a, b). However,

it is generally known that mature rams are normally dominant over young rams. Dominance among ram lambs also was observed (Shreffler and Hohenboken, 1974). Hence, Dyrmundsson (1973) suggested that, if ram lambs are mated singly or in one-age group, then it seems that their mating efficiency is much better than when they are mixed with older rams.

6 - Use of Ram Lambs as Sires

Dyrmundsson (1973) has summarised much of the literature available on the use of ram lambs either by natural mating or artificial breeding. Generally, young rams have a lower breeding capacity than mature rams (Lightfoot, 1968; Lightfoot and Smith, 1968; Crocker and Lindsay, 1972), and the common practice of joining a smaller number of ewes to ram lambs than to older rams appears to be highly desirable (Terrill, 1938). There is no information however on differences in breeding capacity between individual ram lambs. But, Lees (1978) noted that marked differences in breeding capacity were shown among adult rams, given a series of controlled mating loads, and in certain cases sub-normal breeding capacity has almost certainly been inherent in the animal since puberty. McDonald (1974) reported some differences between ram lambs, based on the percentage of ewes not returned to heat in succeeding 34-day period of mating.

In New Zealand, observation by some farmers on the use of ram lambs as sires, suggests that good conception results can be obtained (McDonald, 1974). Experimental data provided by Watt (1974) has also indicated a satisfactory mating capacity of ram lambs when mated with synchronized oestrous ewes (especially at second oestrus after treat-

ment). However, Clarke (1966) noted that where large number of ewes were exhibiting oestrus simultaneously, ram lambs were less effective in detecting heat and mating, than yearling rams.

In general, it can be concluded that a good level of fertility will be obtained when young rams which produce semen of reasonable quality, are used in breeding either by natural mating or artificial insemination. Furthermore, the lambs sired by ram lambs are comparable with those of adult rams in terms of general body growth and vigour (Wiggins *et al.*, 1954).

McDonald (1974) reported the use of ram lamb to ewe ratios of from 1 : 30 to even up to 1 : >100. The length of the mating period for ram lambs should preferably be short (25 - 30 days). Furthermore, Southam *et al.* (1971) used ram lambs, as teasers, and had satisfactory results with two to a maximum of 80 ewe lambs.

Dyrmundsson and Lees (1972a) have reported varying degrees of abnormal testicular development among a small proportion of ram lambs at first mating, such individual lambs, although partly or completely sterile, had normal body growth and fully developed penes and copulated successfully with ewes in oestrus. A decline in the testicular development also was reported in mature rams (Simpson and Edey, 1979) as will be explained later.

The use of ram lambs as sires does not appear to have any adverse effect on their subsequent growth and development (Dyrmundsson, 1973; Lees, 1979). However, the extent to which early breeding from ram

lambs may affect their reproductive performance throughout adult life, does not seem to have been examined.

B - LIBIDO AND MATING PERFORMANCE

1 - Introduction

Generally mating behaviour and libido in most farm animals may be defined as: (Chenoweth, 1981),

Mating behaviour: "The behaviour of the male animal
in the periods immediately before,
during and after service."

Libido: "The willingness and eagerness of a
male animal to mount and attempt
service of a female."

The first term describes all the sexual behaviour patterns which are concerned with the willingness of the male to mate the female. Hence, both aspects are important in the mating performance of the male animal. Sexual behaviour patterns of rams have been studied and described (Banks, 1964; Fraser, 1968; 1974; Ross, 1973; Lindsay, 1979). In the present review, aspects of the rams' libido and mating performance are considered rather than sexual behaviour patterns. Libido and mating performance in other farm animals are reviewed by Wodzicka-Tomaszewska *et al.* (1981) and Chenoweth (1981).

The relationship between libido assessment of rams (in either

pen or paddock) and field mating conditions, stresses the importance of such tests. This was emphasized in several studies (e.g. Mattner *et al.*, 1967; 1971; 1973; Walkley and Barber, 1976). A good relationship between pen libido tests for rams and their mating performance under field conditions has been noted by Mattner *et al.* (1971). They suggested that as a result of libido tests, certain rams can be eliminated from range mating because they are likely to perform poorly. Mattner *et al.* (1973) found that 17 out of 70 rams showed no interest during 48 hours with a flock of ewes (and after 3 pen tests), but most began to serve after a further 3 - 5 weeks in another flock. Their inactivity was, in most instances temporary. Mattner *et al.* (1971) have suggested "worker" and "non-worker" to describe the two conditions, although Hulet *et al.* (1964) had previously referred to sexually inhibited rams.

On the other hand, Cahill *et al.* (1975) and Kelly *et al.* (1975) found no relationship between libido in pen-test ratings and flock fertility, and as a result maintain the pen libido tests in unfamiliar surroundings do not reflect field performance. This is confirmed in a very recent report by Mickelsen *et al.* (1982).

It seems likely that the difference between the findings of Mattner *et al.* (1971; 1973) in contrast with those of Cahill *et al.* (1975) and Kelly *et al.* (1975) may lie in differences in management procedures used in pen libido testing.

2 - Hormonal Control of Male Sexual Activity

Mattner (1980), Chenoweth (1981) and Wodzicka-Tomaszewska *et al.*

(1981) have extensively reviewed work on the effect of gonadal hormones on male sexual behaviour. It is generally agreed that testosterone from the testis is the main hormonal influence on male sexual activity, although the mechanism is obscure. Mattner (1980) has suggested the following mechanism is involved. The gonadal hormones play an organizational role during sexual differentiation of the neural centres which control sexual behaviour in the adult. The presence of testicular hormones at the time of differentiation results in the neural centres developing male function and the potential for the animal to display masculine sexual behaviour. Although testosterone exerts strongly masculinizing effects on the developing neural centres, it does so only after aromatization and conversion to oestrogen. In the adult male, the gonadal hormones facilitate the expression of the predetermined pattern of sexual behaviour. Testosterone is more potent than other androgens in facilitating the complete pattern of male sexual behaviour but may not itself be the active hormone. It may be that the facilitating action of testosterone arises as a result of metabolism to oestrogen and dihydrotestosterone and an action of both these metabolites on the central nervous system.

There does not appear to be any relationship between level of circulating hormone and amount of sexual male activity. This may occur because, (i) the responsiveness to hormones is strongly influenced by the predetermined reactivity of the neural centres, and (ii) the hormonal levels in the majority of normal males may be greater than that necessary for maximal facilitation of sexual activity.

3 - Measurement of Mating Ability of Rams

Methods for assessing mating ability of male farm animals include subjective assessment, reaction time, scoring system and "serving capacity" test. Differences in libido or mating ability in rams may also be described by Reaction time to mount; Reaction time to service; the number of mounts and services; Latent period (time between successive services) (Wiggins *et al.*, 1953; Hulet *et al.*, 1962a, b; Pepelko and Clegg, 1964, 1965a, b; Mattner *et al.* 1967; Alwan, 1980); Libido score (Novoa, 1974); and Percentage of marked ewes by rams in the flock mating (Mattner *et al.*, 1971; 1973; Kelly *et al.*, 1975).

4 - Factors Affecting Mating Ability

Hafez (1960) has described some of the factors involved in the development and expression of the sexual drive in bull. Figure 2.2 is a modification of this work and also includes some additional parameters which have been subjected to experimental test (Wodzicka-Tomaszewska *et al.*, 1981). These factors will now be discussed.

(a) Genetic

A study of sexual inhibition in rams has indicated that inbreeding did not appear to be associated with this trait (Hulet *et al.*, 1964).

Breed differences in the libido have been reported in many studies. Lambourne (1956) found Southdown rams copulated more often than Romney Marsh of similar age. Land (1970) noted that Finnish Landrace rams consistently mounted the ewes more often than did

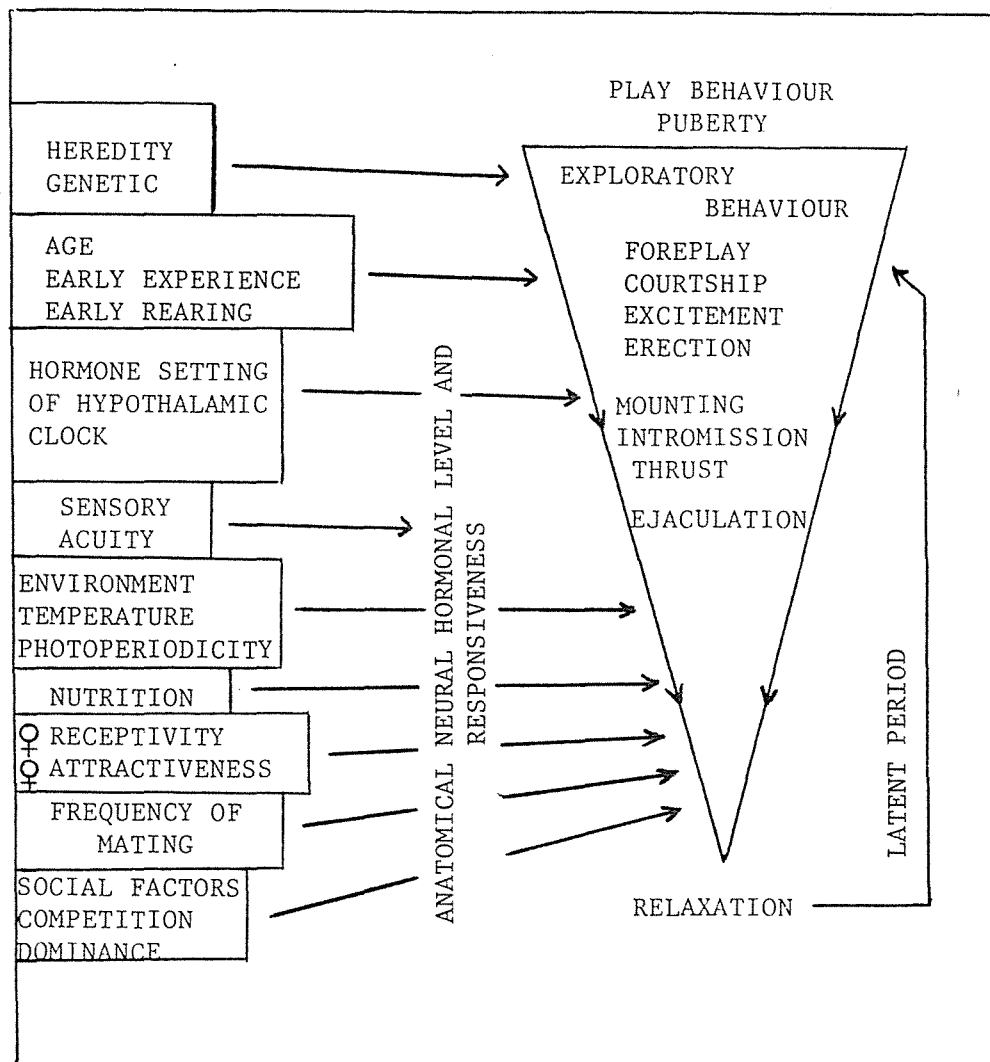


FIG. 2.2 SEXUAL BEHAVIOURAL SEQUENCES AND FACTORS INFLUENCING LIBIDO. (Adapted from Hafez, 1960).

Blackface rams, but from the time that all rams became sexually active it was impossible to differentiate between the mating ability of the two groups of rams. Conversely, another report indicated no breed differences in sexual activity, although Rambouillet rams tended to copulate more often than Targhee and Columbia rams (Hulet *et al.*, 1962b). Lindsay and Ellsmore (1968) found little difference in the proportion of available ewes mounted by either Dorset Horn, Merino or Border Leicester rams, although the Border Leicester rams tended to be less active during the summer than the other breeds.

(b) Nutrition

Mattner and Braden (1975) reported that libido of rams was depressed by a sub-maintenance ration fed for 5 - 10 weeks. Whether or not, physical weakness contributed to the decline is unknown. Warnick *et al.* (1961) found no difference in libido response measured by reaction time in rams on a nitrogen-free diet which led to death in four out of eight rams and a reduction of 40% body weight in the survivors. Overall, considering the unfavourable circumstances in the low nutrition group, there was both a high level of sperm production and development and retention of sexual drive.

A Vitamin A deficiency over 5 - 6 months (Moule, 1970) can lead to decreased sexual efficiency in the ram. Replacement of essential missing elements in the diet restored sexual activity in some male animals.

Okolski (1975) found that adult rams on a higher intake ration, which led to their gaining 25% in body weight, tended to become sluggish and clumsy when trying to mount.

In conclusion, all these trials indicate that unless rams are severely deprived, there will be little effect on the overall sexual responses and efficiency of the ram's mating responses. Overfat ones may become less willing and able to serve.

(c) Season

Seasonal changes in the libido of rams was considered to be directly related to seasonal changes in plasma testosterone levels (Robertson, 1977). Webster (1951) found that a sudden cold snap of weather affected the libido and fertility of rams in New Zealand. With improvement of weather, libido was restored before fertility. Similar results were obtained by Davis (1973), but the gap in lambing dates corresponding to the cold weather could have been caused by many other factors.

Pepelko and Clegg (1965a), Holmberg (1968), Mattner (1977) and Shackell *et al.* (1977) have found seasonal differences in libido measured by reaction time or a performance score, with some reduction in spring and summer. Mattner (1977) found that libido scores of Merino rams were higher in late summer and autumn than late winter and spring, while plasma testosterone levels were not greatly different. Also, the responsiveness of castrates to a standard dosage of testosterone declined during the latter period. His findings indicate that seasonal changes in the functioning of the central nervous system centres controlling libido (e.g. responsiveness to the stimulatory effect of testosterone) are probably more important than variation in base-levels of testosterone in producing seasonal variation in libido in Merino rams.

Moule (1950) shifted rams from a region with greater variation in day length (South Australia) to Queensland. He found that, three of four rams subjected to decreasing day-length showed good libido and mated while the untreated rams did not mate in the equatorial

day-length. Seasonal variation in libido is influenced by photoperiodicity, but provided oestrous ewes are present, most rams should work.

The effect of high temperatures on ram sexual responsiveness has been studied by Smith (1971) who heated rams to 41°C for varying times (4.0 - 13.5 h). Reaction time was generally not directly related to short-term heat-stress. It was shorter after 13.5 h of heat and longest three weeks after the period of heat-stress. These changes were probably brought on by factors other than heat-stress.

(d) Social ranking

Lambourne (1956), Edgar (1961), Hulet *et al.* (1962b), Lindsay (1966), Lindsay *et al.* (1976) and others have found in pen tests where space is limited, that a dominant ram can suppress the mating performance of a subordinate. Hulet *et al.* (1962a) found that this was true even when the dominance ranking was established and the rams were tested individually in pens, and similar results were obtained by Marincowitz *et al.* (1966) when individually ranked rams were presented with single ewes over a period of 12 days.

The suppression of ram's mating performance by another dominant ram watching from a nearby pen is a real phenomenon. It has been termed as the "audience" effect (Lindsay *et al.*, 1976). These workers found that dominant rams showed no difference in mating performance in the presence or absence of an "audience" of two submissive rams. However, submissive rams mounted and ejaculated less often when viewed by dominant rams than when tested alone. But at pasture, Lindsay and

Ellsmore (1968) found each group of rams marked more ewes when working together than alone.

The mating performance of rams working under field conditions does not in general appear to be affected by dominance ranking (Lindsay and Robinson, 1961a, b).

In conclusion, expected differences between pen and field mating conditions are generally found by investigators, and it seems unlikely that dominance or "audience" effects will greatly influence field matings of sheep where adequate space is available (Wodzicka-Tomaszewska *et al.*, 1981).

(e) Early rearing management

Banks (1964) observed the reaction of two rams deprived of female contact from weaning until 16 months. One ram mated the ewe immediately when tested, but the other ram had not mated after 676 days. Zenchak *et al.* (1974) found that four out of eight rams reared in small mono-sexual groups gave little sexual response to an oestrous ewe. Rams similarly reared but denied actual physical contact, although sight, sound and smell of other rams were available, showed normal responses to the female. They considered that the inhibited rams failed to see the ewe as a sexual object. Le Roux and Barnard (1974) found that five out of nine rams kept completely isolated from ewes were inhibited in their presence, although another nine, which were allowed ewe-contact after nine months of age, mated quite normally.

Fletcher (1979) found that one out of 92 allowed previous contact with ewes would not mate, compared with six out of 123 which had no previous contact with ewes from weaning to mating. This difference did not reach statistical significance. Illius *et al.* (1976a, b) found that the ability of a ram to copulate was independent of social rearing conditions such as being reared in all-male or a mixed sex group. Pretorius (1967) reared 36 ram lambs in isolation from ewes and found that initially, 67% did not show sexual interest in ewes. Even after 38 exposures to an oestrous ewe, 33% had not shown any interest. Wodzicka-Tomaszewska *et al.* (1981) reviewed unpublished report in which was found that rams from three rearing treatments, ((i) hand-reared in male groups, (ii) mother-reared and run in all male groups from weaning, and (iii) mother-reared and run in a group with 5% ewe with tied fallopian tubes) all showed ability to copulate after puberty when given 12-minute pen tests. Hulet *et al.* (1964) found that only 17% of his "inhibited" rams had not worked when given eight or nine days' association with oestrous ewes, and this accords with the work of Mattner *et al.* (1973).

Rams and ewes live in separate groups outside the breeding season, and mounting of subordinate by dominant rams is part of the normal behaviour patterns, later transferred to ewes. Although rearing in the absence of the female may initially depress the mating responses in some rams, it is unlikely to be of permanent importance.

(f) Senses

Impairment of senses could be considered as a factor in describing the efficiency of the male in his search for females in oestrus,

and consequently reducing the fertility of the flock or the herd. Banks (1964) failed to detect any significant changes in the courtship behaviour of anosmic rams. It did not appear to prevent detection of oestrous ewes, but detection required substantially more time than that with normal rams. In another study, Lindsay (1965), using two rams rendered anosmic by bilateral olfactory ablation, noted less foreplay and a decreased ability of the ram to detect ewes in oestrus. The rams did mount and serve ewes which remained still. Fletcher and Lindsay (1968) using eight rams (2 controls, 2 deaf, 2 anosmic and 2 blindfolded), found that hearing loss decreased the number of tethered ewes served (95 v 86); anosmia led to less mounting (95 v 55) and blindfolding reduced mounting to about half (95 v 48). In contrast, Signoret (1975) found that the basic sensory cue for the ram to mount an ewe was her immobility, irrespective of her state of oestrus or of her hormonal status. According to Signoret, smell was of minor importance.

(g) Hormonal

Clegg *et al.* (1969) showed that post-pubertal castration in rams slowly reduced their sexual responses, but these could be restored by treatment with testosterone propionate. In a similar study, Mattner (1976) showed that 15 μ g of testosterone restored ram libido to 92% of its original level and ram aggression to former levels. Higher doses further increased aggression without an effect on libido.

Stelmasiak *et al.* (1977) found no relationship between libido measured as performance over time and testosterone levels, and Knight (1973), using testosterone injections on sexually active and inactive

entire rams, could not alter their sexual behaviour pattern.

In Merino ram lambs, Mattner *et al.* (1976) found that there was a critical period (between 5 and 8 weeks after birth) when hormone treatment could influence subsequent libido. Testosterone implants over this period significantly increased the mean adult libido relative to controls by decreasing the number exhibiting low libido. Further, when ram lambs were treated at this age with high-titre testosterone anti-serum, there was a significant decrease in the mean adult libido score (Mattner, 1980). This suggests that during the early post-natal period circulating androgens may exert some effect on the central nervous system centres which control the mating activity in rams, possibly by modifying their subsequent sensitivity to circulating steroids and thus the level of libido expressed as adults.

Stelmasiak *et al.* (1977) found that the LH release response to two small doses of LHRH differed in high and low libido rams, and it seems that the individual sensitivity of animals to sexual stimulation may in some way be associated with responsiveness of the pituitary gland to LHRH stimulus.

(h) Other factors

The exhaustion test method to measure libido, allows the male to continue to court, mount and copulate until no further behavioural response occurs towards the female (Wierzbowski, 1966). A final criterion is usually applied for the ram, such as no symptom of sexual excitability within 30 minutes of the last ejaculation (Pepelko and

Clegg, 1965b) or within 20 minutes (Bermant *et al.*, 1969). Sumner *et al.* (1968) found that rams could serve up to 29 times a day under field conditions. Mattner *et al.* (1971) reported that rams in three 20 minute pen tests have averaged a total of 7.4 services, although some will achieve 18 - 20 services.

When the stimulating animals, i.e. teasers or a female in oestrus, are changed, sexually exhausted males may show renewed interest (Thiery and Signoret, 1978). Pepelko and Clegg (1964) found, in rams, that the recovery shown was 95% with fresh ewes but only 39% if the new ewe had been mated already. If an ewe which had been mated several times was taken out of the pen and then put back again, the recovery was only 18%.

From observation of rams mating in the field, Fowler (1975) reported a characteristic pattern of the ram covering several ewes rather than continuously serving one. In the review of Wodzicka-Tomaszewska *et al.* (1981), it was reported that ewes form a "harem" around a ram, frequently competing for the ram's attention. It was suggested that the distribution of favours by a dominant ram may be a circumstance activity contributed to by ewes rather than simply a predilection of the ram to so distribute himself. However, the ram appears to show a preference for ewes in oestrus, particularly those which have not recently been mated.

Ewe lambs were found to be defective in a number of their courtship responses and as a result were served less frequently than experienced adult ewes in a 2 ha pen test (Edey *et al.*, 1978). Lees

and Weatherhead (1970) found that when rams were given an opportunity to serve several ewes, they showed an early interest in the ewe of their own breed, and this was also found during pen tests by Kilgour and Winfield (1974) and Winfield and Kilgour (1977).

Some research has considered the ratio of ram to ewe required so that rams are not exhausted during field mating. It would seem that provided the mature rams are fertile and healthy and working on good terrain, ratios of 1 : 200 are satisfactory for sheep (Allison, 1975b; 1978).

5 - Mating Efficiency of Rams

Apart from those factors affecting the libido and mating ability in rams, which are a function of mating efficiency or performance of rams, the latter is also determined by the ram : ewe ratios, age of rams and ewes, paddock size and its topography, and the mating systems.

Generally, the use of ram : ewe ratios in sheep industry underestimate the sexual capacity of rams. One ram to 50 ewes is widely adopted (Allison, 1975a). Doubling of the number of ewes per ram (1 : 100), had no detrimental effects on pregnancy rate (Allison, 1975b), and rams may be successfully joined with higher numbers of ewes (Allison, 1978).

Allison (1975b) found that within experiments, there were no large differences between the percentage of ewes mated in the first cycle, returns to service, barrenness or twinning, when ram : ewe

ratios from 1 : 50 to 1 : 210 were used. Also, Allison (1978) showed that although there was a massive decline in semen volume, density and number of sperm per ejaculate collected nine days after the start of mating, there was little difference between groups of rams joined with different numbers of ewes. Overall, rams tended to distribute their services among receptive ewes through the choice of ewes with which they had not mated before or with which they had mated less frequently (Hulet *et al.*, 1975). Rams show a preference for ewes which are recently in oestrus or have not mated.

On recent Australian report in which three ram percentages (1%, 0.5% and 0.25%) were used in joining with ewes, Fowler (1982) suggests that the percentage of mature Merino rams joined with mature Merino ewes should not be less than one, because below this percentage, reproductive performance declines. This decline in the reproductive performance associated with low percentages of rams, was attributed to oestrous ewes crowding around the rams from increasing service activity thereby reducing services per ewe, ewes mated and ewes pregnant. These findings are in agreement with Allison (1975b) who stated that as the ram : ewe ratio increased the number of ewes mated per ram increased and the mean number of rams mating individual ewes decreased. Hence, when most rams are capable of breeding 200 ewes or more in one oestrous cycle, traditional ram : ewe ratio must be questioned (Allison, 1982). This is feasible in a group mating system where infertile or inactive rams will be compensated for by other rams in the group.

Lightfoot and Smith (1968) demonstrated the relationship between

the age of the rams and the number of ewes with which they joined. They conducted trials in which rams of different ages ($1\frac{1}{2}$ v $3\frac{1}{2}$ - $5\frac{1}{2}$ year-old) were joined either singly or in groups to varying numbers of ewes so that the number of ewes joined per ram varied between 25 and 100. They found that, although the increased fertility of flock (proportion of ewes lambing and ewes twinning to ewes joined) was associated with decreasing the number of ewes joined per ram, there was a highly significant interaction between number of ewes joined per ram and ram age. It was noted that joining 25 ewes per ram gave higher fertility than 50 ewes per ram when $1\frac{1}{2}$ year-old rams were used, but similar fertility with $3\frac{1}{2}$ - $5\frac{1}{2}$ year-old rams; and older rams were more fertile than $1\frac{1}{2}$ year-old rams when joined at 50 ewes per ram, but not at 25 ewes per ram. The decreased fertility associated with increased number of ewes joined per ram was attributed to a lower number of ewes mated (Crocker and Lindsay, 1972), and/or to reduced semen quality (Wallace, 1961). Failure to mate by $1\frac{1}{2}$ year-old rams which have not previous mating experience has been discussed previously, but in New Zealand conditions, such problem does not seem important. Allison (1978) reported that a ram : ewe ratio of 1 : 60, young rams have shown to have a comparable mating activity to older rams, but appear to have a somewhat lower activity at 1 : 80.

The use of the ram lambs (7 - 8 month-old) has been mentioned earlier.

The relationship between age of ewes and the percentage of rams to be joined with them has been studied by many workers (Dawe *et al.*,

1974; Allison and Davis, 1976a, b; Allison, 1977). It was recommended for Australian conditions that 3% of rams should be joined to maiden ewes and the possible use of a ram percentage intermediate between one and three can not be discounted (Dawe *et al.*, 1974).

Another factor which is inter-related with mating performance of rams is the paddock size and its topography. This factor has been studied extensively by many workers using different ram : ewe ratios (Lindsay and Robinson, 1961a, b; Lightfoot and Smith, 1968; Allison and Davis, 1976a, b). The latter authors showed that an increase in paddock size reduced flock fertility (as measured by proportion of mated ewes) particularly in two-tooth ewes than in mature ewes when they joined with tethered rams. These findings accord with conclusions of Inkster (1957) and Lindsay and Robinson (1961b), although Lindsay and Robinson (1961a) have reported no effect of increasing paddock size from 0.08 to 6.9 ha on number of ewes mated by rams.

The shape, topography and ground cover of mating areas seem probably of more importance than the absolute area (Allison and Davis, 1976a). It was recommended that ewes should not be divided from contact with rams by any natural barriers in the mating paddock (Allison, 1982). Different ram : ewe ratios have been reported for different paddock sizes. Generally speaking, lower numbers of ewes are allocated per ram in hill country than in the flat areas, that is, to ensure an equal chance for all ewes to be mated by rams.

Group and single-sire mating systems will affect flock fertility. Usually ewe fertility in group mating systems is higher than single-sire mating because inactive or infertile rams tend to have little effect on flock fertility (Allison, 1982). Hence, in order to increase mating efficiency of rams in single-sire mating system, the number of ewes per ram should be decreased so that satisfactory levels of flock fertility can be obtained. Using vasectomised rams to detect ewes in oestrus, and then introduce them to rams in small pen may enhance the ewe fertility (Clarke *et al.*, 1974), but in general pen mating will often result in a substantial decrease in the percentage of ewes mated (Allison, 1982).

C - SEMEN PRODUCTION AND EVALUATION

Two methods are commonly used to collect ejaculates from rams:

- (i) Electro-ejaculation
- (ii) Artificial vagina

Descriptions of the procedures of semen collection by these two methods as well as a comparison between them are given by Salamon (1976), Sorenson, Jr (1979) and Bearden and Fuquay (1980).

1 - Semen Production and Testes Measurements

Since the job of the ram is to get ewes pregnant, rams have to find oestrous ewes, serve them and fertilize them, and the ewe must retain the newly fertilized egg(s). In order to do this a ram needs a high libido and serving ability and a good supply of high quality

semen. Thus mating efficiency in rams depends on semen quality and quantity, and mating capacity. The latter parameter has already been considered. In this section the relationship between semen production and testes measurements will be considered.

A positive relationship exists between semen production and ram's testes measurements (Knight, 1977; Islam and Land, 1977; Courot, 1979), and semen quality and quantity seem to be closely related to ewe fertility (Allison, 1978). Kilgour (1979) stated that semen production (quality and quantity) is difficult to measure, but a good estimate can be obtained by measuring the size of testes. Knight (1972) has found that semen is produced at a rate of about 20×10^6 spermatozoa per gram of testicle per day. Hence, the more grams of testicle, the more spermatozoa there are available for fertilization.

Knight (1977) compared measurements of scrotal volume, scrotal circumference (scrotal wool removed), and mean testicle diameter. He found that they all gave equally good measures of semen production. Simpler measurement has been described by Lindsay *et al.* (1979), the testicles are palpated and their volume compared with that of testis-shaped wooden beads ranging in volume from 50 to 400 ml. Testicular volume also may be measured by water displacement or calipers.

D. Lindsay considers that, (see Kilgour, 1979), simple palpation of the ram's testicles will indicate semen quality; rams with firm testicles have good semen, while a high proportion of those with

soft testicles have poor semen. Animals with soft testicles may require semen evaluation.

2 - Semen Evaluation

Semen may be evaluated for several characteristics according to its intended use (for either artificial insemination or natural breeding). Overall, the objective of semen evaluation is to accurately predict semen fertility.

Of various semen characteristics, only volume of semen, estimated motility count, percentage of normal sperm, percentage of abnormal head and percentage of live normal sperm, were significantly related to percentage of ewes lambing from normal service (Wiggins *et al.*, 1953). It appears that no single laboratory test has high predictive value of potential fertility.

Hulet and Ercanbrack (1962) have developed two indices with a high correlation between some semen characteristics and actual fertility ($r = 0.76$; 0.73). The first index is based on pH, percentage of live normal sperm, percentage of abnormal sperm, and percentage of abnormal sperm necks. The second index includes motility scores instead of percentage of live normal sperm plus the other above semen characteristics. A rough appraisal of ram's semen which is often sufficient for practical purposes, can be made without equipment. Good ram semen has a creamy appearance and consistency. This gives a good approximation of semen density which can be graded^d using a 0 - 5 scale (Allison, 1982). The swirling motion which accompanies high motility can be observed with the

naked eye (Salamon, 1976). Semen containing a high concentration, but mostly of dead spermatozoa has a brownish yellow appearance. High concentration of sperm is indicated by a rich creamy appearance and as the concentration of spermatozoa decrease, the semen becomes thinner and milky or watery in appearance.

Many reports (e.g. Courot, 1979; Moss *et al.*, 1979) emphasize that semen motility is a good guide by which to assess semen quality. The latter authors indicated that the best guide for evaluating semen quality is the sperm count in association with a subjective assessment of overall motility and percentage of motile spermatozoa. Semen motility can be graded on a 0 - 5 scale after a low power microscopic examination immediately after collection (Salamon, 1976).

Further assessments of semen quality can be made for the purpose of artificial insemination. Livability in storage is used extensively when semen is utilized in the liquid form. This involves daily motility determinations on the semen stored at 5°C. The freezing of semen has largely eliminated this procedure. The resistance of sperm to cold shock has been used as a measure of quality. Several methods of measuring metabolic activity such as oxygen uptake, fructolysis, methylene blue reduction time, resazurin reduction time and pH change, all provide some information (Bearden and Fuquay, 1980).

An average ram's ejaculate is about 0.8 - 1.2 ml of creamy appearance semen, with sperm concentration in the range of $2 - 3 \times 10^9$ cell per ml, of which about 90% are alive. Semen of high concentration is usually slightly acid in reaction, while that of low

concentration is slightly alkaline. The motility is characterised by a swirling motion so rapid that it is difficult to distinguish individual sperm. The percentage of motile sperm is probably about 75%; and 5 - 15% of the spermatozoa may be abnormal in morphology (Gomes, 1977).

Procedures for evaluating semen characteristics have been described in many text books (e.g. Bearden and Fuquay, 1980).

3 - Factors Affecting the Quantity and Quality of Semen

Many factors have been reported to affect the quantity and quality of semen, and the main ones are considered below:

(a) Genetic

Generally there is considerable disagreement concerning the degree to which inheritance may be a factor in male reproductive efficiency (Perry, 1968). However in a comparison of Finnish Landrace, Merino and their cross rams, Islam and Land (1977) found that the seasonal increase in testis varied among the breed types (the Merino rams started earlier than the Finnish sheep). Sperm production showed a significant breed x season interaction. In another study, Land (1970) demonstrated that there was no difference between Finnish Landrace and Scottish Blackface in semen ejaculate's characteristics (motility, density and proportion of live sperm). This is in agreement with findings of Mittal (1980) when he studied semen characteristics from rams of two Indian breeds. Moore and Whyman (1980) have shown that fertilizing capacity of New Zealand Romney rams selected for high and low prolificacy may differ (71% v

40% fertilization rates respectively).

(b) Age of the ram

Courot (1979) has reviewed the literature which illustrate the effect of age of rams on semen production. Generally, the ejaculate volume from the ram lamb is less than from the mature ram and abnormal sperm, especially of an immature type may be more frequently produced. Density of semen from young rams is also low in comparison with that from mature rams (Terrill, 1938; Dun, 1955; Watson *et al.*, 1956; Symington, 1961; Skinner and Rowson, 1968). These workers have all concluded that ejaculate volume, semen density and percentage of normal live sperm increase at a considerable rate with advancing age of the animal, at least up to some physiological limit.

This increase in sperm production and increased sexual experience with age would partly explain why older rams (3.5 to 5.5 year old) are more fertile than 1.5 year old when joined to 50 ewes per ram, the fertility of the latter being higher if joined to 25 instead of to 50 ewes (Lightfoot and Smith, 1968).

Courot (1979) considered that the increase in sperm production with age could be related to the multiplication of the so-called "reserve" stem spermatogonia (A_0) and their differentiation into "renewing" stem spermatogonia (A_1) which originate sperm formation through spermatogenetic cycles.

(c) Nutrition

Perry (1968) has reviewed the literature for most animals. In

general, faulty nutrition is one factor that exerts a deleterious effect upon the male reproductive system. Prolonged restricted energy intake will cause a decrease in testicular weight and subsequently in semen production as shown by a reduction in ejaculate volume, sperm production, live sperm, motility, freezing resistance, viability and survival, and increase in abnormals. The quantity and quality of protein appears to be relatively unimportant in its effect on spermatogenesis unless it results in depressed food intake (Tassell, 1967a, b; Mattner and Braden, 1975). There have been responses in sperm production, semen quality and fertility in sheep to vitamins : A, C, and E; and trace elements : Cu, Co, Zn, Mn, and I (Moule, 1970).

In conclusion, Gunn *et al.* (1942) in Australia found that, the fertility of rams was reduced when they were deprived of green feed for several months during prolonged droughts, and two or three months were required to allow recovery after supplementation was begun. This may be implemented in the conclusion of Perry (1968) in which he stated that "...it can be said that although nutrition may affect the reproductive performance of male livestock in various ways, a deficiency of a single element is very seldom noted under conditions usually prevailing on farms or at headquarters of breeding organizations."

(d) Season

Climatic conditions include the atmospheric temperature and daylight length which are important factors affecting the quantity and quality of semen. Seasonal variation in semen characteristics have

been studied very extensively by many investigators for most farm animals (Holmberg, 1968; Islam and Land, 1977; Courot, 1979; Mittal, 1980; Galil and Galil, 1982a, b). Most of these authors have concluded that many semen characteristics are improved during autumn and winter and decline during spring and summer. These improvements in semen characteristics are associated with decreases in both atmospheric temperature and daylight length, although the latter is said to have less influence on semen quality (Courot, 1979). However, these seasonal variations in semen characteristics seem to be related more to the breeds of temperate regions which have a restricted breeding season compared with breeds of tropical and probably sub-tropical origin which do not have any distinct breeding season (Mittal, 1980; Galil and Galil, 1982a, b).

In respect to the fertilizing capacity of deep frozen semen collected in spring and autumn, Courot (1979) reviewed that fertilizing capacity of deep frozen semen was lower for semen frozen in spring than in autumn when both were used on oestrus synchronized ewes either in spring or in autumn with same number of motile sperm per ewe. However, although Courot (1979) tried to emphasize the effect of season on semen quality, one should remember that ewes may vary in their responsiveness to oestrus synchronization treatment due to a seasonal influence (see Robinson, 1967).

Elevated temperatures can reduce semen quality and fertility. Shearing of rams may prevent the lowering of quality in hot weather (see Perry, 1968). Longer daylight periods and long exposures to artificial light for several months resulted in testicular germ

cells degeneration, decreased ejaculate volume, and sperm concentration in ejaculate (see Courot, 1979).

(e) Frequency of ejaculation

Early reports reviewed by Perry (1968) show that after 42 ejaculations from a ram within nine hours, the sperm concentration was still 1×10^8 /ml. The first ejaculate contained 25 times more sperm than those of subsequent ejaculates. Spermatozoa available for ejaculation comes from the ampulla and the distal Cauda epididymis; stocks are limited for a given day; thus only a limited number of sperm cells can be released at ejaculation (Salamon, 1962).

This is of importance in AI and also natural breeding because after repeated ejaculations the number of spermatozoa delivered into the ewe reproductive tract could decrease below the level consistent with normal fertility (Lightfoot, 1968), especially in oestrus induced ewes where the required number of sperm are particularly elevated. Using three ram : ewe ratios (1 : 50, 1 : 100 and 1 : 150), Allison (1972) showed that semen characteristics (ejaculate volume, density and sperm concentration) declined during the mating period (one oestrous cycle). Generally, spermatozoa per ejaculate rose gradually and that was most evident in the 1 : 50 and 1 : 100 groups. Overall, conception rates were unaffected. Similar findings were also noted when even higher ram : ewe ratios were used (Allison, 1978). Paddock mating for eight weeks and at a ratio of 1 : 50 also showed a decline in semen characteristics and even in testicular volume and body weight (Simpson and Edey, 1979). Most semen characteristics recovered at a steady rate after two weeks of mating

and within two weeks after removal of rams.

In conclusion, a decrease in the total sperm per ejaculate has been observed at the beginning of the breeding period, a negative correlation has been shown between number of sperm per ejaculate and an increase in the number of females joined (Courot, 1979), and better fertility was obtained by lowering the ratio of ewes per ram (Lightfoot and Smith, 1968). On the other hand, Allison (1978) and Simpson and Edey (1979) concluded that, there is no clear evidence that the stress placed on rams during the early period of mating is sufficient to reduce ewe fertilization rates in systems in which multiple mating is possible. The results of Allison (1972) show that repeat mating is an important factor in improving fertilization rate. This could be due to sub-optimal ejaculate characteristics or improved timing of insemination relative to the time of ovulation. However, this may not apply in synchronized groups of ewes where the transport and survival of sperm within the reproductive tract is impaired (Quinlivan and Robinson, 1969), making density of the ejaculate a more critical factor in determining conception rates (Allison and Robinson, 1971).

CHAPTER THREE

MATERIALS AND METHODS

A - TUAPAKA FARM

The trial was conducted at "Tuapaka" Sheep Farm, Massey University, Palmerston North, New Zealand, in 1981 and until early 1982. "Tuapaka" is mainly a hill country property and comprises 394 ha of hills and 81 ha of flat land. Plates 3.1 and 3.2 show some topographic views of "Tuapaka" farm.

B - THE ANIMALS AND GENERAL MANAGEMENT

1 - Ram Lambs

Eighteen Booroola x Romney ram lambs were used. These arose from matings in 1980 when 122 Romney ewes (purchased as cast-for-age 5 year old from a farm in Wairarapa) were mated to three Booroola Merino rams (available from Tara Hills Research Station). The ram lambs were selected according to weaning weight, fleece weight, absence of fleece faults (e.g. pigmentation), feet "conditions", and general body condition and shape. There were six ram lambs per sire group.

All animals grazed as one group until selected for the trial in mid March 1981, when their average age was 204 days (range 193 - 210 days). All ram lambs produced a satisfactory semen sample (3 - 5 score for general semen motility, Salamon, 1976).



PLATE 3.1 TOPOGRAPHICAL VIEW OF "TUAPAKA" FARM.



PLATE 3.2 TOPOGRAPHICAL VIEW OF "TUAPAKA" FARM.

2 - Ewes

Seven hundred and sixty commercial two-tooth and four-tooth ewes were available. They were allocated to six mating groups (Groups 1, 2, 3, 4 comprising 140 ewes each and Groups 5 and 6 comprising 100 ewes each). The unequal distribution of sheep in the groups was determined by the size of the paddocks available at mating and lambing.

The ewes allocated to each sire group were colour marked on the wool. These marks remained until after lambing. In addition, all ewes in Groups 1 - 4 were eartagged prior to mating and in Groups 5 and 6 after mating. The ewes were crutched prior to mating and before lambing.

C - LIVE WEIGHT OF RAM LAMBS

The weaning weights recorded on 9 December 1980 were available. The ram lambs were weighed at weekly intervals commencing in March until the end of mating and then at monthly intervals until the end of the trial.

Weighing of the animals was not restricted to any time of the day, but was usually done in the morning. Furthermore, wet days were ignored in respect of an effect on the actual live weight of the ram lambs.

The ram lambs were shorn on 7 July 1981 and the fleece weight recorded (average 3.013 kg).

D - MATING PROCEDURES

1 - Training of Ram Lambs

To determine if pre-mating experience would improve mating performance, nine ram lambs (3 per sire group) were run with a small flock of ewes for two weeks prior to mating. The remaining nine ram lambs were kept separate from any ewes.

2 - Flock Mating

Twelve ram lambs (Mating group) were chosen as sires (4 per sire group) and the remaining six were considered as control animals. The mating group sires were fitted with "Sire-Sine" harnesses and crayons.

Each group of ewes was allocated two ram lambs which were "Single-Sire" mated, and the ram lambs changed after eight, eight, seven and seven days of mating (Periods P₁, P₂, P₃ and P₄) respectively. Between successive mating periods at least one day was allowed when no rams were present in the flocks (to avoid ewes on heat being mated by the replacement ram lamb). Thus a total of 12 "Single-Sire" mating groups were generated. The size of the groups was dependent upon the incidence of ewes in oestrus in the successive mating periods.

The six main flocks were mated separately over about two oestrous cycles (the 4 periods) and then all ewes were joined together and placed with Suffolk rams for a further oestrous cycle.

The colours on the mating harnesses were changed when fresh ram lambs joined the flocks. All mating marks were recorded when the ram

lambs were changed.

After mating all ewes were kept together until near the start of lambing when they were separated into sire groups. Thus there were 12 lambing groups (no removal of ewes mated to the Suffolk rams was done until lambing was completed).

E - RECORDING OF LAMBING DATA

Identification of the lambs was made at docking when the lambs were eartagged and noted for sex according to the sire group.

The lambs present at weaning on 14 December 1981 were recorded when they were also weighed and examined for foot "conditions".

F - SEMEN COLLECTION AND EXAMINATION

Semen samples were collected on 9 and 24 March 1981 from the 18 ram lambs, and assessed for general motility. Semen samples were also collected on at least three occasions after each mating period (only from those ram lambs which were joined with flocks). Again on two occasions 1 and 20 April 1982 semen samples were collected from 15 two-tooth rams (the same ram lambs which were described earlier). Semen was collected by electro-ejaculation using a "Ruakura Ram Probe" (see Plates 3.3 and 3.4) as described by Salamon (1976).

Immediately after collection, the semen of each ram was assessed microscopically for general motility using a scoring system



PLATE 3.3 THE "RUAKURA RAM PROBE" FOR COLLECTION OF SEMEN.



PLATE 3.4 COLLECTION OF SEMEN FROM THE RAM BY ELECTRICAL STIMULATION USING "RUAKURA RAM PROBE".

(0 - 5 scale) as described by Salamon (1976).

General semen motility scores were used to measure the number of days required for each ram lamb to recover after mating. This test was performed after each mating period at least for three days.

Percentage of live sperm was examined by making stained smears using Eosin/Nigrosin stain as described by Salisbury and van Demark (1961). The composition of Eosin/Nigrosin stain was

4.80 g	Sodium Citrate
0.80 g	Eosin (Water Soluble Yellow)
0.50 g	Nigrosin (Microscopical Stain BDH)
100.00 ml	Distilled Water.

Sperm concentration was determined using a haemocytometer method (Salamon, 1976). The equation which was used to calculate the sperm concentration was

$$N \times 10^7 = \text{sperm/cm}^3$$

Where N is the total number of spermatozoa counted in five large squares (each large square consists of 16 small squares).

G - LIBIDO TEST

Fifteen two-tooth rams were tested for libido. Ten were sires

in the 1981 mating group, while the remaining five were from the control group.

On three occasions (5, 8 and 15 April 1982), each of the 15 rams was introduced for 20-minutes into a pen (3 x 3 m) containing two ewes in oestrus. Ram entry into the pen was determined by a restricted randomization sequence whereby two mating-group rams, chosen randomly, were followed by one randomly chosen control group ram.

Records were kept on the number of mounts and services that each ram performed and the times at which they occurred. The reaction time to mount was the interval between introduction of the ram into the pen and the first mount. The reaction time to service was the time between introduction of the ram and the first service.

H - ANALYSIS OF DATA

Data on mating performance (% of ewes raddled, % of ewes returning to service, % of pregnant ewes, % of ewes lambing, docking rate and weaning rate) were examined by analysis of variance procedures. The general form of the linear model used to describe the data is given below. Depending upon the circumstances the model and a sub-model used were:

$$y_{ijkl} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \lambda_k + (\alpha\lambda)_{ik} + e_{ijkl}$$

Where

- y_{ijkl} = the l^{th} record of each mating performance characteristic taken in the k^{th} oestrous cycle and j^{th} period of mating of i^{th} sire group.
- μ = the general mean.
- α_i = the effect of the i^{th} sire group (trained v untrained).
- β_j = the effect of the j^{th} period of mating of each sire group ($P_1 + P_3$ v $P_2 + P_4$).
- $(\alpha\beta)_{ij}$ = the interaction effect between the i^{th} sire group and j^{th} period of mating.
- λ_k = the effect of the k^{th} oestrous cycle (first v second).
- $(\alpha\lambda)_{ik}$ = the interaction effect between the i^{th} sire group and k^{th} oestrous cycle.
- e_{ijkl} = the random effect unique to the y_{ijkl} . The error effects were assumed to be independently and identically distributed with mean zero and common variance. Normality was assumed for the purpose of testing hypotheses.

Data on live weight, reaction time to mount, reaction time to service, number of mounts, number of services and semen characteristics were analysed by analysis of variance. The linear model used to describe the data was:

$$y_{ij} = \mu + t_i + e_{ij}$$

where

y_{ij} = the record taken on the j^{th} animal in the i^{th} treatment.

μ = the general mean.

t_i = the effect of the i^{th} treatment

e_{ij} = the random effect unique to the y_{ij} . The error effects were assumed to be independently and identically distributed with mean zero and common variance. Normality was assumed for the purpose of testing hypotheses.

Angular transformation of the data was applied in order to reduce heterogeneity of variance (Snedecor and Cochran, 1967).

In following chapter abbreviations for level of significance are:

NS = Not Significant or $P > 0.05$
* = $P < 0.05$
** = $P < 0.01$
*** = $P < 0.001$

CHAPTER FOUR

RESULTS

A - LIVE WEIGHTS

Figure 4.1 shows the mean body weights of the mating and control group ram lambs during the trial. There was a 5 kg difference between the mean weaning weight of the mating and control group ram lambs. This difference was found to be highly significant ($P < 0.01$). No severe loss in body weight occurred in either group especially over the mating period. Figure 4.1 indicates that only after the first period of mating (P_1), a significant difference ($P < 0.05$) was found between the mean body weight of the mating and control group ram lambs. There were no significant differences between mean body weights of the control and mating group ram lambs in either post-mating or post-shearing periods.

B - EXHAUSTION TEST

Table 4.1 shows the general semen motility scores for the mating group ram lambs in the consecutive days after each period of mating. Ram lambs usually required four days in order to reproduce semen of high score (as an indication of recovery from mating exhaustion) after the first period of mating (P_1), while six days were required after the second period of mating (P_2). Three and two days were required after the third (P_3) and fourth (P_4) periods of mating respectively.

C - FLOCK MATING PERFORMANCE

Appendices XII and XIII show details of the flock mating

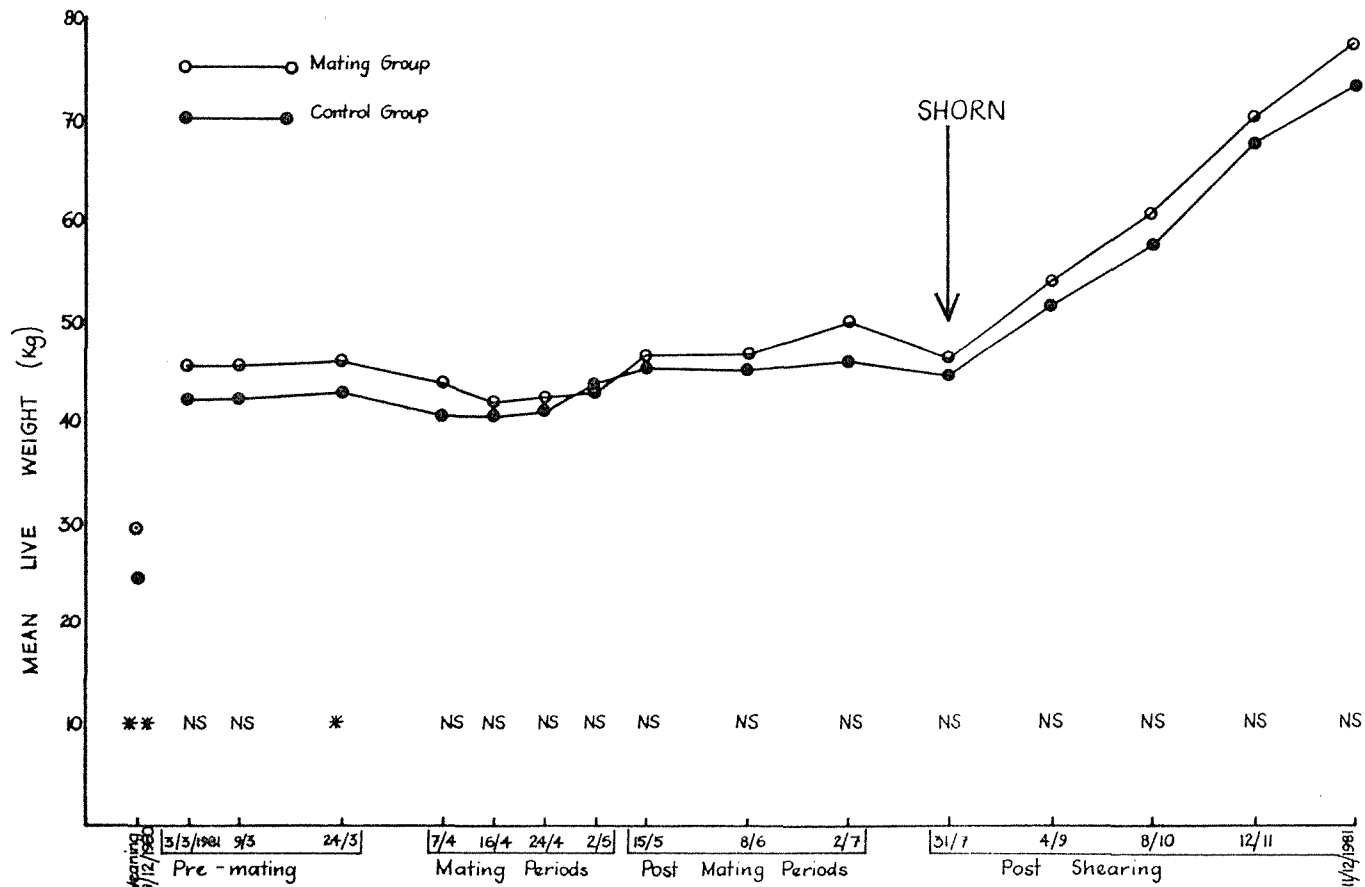


FIG 4-1 MEAN LIVE WEIGHT OF RAM LAMBS IN MATING AND CONTROL GROUPS OVER THE TRIAL PERIOD. THE SIGNIFICANCE OF THE DIFFERENCES BETWEEN GROUPS AT EACH MEASUREMENT IS INDICATED BY NS ($P > 0.05$), * ($P < 0.05$) AND ** ($P < 0.01$).

TABLE 4.1 NUMBER OF DAYS REQUIRED FOR RECOVERY FROM EXHAUSTION AS MEASURED BY SEMEN MOTILITY SCORES AFTER THE RAM LAMBS WERE REMOVED FROM THE FLOCKS.

RAM NO.	DAYS AFTER FIRST PERIOD OF MATING					DAYS AFTER SECOND PERIOD OF MATING							DAYS AFTER THIRD PERIOD OF MATING					DAYS AFTER FOURTH PERIOD OF MATING			
	1st day	2nd day	3rd day	4th day	5th day	1st day	2nd day	3rd day	4th day	5th day	6th day	7th day	1st day	2nd day	3rd day	4th day	5th day	1st day	2nd day	3rd day	4th day
1	0	0	4	4	5								2			5	5				
2	1	†	3	4	5								3	No semen test	No semen test	5	5				
3	1	1	3	4	5								0	No semen test	No semen test	5	5				
4	†	†	1	4	5								0	No semen test	No semen test	4	5				
5	†	†	3	4	5								0	No semen test	No semen test	5	5				
6	†	2	2	5	5								3	No semen test	No semen test	5	5				
7						†			2		5	5						1		5	5
8						†	No semen test	No semen test	3	No semen test	4	5						0	No semen test	3	5
9						0	No semen test	No semen test	3	No semen test	5	5						1	No semen test	5	5
10						1	No semen test	No semen test	4	No semen test	5	5						3	No semen test	5	5
11						1	No semen test	No semen test	0	No semen test	5	5						3	No semen test	5	5
12						0	No semen test	No semen test	4	No semen test	4	5						4	No semen test	5	5

† No semen obtained from the ram lamb.

performance of the trained and untrained ram lambs of the mating group.

1 - Percentage of Raddled Ewes¹

Table 4.2 shows an analysis of variance of data of the percentage of raddled ewes. It also shows the mean \pm SE percentage of raddled ewes attributed to different variables included in the analysis. Figure 4.2 shows the percentage of ewes raddled by each ram lamb in the trained and untrained groups in each flock of ewes. There were no significant effects of sire-groups on the percentage of raddled ewes.

Figure 4.3 shows the percentage of ewes raddled during each period of mating by each sire group. The percentage of ewes which were raddled in periods 1 and 3 combined ($P_1 + P_3$) did not differ significantly from the percentage of raddled ewes in periods 2 and 4 combined ($P_2 + P_4$). However, there was significant ($P < 0.05$) interaction between the sire-groups and periods of sire-groups in the percentage of ewes raddled. Trained ram lambs raddled a higher percentage of ewes in periods $P_2 + P_4$ than in $P_1 + P_3$. Conversely, untrained ram lambs raddled a higher percentage of ewes in periods $P_1 + P_3$ than in $P_2 + P_4$.

Figure 4.4 shows mean percentage of raddled ewes during each oestrous cycle for each sire-group separately. There were highly

1 Percentage of raddled ewes

$$= \frac{\text{Number of raddled ewes during each period of mating}}{\text{Total number of ewes joined in the flock}} \times 100$$

TABLE 4.2 ANALYSIS OF VARIANCE OF PERCENTAGE OF RADDLED EWES
(ANGULAR TRANSFORMED DATA) AND MEAN \pm SE PERCENTAGE
OF RADDLED EWES ATTRIBUTED TO DIFFERENT VARIABLES.

SOURCE OF VARIATION	D.F.	MS	F-RATIO
SIRE-GROUPS (TRAINED v UNTRAINED)	1	7.348	0.44 NS
PERIODS OF SIRE-GROUPS (P ₁ + P ₃ v P ₂ + P ₄)	1	0.144	0.008 NS
SIRE-GROUPS x PERIODS OF SIRE-GROUPS	1	89.86	5.366 *
OESTROUS CYCLES (FIRST v SECOND)	1	2859.73	170.77 ***
SIRE-GROUPS x OESTROUS CYCLES	1	4.23	0.25 NS
ERROR	18	16.746	

<u>MEANS</u>	
SIRE-GROUPS	OESTROUS CYCLES
TRAINED 50.70 \pm 0.02	FIRST CYCLE 82.68 \pm 0.02
UNTRAINED 52.36 \pm 0.02	SECOND CYCLE 20.35 \pm 0.02
PERIODS OF SIRE-GROUPS	SIRE-GROUPS x OESTROUS CYCLES
P ₁ + P ₃ 51.40 \pm 0.02	TRAINED x FIRST CYCLE 82.33 \pm 0.02
P ₂ + P ₄ 51.80 \pm 0.02	TRAINED x SECOND CYCLE 19.20 \pm 0.02
SIRE-GROUPS x PERIODS OF SIRE-GROUPS	UNTRAINED x FIRST CYCLE 83.03 \pm 0.02
TRAINED x P ₁ + P ₃ 44.52 \pm 0.02	UNTRAINED x SECOND CYCLE 21.50 \pm 0.02
TRAINED x P ₂ + P ₄ 57.09 \pm 0.02	
UNTRAINED x P ₁ + P ₃ 58.28 \pm 0.02	
UNTRAINED x P ₂ + P ₄ 46.52 \pm 0.02	

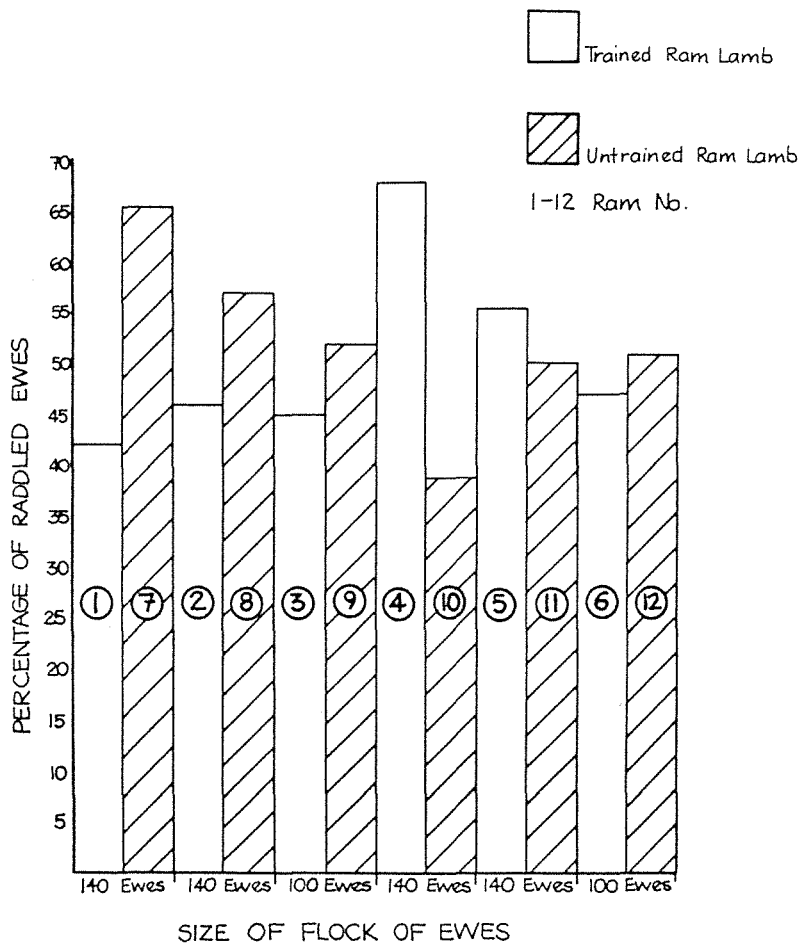


FIG 4.2 PERCENTAGE OF RADDLED EWES FOR EACH TRAINED AND UNTRAINED RAM LAMB IN EACH FLOCK OF EWES.

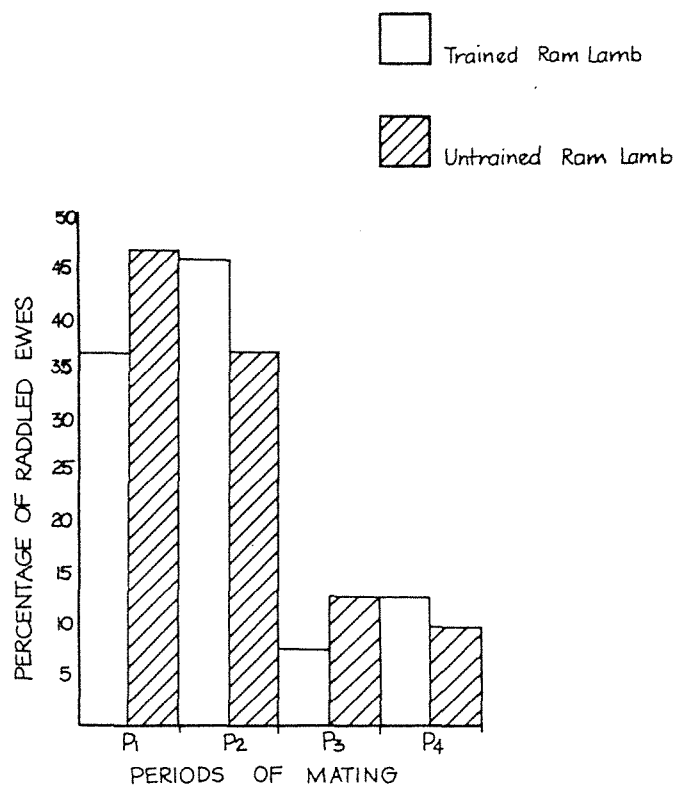


FIG 4.3 PERCENTAGE OF RADDLED EWES DURING EACH PERIOD OF MATING BY EACH SIRE-GROUP.

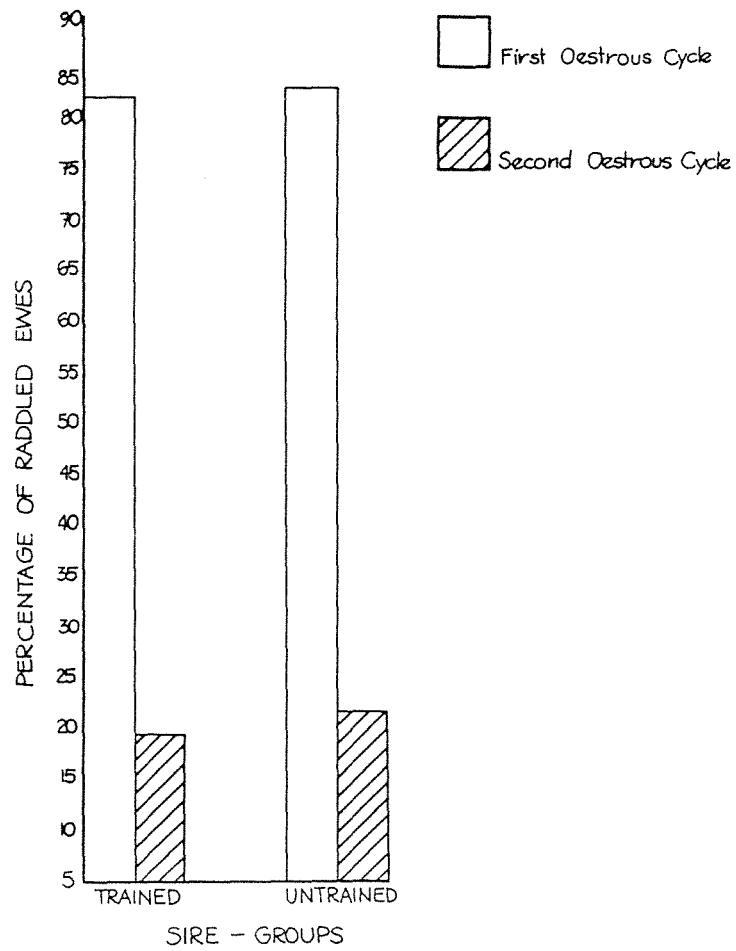


FIG 4.4 MEAN PERCENTAGE OF RADDLED EWES DURING EACH OESTROUS CYCLE BY TRAINED AND UNTRAINED SIRES.

significant differences ($P < 0.001$) in the percentage of raddled ewes between the two oestrous cycles. Although there was a higher percentage of raddled ewes during the first cycle than in the second cycle, there was no significant interaction between sire-groups and the oestrous cycles.

2 - Percentage of Ewes Returning to Service²

Table 4.3 presents an analysis of variance of data of the percentage of ewes returning to service. It also shows the mean \pm SE percentage of ewes returning to service attributed to different variables included in the analysis. Figure 4.5 shows the percentage of ewes returning to service for each ram lamb of the trained and untrained groups in each flock of ewes. There were no significant differences between sire-groups in the percentage of ewes returning to service, although the mean percentage of ewes returning to service for the trained sires was higher than for untrained sires.

Figure 4.6 shows the percentage of ewes returning to service after each period of mating for each sire-group. The difference in percentage of ewes returning to service after periods $P_1 + P_3$ and $P_2 + P_4$ was not significant. But the mean percentage of ewes returning to service after periods $P_1 + P_3$ was lower than after $P_2 + P_4$. There was no interaction between the sire-groups and their periods of mating in the percentage of ewes returning to service. Of the ewes raddled by trained sires during periods $P_2 + P_4$, 26.38% returned

² *Percentage of ewes returning to service*

$$= \frac{\text{Number of ewes returning to service after each period of mating}}{\text{Total number of raddled ewes by each sire}} \times 100$$

TABLE 4.3 ANALYSIS OF VARIANCE OF PERCENTAGE OF EWES RETURNING TO SERVICE (ANGULAR TRANSFORMED DATA) AND MEAN \pm SE PERCENTAGE OF EWES RETURNING TO SERVICE ATTRIBUTED TO DIFFERENT VARIABLES.

SOURCE OF VARIATION	D.F.	MS	F-RATIO
SIRE-GROUPS (TRAINED v UNTRAINED)	1	25.4	0.4 NS
PERIODS OF SIRE-GROUPS (P ₁ + P ₃ v P ₂ + P ₄)	1	98.45	1.54 NS
SIRE-GROUPS x PERIODS OF SIRE-GROUPS	1	102.89	1.648 NS
OESTROUS CYCLES (FIRST v SECOND)	1	172.645	2.76 NS
SIRE-GROUPS x OESTROUS CYCLES	1	86.146	1.38 NS
ERROR	18	62.42	

<u>MEANS</u>	
SIRE-GROUPS	OESTROUS CYCLES
TRAINED 17.33 \pm 0.08	FIRST CYCLE 18.38 \pm 0.08
UNTRAINED 11.66 \pm 0.08	SECOND CYCLE 10.20 \pm 0.08
PERIODS OF SIRE-GROUPS	SIRE-GROUPS x OESTROUS CYCLES
P ₁ + P ₃ 10.26 \pm 0.08	TRAINED x FIRST CYCLE 19.21 \pm 0.08
P ₂ + P ₄ 18.74 \pm 0.08	TRAINED x SECOND CYCLE 14.62 \pm 0.08
SIRE-GROUPS x PERIODS OF SIRE-GROUPS	UNTRAINED x FIRST CYCLE 17.55 \pm 0.08
TRAINED x P ₁ + P ₃ 8.27 \pm 0.08	UNTRAINED x SECOND CYCLE 5.77 \pm 0.08
TRAINED x P ₂ + P ₄ 26.38 \pm 0.08	
UNTRAINED x P ₁ + P ₃ 12.24 \pm 0.08	
UNTRAINED x P ₂ + P ₄ 11.09 \pm 0.08	

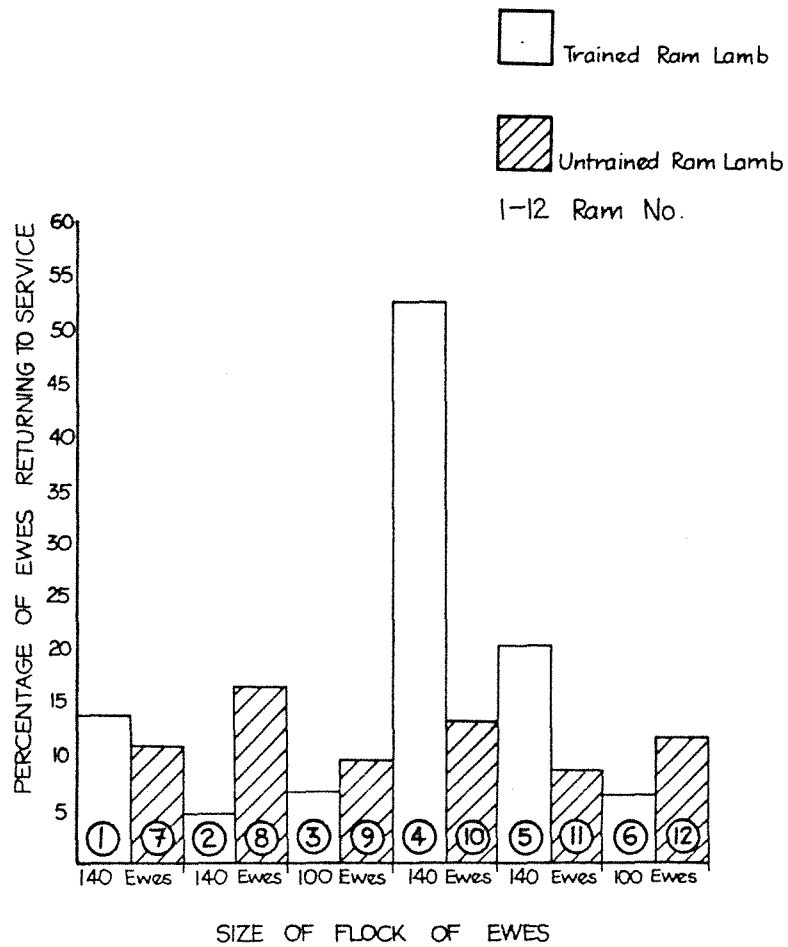


FIG 4-5 PERCENTAGE OF EWES RETURNING TO SERVICE FROM THOSE WHICH WERE RADDLED BY EACH TRAINED OR UNTRAINED RAM LAMB IN EACH FLOCK OF EWES.

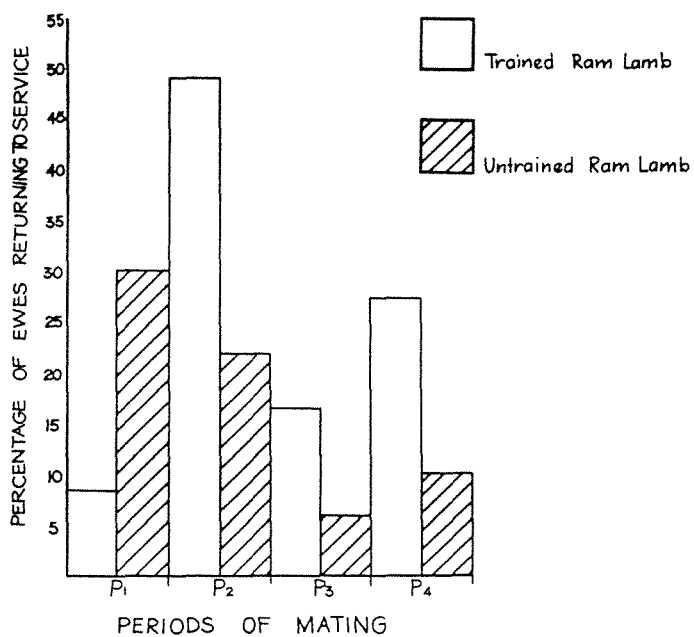


FIG 4-6 PERCENTAGE OF EWES RETURNING TO SERVICE FROM THOSE WHICH WERE RADDLED DURING EACH PERIOD OF MATING BY EACH SIRE-GROUP.

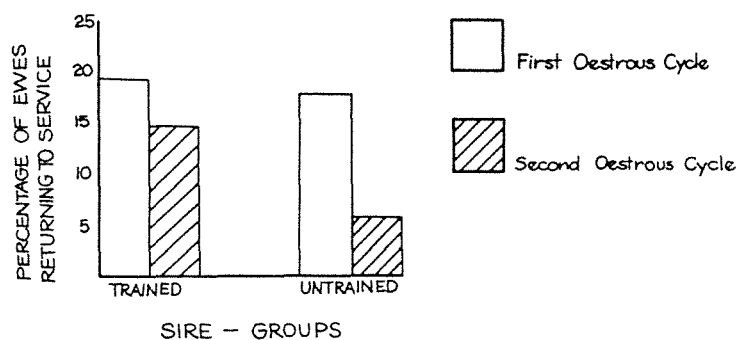


FIG 4-7 MEAN PERCENTAGE OF EWES RETURNING TO SERVICE FROM THOSE WHICH WERE RADDLED DURING EACH OESTROUS CYCLE BY TRAINED AND UNTRAINED SIRES.

to service, and for periods $P_1 + P_3$ it was 8.27%. The percentages of ewes returning to service after being mated by untrained sires during periods $P_1 + P_3$ and $P_2 + P_4$ were 12.24% and 11.09% respectively.

Figure 4.7 shows the mean percentage of ewes returning to service after each oestrous cycle during which both sire-groups joined the flocks. Although the mean percentage of ewes returning to service after the first cycle was higher (by 8.18%) than the mean percentage of ewes returning to service after the second cycle, this difference was not significant. Furthermore, there was no significant interaction between sire-groups and oestrous cycles.

3 - Percentage of Pregnant Ewes³

Table 4.4 presents an analysis of variance of data of the percentage of pregnant ewes. It also shows the mean \pm SE percentage of pregnant ewes attributed to different variables included in the analysis. Figure 4.8 shows the percentage of pregnant ewes for each ram lamb of the trained and untrained groups in each flock of ewes. There were no significant differences between sire-groups in the percentage of pregnant ewes.

There was no significant difference between periods $P_1 + P_3$ and $P_2 + P_4$ in the percentage of pregnant ewes. But, the mean percentage of pregnant ewes mated during periods $P_1 + P_3$ was higher (by 9.17%) than in $P_2 + P_4$. Trained and untrained sires fertilized more ewes

3 Percentage of pregnant ewes

$$= \frac{\text{Number of pregnant ewes for each sire}}{\text{Total number of ewes raddled by each sire}} \times 100$$

in periods $P_1 + P_3$ than in $P_2 + P_4$. Consequently, there was no interaction between the sire-groups and their mating periods in the percentage of pregnant ewes.

4 - Percentage of Ewes Lambing⁴

Table 4.5 presents an analysis of variance of data of the percentage of ewes lambing. It also shows the mean \pm SE percentage of ewes which lambled, attributed to different variables considered in the analysis. Figure 4.9 shows the percentage of ewes which lambled to matings by each ram lamb of the trained and untrained groups in each flock of ewes. There were no significant differences between sire-groups in the percentage of ewes lambing.

No statistically significant difference was found in the percentage of ewes which lambled in periods $P_1 + P_3$ and $P_2 + P_4$. Furthermore, there was no significant interaction between the sire-groups and periods of mating in the percentage of ewes which lambled.

5 - Docking Rate⁵

Table 4.6 shows an analysis of variance of data for docking rate. The table also shows the mean \pm SE docking rates of the lambs relative

4 *Percentage of ewe lambing*

$$= \frac{\text{Number of ewes lambing for each sire}}{\text{Number of pregnant ewes for each sire}}$$

5 *Docking rate*

$$= \frac{\text{Number of lambs docked and sired by each sire}}{\text{Number of ewes lambing for each sire}}$$

TABLE 4.4 ANALYSIS OF VARIANCE OF PERCENTAGE OF PREGNANT EWES (ANGULAR TRANSFORMED DATA) AND MEAN \pm SE PERCENTAGE OF PREGNANT EWES ATTRIBUTED TO DIFFERENT VARIABLES.

SOURCE OF VARIATION	D.F.	MS	F-RATIO
SIRE-GROUPS (TRAINED v UNTRAINED)	1	2.51	0.03 NS
PERIODS OF SIRE-GROUPS (P ₁ + P ₃ v P ₂ + P ₄)	1	98.67	1.48 NS
SIRE-GROUPS x PERIODS OF SIRE-GROUPS	1	34.57	0.52 NS
ERROR	8	66.46	
<u>MEANS</u>			
SIRE-GROUPS			
TRAINED		76.27 \pm 0.18	
UNTRAINED		78.70 \pm 0.18	
PERIODS OF SIRE-GROUPS			
P ₁ + P ₃		82.07 \pm 0.18	
P ₂ + P ₄		72.90 \pm 0.18	
SIRE-GROUPS x PERIODS OF SIRE-GROUPS			
TRAINED x P ₁ + P ₃		83.75 \pm 0.18	
TRAINED x P ₂ + P ₄		68.80 \pm 0.18	
UNTRAINED x P ₁ + P ₃		80.40 \pm 0.18	
UNTRAINED x P ₂ + P ₄		77.00 \pm 0.18	

TABLE 4.5 ANALYSIS OF VARIANCE OF PERCENTAGE OF EWES LAMBING
(ANGULAR TRANSFORMED DATA) AND MEAN \pm SE PERCENTAGE
OF EWES LAMBING ATTRIBUTED TO DIFFERENT VARIABLES.

SOURCE OF VARIATION	D.F.	MS	F-RATIO
SIRE-GROUPS (TRAINED v UNTRAINED)	1	4.97	0.12 NS
PERIODS OF SIRE-GROUPS (P ₁ + P ₃ v P ₂ + P ₄)	1	26.49	0.65 NS
SIRE-GROUPS x PERIODS OF SIRE-GROUPS	1	49.59	1.21 NS
ERROR	8	40.78	

<u>MEANS</u>	
SIRE-GROUPS	
TRAINED	93.26 \pm 0.1
UNTRAINED	94.12 \pm 0.1
PERIODS OF SIRE-GROUPS	
P ₁ + P ₃	92.31 \pm 0.1
P ₂ + P ₄	95.06 \pm 0.1
SIRE-GROUPS x PERIODS OF SIRE-GROUPS	
TRAINED x P ₁ + P ₃	90.39 \pm 0.1
TRAINED x P ₂ + P ₄	96.10 \pm 0.1
UNTRAINED x P ₁ + P ₃	94.23 \pm 0.1
UNTRAINED x P ₂ + P ₄	94.02 \pm 0.1

TABLE 4.6 ANALYSIS OF VARIANCE OF DOCKING RATE AND MEAN \pm SE DOCKING RATE ATTRIBUTED TO DIFFERENT VARIABLES.

SOURCE OF VARIATION	D.F.	MS	F-RATIO
SIRE-GROUPS (TRAINED v UNTRAINED)	1	0.000015	0.002 NS
PERIODS OF SIRE-GROUPS (P ₁ + P ₃ v P ₂ + P ₄)	1	0.07881	10.904 *
SIRE-GROUPS x PERIODS OF SIRE-GROUPS	1	0.00087	0.121 NS
ERROR	8	0.0072	
<u>MEANS</u>			
SIRE-GROUPS			
TRAINED		1.303 \pm 0.024	
UNTRAINED		1.301 \pm 0.024	
PERIODS OF SIRE-GROUPS			
P ₁ + P ₃		1.212 \pm 0.024	
P ₂ + P ₄		1.383 \pm 0.024	
SIRE-GROUPS x PERIODS OF SIRE-GROUPS			
TRAINED x P ₁ + P ₃		1.293 \pm 0.024	
TRAINED x P ₂ + P ₄		1.310 \pm 0.024	
UNTRAINED x P ₁ + P ₃		1.310 \pm 0.024	
UNTRAINED x P ₂ + P ₄		1.293 \pm 0.024	

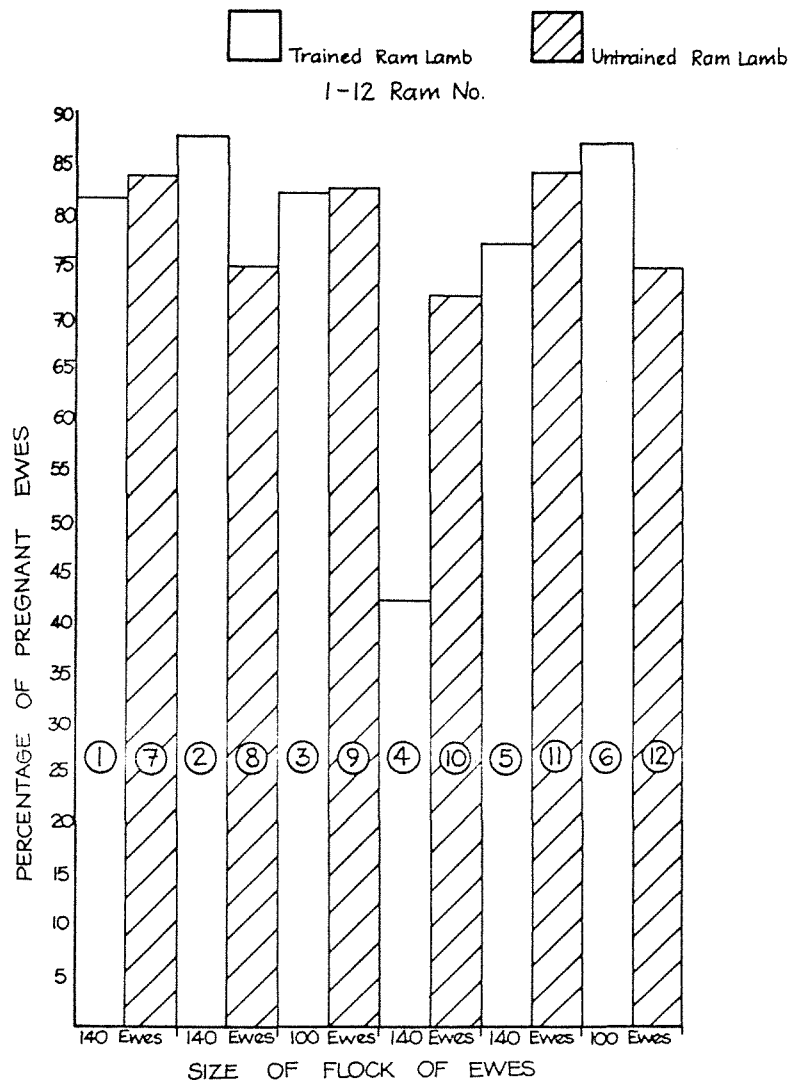


FIG 4-8 PERCENTAGE OF PREGNANT EWES OF THOSE WHICH WERE RADDLED BY EACH TRAINED OR UNTRAINED RAM LAMB IN EACH FLOCK OF EWES.

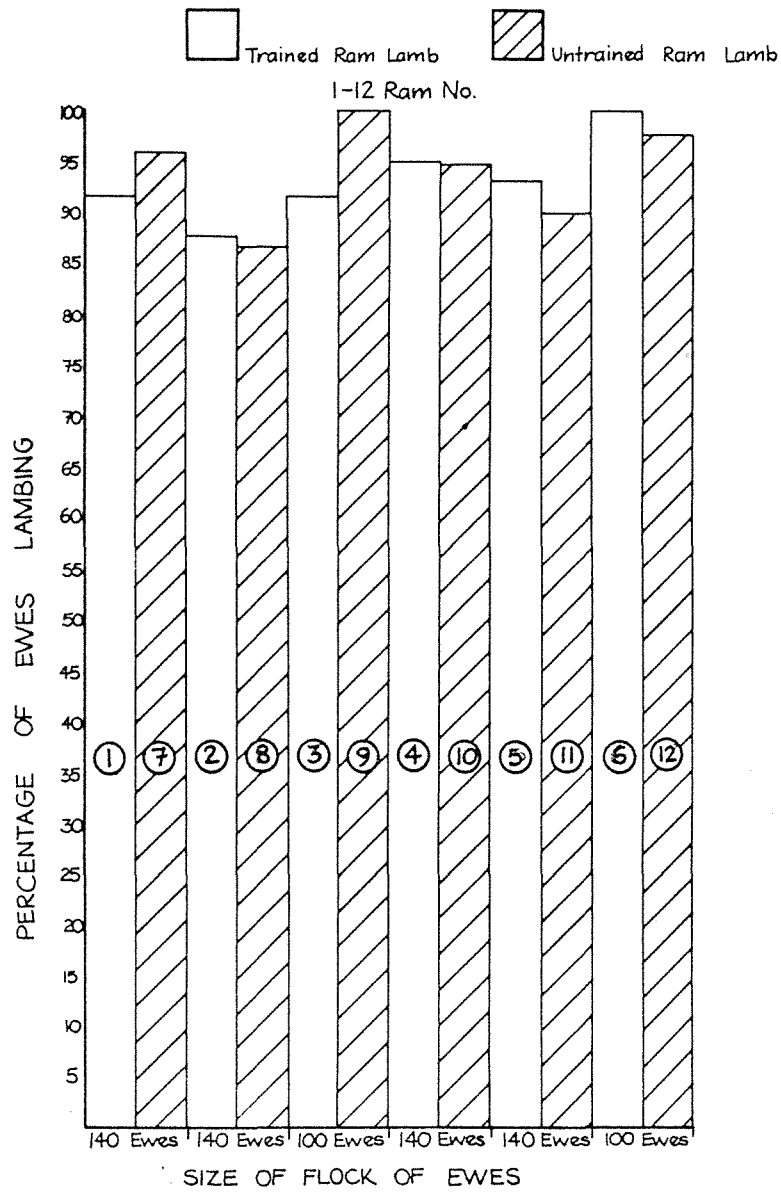


FIG 4-9 PERCENTAGE OF EWES LAMBING OF THOSE WHICH WERE PREGNANT AS BEING MATED BY EACH TRAINED OR UNTRAINED RAM LAMB IN EACH FLOCK OF EWES.

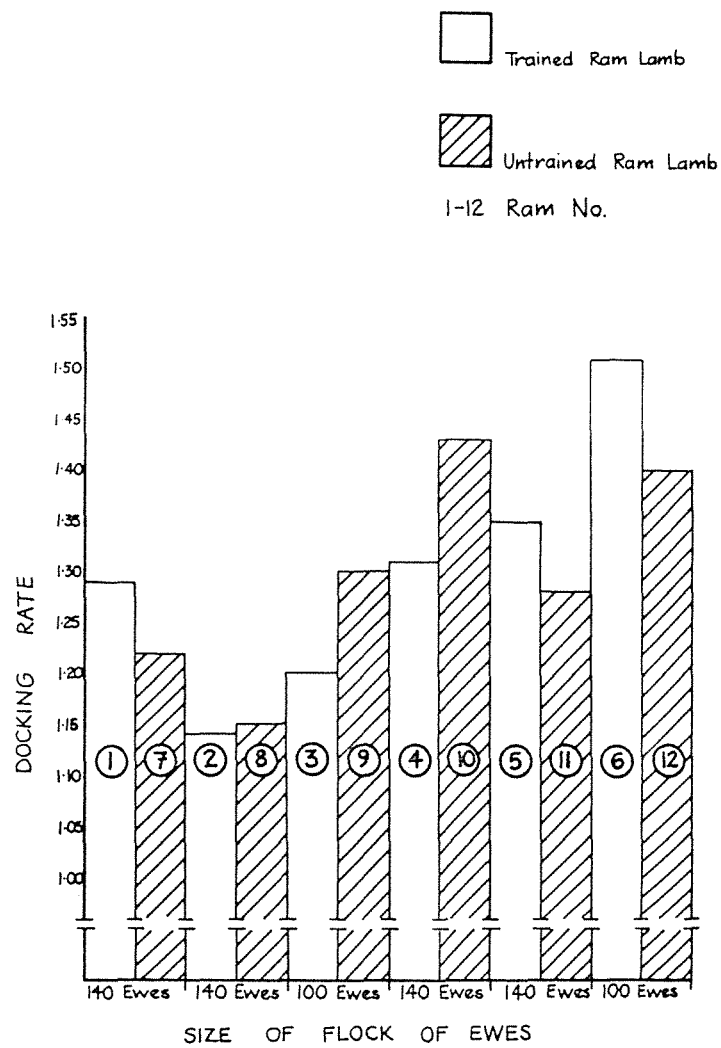


FIG 4-10 DOCKING RATE OF LAMBS Sired BY EACH TRAINED OR UNTRAINED RAM LAMB IN EACH FLOCK OF EWES.

to several factors. Figure 4.10 shows the docking rate of lambs sired by each ram lamb of the trained and untrained groups. There were no significant differences between sire-groups for docking rate.

There was a significant difference ($P < 0.05$) in docking rate between mating periods $P_1 + P_3$ and $P_2 + P_4$. Mean docking rate of lambs for periods $P_1 + P_3$ was less (by 0.163%) than for periods $P_2 + P_4$. There was no significant interaction between the sire groups and their mating periods in the docking rates of lambs. But the mean docking rate of lambs sired by trained ram lambs in periods $P_1 + P_3$ was less than in $P_2 + P_4$. Conversely mean docking rate of lambs sired by untrained ram lambs in periods $P_1 + P_3$ was higher than in $P_2 + P_4$.

6 - Weaning Rate⁶

Table 4.7 presents an analysis of variance of data for weaning rate. The table also shows the mean \pm SE weaning rates of the lambs attributed to different factors included in the analysis. Figure 4.11 shows the weaning rate of lambs sired by each ram lamb of the trained and untrained groups. There were no significant differences between sire-groups in the weaning rate.

There was a significant difference ($P < 0.01$) in weaning rate between the mating periods $P_1 + P_3$ and $P_2 + P_4$. Mean weaning rate

6 Weaning rate

$$= \frac{\text{Number of lambs weaned and sired by each sire}}{\text{Number of ewes lambing for each sire}}$$

of lambs for periods $P_1 + P_3$ was less (by 0.16%) than for $P_2 + P_4$. There was no significant interaction between the sire-groups and their mating periods in the weaning rates of lambs. But, mean docking rate of lambs sired by trained ram lambs in periods $P_1 + P_3$ was less than in $P_2 + P_4$, while mean docking rate of lambs sired by untrained ram lambs in $P_1 + P_3$ was higher than in $P_2 + P_4$.

D - SEMEN CHARACTERISTICS

Tables 4.8, 4.9 and 4.10 present the analyses of variance of data for semen motility scores, sperm concentration, and percentage of live sperm, respectively. The results of the individual analyses show that, significant differences in semen characteristics of the two-tooth rams could not be observed either between the mating and control-group rams or between the times of the two semen examinations. The means \pm SE of each of the observed semen characteristics are shown in Table 4.11.

E - LIBIDO TEST

1 - Number of Mounts

Figure 4.12 shows the mean number of mounts performed by the two-tooth rams from the mating and control groups. There were no significant differences between the number of mounts performed by the two groups of rams within each of the three libido tests.

Figure 4.12 also shows that there was an increase in the mean number of mounts performed by both groups associated with successive

TABLE 4.7 ANALYSIS OF VARIANCE OF WEANING RATE AND MEAN \pm SE
WEANING RATE ATTRIBUTED TO DIFFERENT VARIABLES.

SOURCE OF VARIATION	D.F.	MS	F-RATIO
SIRE-GROUPS (TRAINED v UNTRAINED)	1	0.000025	0.004 NS
PERIODS OF SIRE-GROUPS (P ₁ + P ₃ v P ₂ + P ₄)	1	0.076159	13.628 **
SIRE-GROUPS x PERIODS OF SIRE-GROUPS	1	0.001043	0.187 NS
ERROR	8	0.005588	
<u>MEANS</u>			
SIRE-GROUPS			
TRAINED		1.281 \pm 0.021	
UNTRAINED		1.278 \pm 0.021	
PERIODS OF SIRE-GROUPS			
P ₁ + P ₃		1.200 \pm 0.021	
P ₂ + P ₄		1.360 \pm 0.021	
SIRE-GROUPS x PERIODS OF SIRE-GROUPS			
TRAINED x P ₁ + P ₃		1.271 \pm 0.021	
TRAINED x P ₂ + P ₄		1.289 \pm 0.021	
UNTRAINED x P ₁ + P ₃		1.289 \pm 0.021	
UNTRAINED x P ₂ + P ₄		1.271 \pm 0.021	

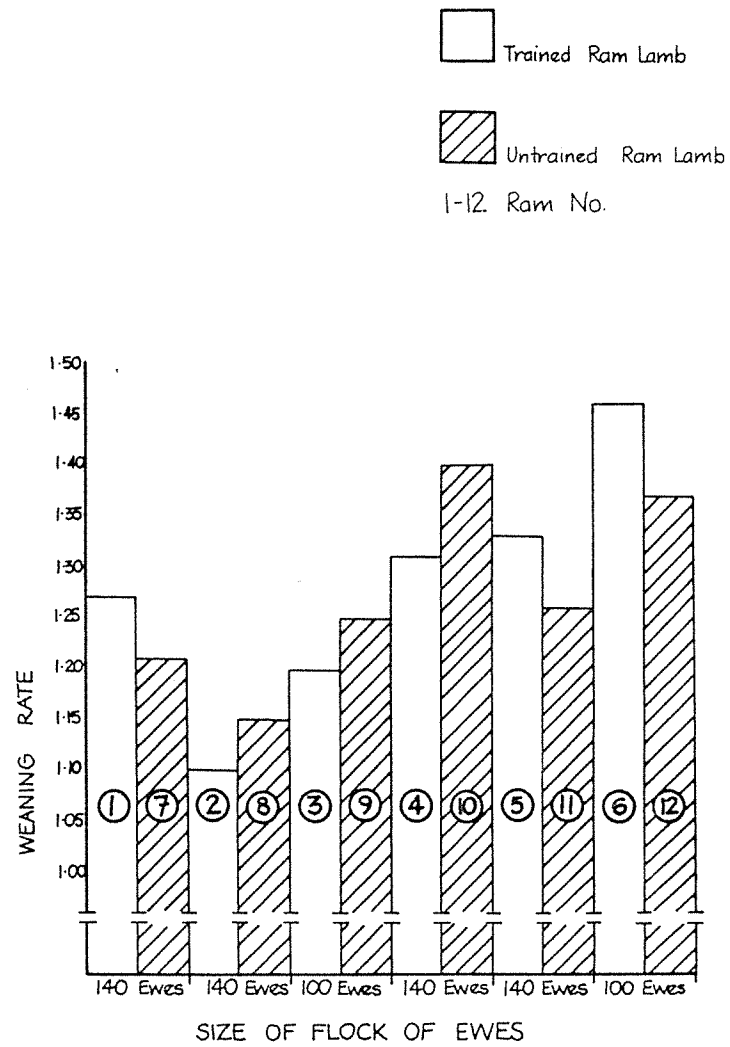


FIG 4-11 WEANING RATE OF LAMBS Sired BY EACH TRAINED OR UNTRAINED RAM LAMB IN EACH FLOCK OF EWES.

TABLE 4.8 ANALYSIS OF VARIANCE OF SEMEN MOTILITY SCORES.

SOURCE OF VARIATION	D.F.	SS	MS	F-RATIO
TOTAL	25	6.615		
TIMES	1	0.153	0.153	0.556 NS
RAM-GROUPS	1	0.129	0.129	0.469 NS
ERROR	23	6.332	0.275	

TABLE 4.9 ANALYSIS OF VARIANCE OF SEMEN DENSITY (NO. OF SPERM/ML).

SOURCE OF VARIATION	D.F.	SS	MS	F-RATIO
TOTAL	25	278212.039		
TIMES	1	84.962	84.962	0.0075 NS
RAM-GROUPS	1	19252.164	19252.164	1.71 NS
ERROR	23	258874.913	11255.431	

TABLE 4.10 ANALYSIS OF VARIANCE OF PERCENTAGE OF LIVE SPERM.

SOURCE OF VARIATION	D.F.	SS	MS	F-RATIO
TOTAL	25	380.567		
TIMES	1	2.1146	2.1146	0.133 NS
RAM-GROUPS	1	13.7351	13.7351	0.866 NS
ERROR	23	364.7173	15.857	

TABLE 4.11 MEANS \pm SE OF SEMEN CHARACTERISTICS FROM THE TWO-TOOTH RAMS.

DATE OF SEMEN COLLECTION AND EXAMINATION	RAM-GROUPS	SEMEN MOTILITY SCORE	SEMEN DENSITY ($\times 10^9/\text{cm}^3$)	% OF LIVE SPERM
1-4-1982	MATING	4.66 \pm 0.1	2.85 \pm 0.21	96.56 \pm 9.36
	CONTROL	4.75 \pm 0.1	2.67 \pm 0.21	94.97 \pm 9.36
20-4-1982	MATING	4.80 \pm 0.1	2.63 \pm 0.21	98.23 \pm 9.36
	CONTROL	5.00 \pm 0.1	3.77 \pm 0.21	98.23 \pm 9.36
OVERALL MEAN		4.71	2.84	96.37

libido tests.

2 - Number of Services

Figure 4.13 shows the mean number of services performed by the two-tooth rams from the mating and control groups. There were no significant differences between the number of services performed by the groups of rams within each of the three libido tests.

Figure 4.13 also indicates that there was little increase in the mean number of services performed by both groups at successive libido tests.

The correlation coefficients between number of mounts and number of services performed by rams of both groups at the first, second and third libido tests are 0.60, 0.51 and 0.15 respectively. The overall correlation coefficient over the three libido tests is 0.34.

3 - Reaction Time to Mount

Figure 4.14 shows the mean reaction time to mount for the two-tooth rams from the mating and control groups for each libido test. At the first test there was a highly significant difference ($P < 0.01$) in the reaction time to mount between the rams of the two groups, but no such effect occurred at the second and third libido tests.

Figure 4.14 also shows that the mean reaction time to mount for rams from the control group reduced at consecutive libido tests.

In contrast, the mean reaction time to mount for rams from the mating group increased at consecutive libido tests.

4 - Reaction Time to Service

Figure 4.15 shows the mean reaction time to service for the two-tooth rams from the mating and control groups for each libido test. A significant difference ($P < 0.05$) existed between the two groups at the first libido test, but not at the second and third tests.

Figure 4.15 also shows that, whilst there was an increase in the mean reaction time to service for rams from the mating group at consecutive libido tests, there was a decrease in the mean reaction time for rams from the control group at the second test. But the reaction time to service for the control group increased again at the third test.

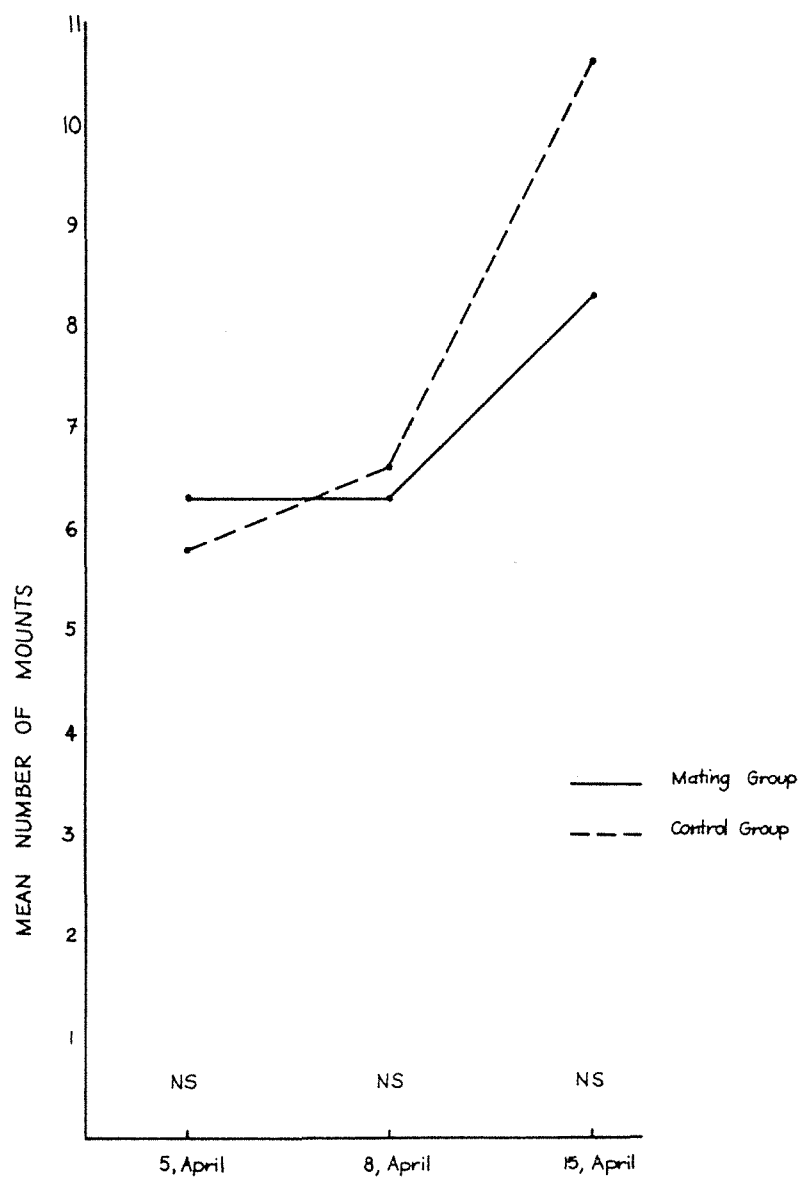


FIG 4-12 THE MEAN NUMBER OF MOUNTS FOR THE TWO-TOOTH RAMS FOR EACH TEST OF LIBIDO. THE SIGNIFICANCE OF THE DIFFERENCES BETWEEN GROUPS AT EACH TEST IS INDICATED BY NS ($P > 0.05$).

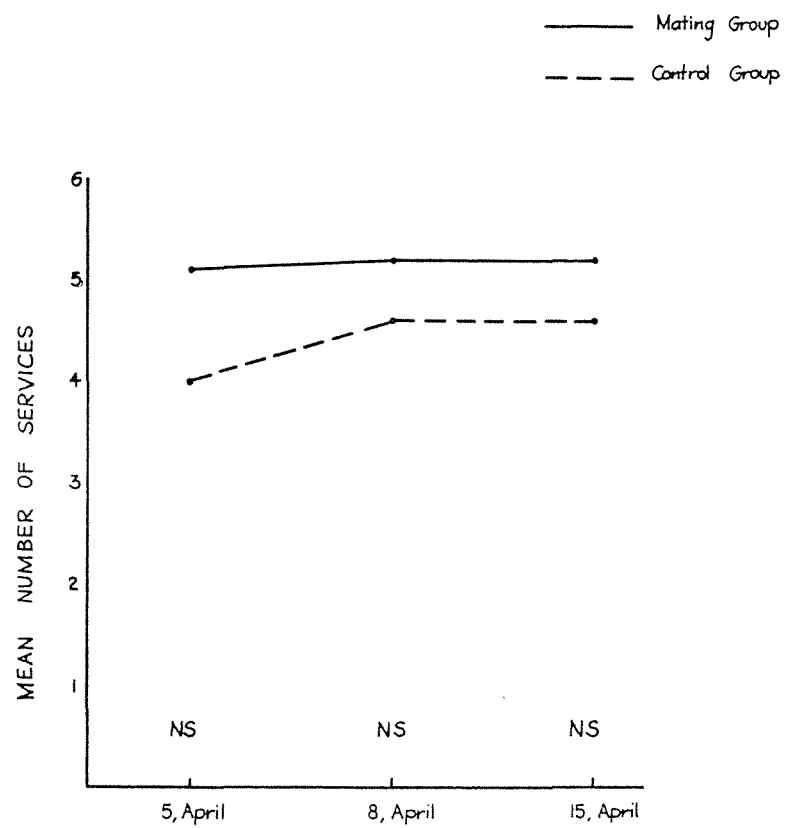


FIG 4-13 THE MEAN NUMBER OF SERVICES FOR THE TWO-TOOTH RAMS FOR EACH TEST OF LIBIDO. THE SIGNIFICANCE OF THE DIFFERENCES BETWEEN GROUPS AT EACH TEST IS INDICATED BY NS ($P > 0.05$).

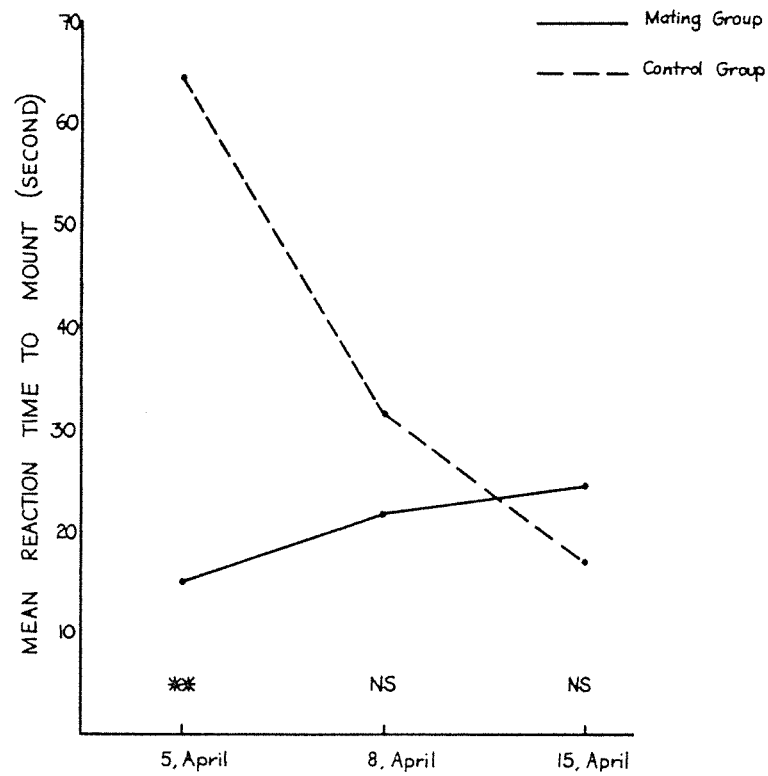


FIG 4-14 THE MEAN REACTION TIME TO MOUNT FOR THE TWO-TOOTH RAMS FOR EACH TEST OF LIBIDO. THE SIGNIFICANCE OF THE DIFFERENCES BETWEEN GROUPS AT EACH TEST IS INDICATED BY NS ($P > 0.05$) AND ** ($P < 0.01$).

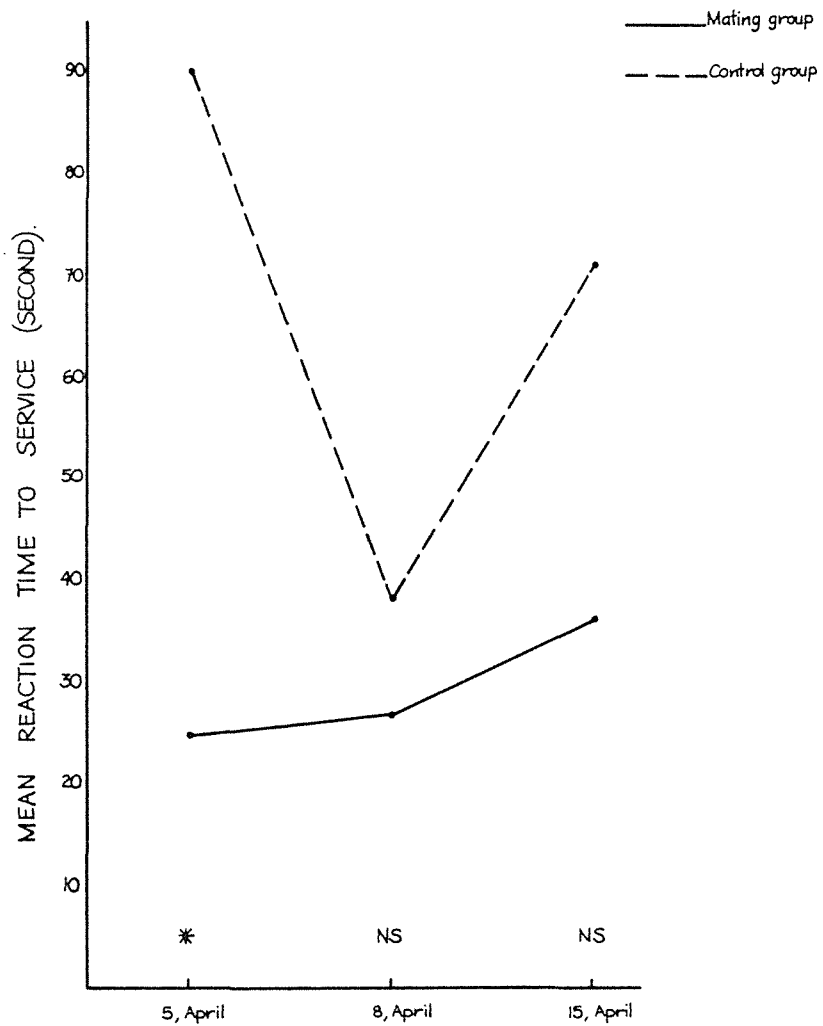


FIG 4:15 THE MEAN REACTION TIME TO SERVICE FOR THE TWO-TOOTH RAMS FOR EACH TEST OF LIBIDO. THE SIGNIFICANCE OF THE DIFFERENCE BETWEEN GROUPS AT EACH TEST IS INDICATED BY NS ($P > 0.05$) AND * ($P < 0.05$).

CHAPTER FIVEDISCUSSION AND CONCLUSIONSA - EFFECT OF MATING ON BODY WEIGHT

The live weight of the ram lambs increased from weaning until the pre-mating period. In the pre-mating period the rams in both the control and mating groups had similar growth. However the ram lambs used for mating were initially heavier than the control ram lambs.

The results also reveal that there was only a small loss in weight during the first period of mating (P_1). The results agree with those of Watt (1974) who also found a slight decrease in the body weights of ram lambs which were used in mating with synchronized oestrous ewes at Massey University. Simpson and Edey (1979) noted that mature rams showed a rapid and substantial weight-loss when used in an eight week period of mating, although the weights recovered after the sixth week and good growth rates occurred after removal from the flock. Similar results were obtained by Russel *et al.* (1976) with mature rams. Thus, the present results suggest that using ram lambs for mating as in this trial could only have adversely affected their body development for a short period during mating. This conclusion would generally support the findings of Stepanov *et al.* (1962), Ga'al (1964) and Dukin (1966) who found no weight-loss in ram lambs that were used for semen collection for artificial insemination.

A consistent increase in body weights of both groups of ram lambs was associated with advancement of age, especially during the post-

mating and post-shearing periods. Despite the insignificant differences between the mean body weight of both groups during these two periods, these differences were consistent. Ram lambs of the mating group had a higher mean live weight than the ram lambs of the control group after mating.

Considering the present results and those in the literature, it appears that the type of management of the ram lambs has a considerable effect on live weight during the mating period. Therefore, in order to maintain reasonable live weight, it is suggested that ram lambs be used for only a short period of mating, or mating with ewe lambs which might only show a low incidence of oestrus (Hafez, 1952). Also, to ensure the best opportunity to regain any loss in weight that may occur, the animals need to be well fed before, during and especially after the mating period.

B - EFFECT OF MATING ON SEMEN QUALITY

During the mating period, semen from the ram lambs was collected and assessed for general motility as an indication of semen quality, and this in turn as an indication of mating exhaustion. The results show that between two and six days were required to regain normal semen quality after the ram lamb was removed from the flock. Hence, the number of days required to recover from mating exhaustion was associated with each mating period during which the ram lambs joined with the flocks. For example, four and six days were required for recovery after P_1 and P_2 , respectively, while three and two days were required after P_3 and P_4 , respectively. The first two mating periods

involved the first oestrous cycle of joining, and the next two periods involved the second oestrous cycle. These differences in the number of days required for recovery from mating exhaustion were probably due to the higher proportion of ewes exhibiting oestrus during the first two periods.

The present results are in general agreement with those of Allison (1978) and Simpson and Edey (1979) who found that most semen characteristics of mature rams had markedly deteriorated after a short period of mating. Reasons for this rapid depletion in semen quality are partly explained by Salamon (1962) and Perry (1968). They have suggested that spermatozoa available for ejaculation come from the ampulla and the cauda epididymis and stocks are limited for given days, thus allowing a limited number of sperm cells to be released at ejaculation. So, the total sperm cells per ejaculation is decreased by increasing the frequency of removal, and this in turn would result in low semen quality.

Courot (1979) has reported that a decrease in the total sperm per ejaculate has been observed at the beginning of the breeding period; and a negative association has been shown between the number of sperm per ejaculate and an increase in the number of females joined. This in turn would lead to rapid mating exhaustion, particularly in the case of ram lambs, if a high proportion of ewes exhibited oestrus early in the mating season. It is suggested therefore that if ram lambs are joined with ewes in a system in which multiple mating is possible then the effect of stress resulting from mating might be less than where "single-sire" mating is practised.

Careful use of ram lambs for short periods should not impose too much stress ^{should not} and lead to low fertility.

C - FLOCK MATING PERFORMANCE

1 - Effect of Training

Results for the mating performance of the ram lambs of trained and untrained groups was similar in most observed parameters of flock mating performance. Therefore, it is suggested that training the ram lamb prior to the mating season is not likely to be worthwhile in improving the flock fertility.

Previous reports have indicated that rearing ram lambs in mixed-sex groups may lead to enhancement of their sexual patterns when they are later joined with ewes for breeding (Banks, 1964; Zenchak *et al.*, 1974). Conversely, many authors could not detect statistically significant differences in the sexual patterns of different rams when reared in different sex groups (Pretorius, 1967; Illius *et al.*, 1976a, b; Fletcher, 1979). However, in this earlier work, the workers did not determine the flock mating performance of animals after rearing in either mono- or hetero-sex groups.

From the present results, it is apparent that ^{when} using ram lambs of the Booroola Merino strain or its crosses ^{are used} for breeding under conditions similar to those at "Tuapaka" farm, then any differences in mating performance between trained and untrained rams were not noticeable. However, differences in mating performance of individual ram lambs would be expected similarly as in mature rams (Lees, 1978).

2 - Effect of Periods of Sire-Groups

The results indicate that there were no differences in the percentage of raddled ewes, percentage of ewes returning to service, percentage of pregnant ewes and percentage of ewes lambing which were mated by the ram lambs in the different periods of mating ($P_1 + P_3$ v $P_2 + P_4$). However, significant differences occurred in docking rate and in weaning rate of lambs mothered by the ewes which were mated by the ram lambs. These findings suggest that since no differences occurred in many parameters of the sires' mating performance, the significant differences in docking rate and weaning rate of lambs are attributable to other factors rather than due to the differences between mating periods of the sire-groups. Such factors are probably the different multiple birth rate, mothering ability and other environmental and genetic factors which affect the survival rate of lambs (Edey, 1969; Dalton and Rae, 1978; Duff *et al.*, 1982).

In fact, the above results indicate in a way that, there were no differences between individual ram lambs within each sire-group (trained or untrained) in their mating performance. Moreover, this view is emphasized by the results of the interaction between sire-groups and their mating periods. The results did not show any significant effect of interaction on the percentage of ewes returning to service, percentage of pregnant ewes, percentage of ewes lambing, docking rate and weaning rate.

3 - Effect of Oestrous Cycle

The percentage of raddled ewes was significantly greater ($P < 0.001$) in the first cycle compared to the second cycle (82.68% v

20.35% respectively). This indicates that a higher proportion of ewes had exhibited oestrus in the first cycle of mating. Similar findings were reported by Allison and Davis (1976a) and Allison (1977), who observed a higher proportion of ewes had exhibited oestrus in the first 17-day period than in subsequent periods of mating.

The present results are in general agreement with the suggestion of Hulet (1966) that oestrous activity in ewes is highly associated with the introduction of rams into the ewe flock during the breeding season. According to the suggestion of Allison (1977), with which the present results agree, it would seem that decreased ram-seeking activity, particularly in the second cycle, could have contributed to some oestrous ewes not being mated when a large number of ewes were present, but very few were actually displaying oestrus.

Although a higher percentage of ewes returned to service after first cycle than after second cycle, the difference was not statistically significant. However, the lack of a significant difference could be attributed to the small proportion of ewes mated in the second cycle, and consequently only a small proportion of them would be expected to return to service in comparison to the first cycle. On the other hand, the high percentage of ewes returning to service after first cycle could be due to a rapid deterioration in semen quality during the same period of mating. This suggestion is at variance with the results presented by Allison (1973) who found that decreased numbers of sperm per ejaculate during first cycle from two-tooth rams did not significantly contribute to the percentage of ewes

returning to service. But, Allison (1973) used a "group-sire" mating system in which ewe fertility rate is higher than following "single-sire" mating (Allison, 1982).

D - SEMEN CHARACTERISTICS

The early use of ram lambs as sires is often believed to have an adverse effect on their productivity in later life. But, the review of Dyrmondsson (1973) has indicated that there was no work available to support this view. Therefore, part of this trial was to study some of the semen characteristics of two-tooth rams previously used for breeding as ram lambs.

Results of the analysis of variance of data for the three semen characteristics (general semen motility, sperm concentration and percentage of live sperm) showed that there were no significant differences in semen of the two-tooth rams from the mating and control groups. Means of these semen characteristics (Table 4.11) indicate reasonable semen quality produced by both groups of two-tooth rams. These results support the view that the early use of ram lambs as sires did not adversely affect semen production at least at the two-tooth age. In conclusion, it should be noted however that any adverse effect of mating on semen production in mature rams is usually for only a short period unless it is accompanied by severe loss in body condition as well as in testicle weight (Kilgour, 1979; Simpson and Edey, 1979).

E - LIBIDO TEST

1 - Number of Mounts

Mating experience as a ram lamb did not contribute significantly to the differences in the number of mounts performed by rams at the two-tooth age. The mean number of mounts performed by rams of each group increased with successive libido tests. Although the rams of mating group performed a higher number of mounts at first libido test than rams of the control group, the later group were more active at the second and third libido tests.

The increase in the mean number of mounts performed by the rams of both groups was probably due to the test ewes being in the late stage of oestrus when joined with rams during libido tests. Thus, the ewes did not stand firmly for the rams and many mounts occurred prior to service. This suggestion is supported by the estimated size of the correlation coefficients between the number of mounts and the number of services that were performed by rams in both groups at the first, second and third libido tests ($r = 0.60, 0.51$ and 0.15 respectively). On the other hand, the results are in general agreement with those of Knight (1976) who suggested that mounting several times prior to ejaculation seems to be part of normal foreplay in rams and the correlation between number of mounts without ejaculation and number of ejaculations in unit time is very poor. Such a correlation was estimated in the present study to be 0.34 (the overall correlation between number of mounts and number of services over the three libido tests).

2 - Number of Services

Again it seems that the mating experience did not increase the number of services achieved by the two-tooth rams (non significant difference). The mean number of services performed by rams of each group indicated a satisfactory level of libido performance in a given 20-minute test. Hulet *et al.* (1962a) has reported that ewes were mated by mature rams on 3.9 occasions during the first half of oestrus as compared to 2.4 during the second half of oestrus. The present results with two-tooth rams are similar to those obtained by Hulet *et al.* (1962a).

In conclusion it would appear that no deleterious effect on mating ability at the two-tooth age was apparent.

3 - Reaction Time to Mount

The results of the analysis of data for reaction time to mount may suggest that the mating experience gained by the ram lambs may have contributed to the significantly ($P < 0.01$) shorter time shown by the two-tooth rams at the first test. However, no difference persisted at the two successive libido tests. Presumably the rams acquired some mating experience at the first encounter with oestrous ewes and no further differences were apparent.

These results are in general agreement with those of Banks (1964) and Alwan (1980), who reported that mating experience of young rams improves gradually with advancement of age and as the number of sexual encounters increases.

4 - Reaction Time to Service

Mating experience gained as a ram lamb might lead to the significant ($P < 0.05$) differences in the reaction time to service for the two-tooth rams at the first libido test. These differences in the reaction time to service were not statistically significant at the successive libido tests. However at the third libido test, the reaction time required by rams of both groups to accomplish a service was increased. This was probably because of the low intensity of oestrus in the ewes with which the rams were joined. Therefore, the time required by rams to perform a successful ejaculation immediately after the first mount was prolonged.

In conclusion, the four parameters of the libido test (number of mounts, number of services, reaction time to mount and reaction time to service) used in this study showed that mating as a ram lamb for a limited period did not materially reduce reproductive performance in the following year. This conclusion would be stronger if satisfactory fertility results following the mating with ewes had been available for these two-tooth rams. However, from other observations of two-tooth rams used at Massey University after having had ram lamb mating experience (M.F. McDonald, 1983, unpublished report), it is believed that the animals in this study would have performed adequately under flock mating conditions.

F - GENERAL CONCLUSION

In this study, there were clear indications that joining ram lambs with ewes prior to the mating season did not markedly influence the flock mating performance. Individual differences between ram

lambs of either the trained or untrained group were not significant for any parameter of mating performance. However, ram lambs differed significantly in the percentage of ewes which were raddled due to differences in the incidence of oestrus occurring during the various mating periods ($P_1 + P_2$ v $P_3 + P_4$). Overall, the flock mating performance performed by the Booroola Merino crossbred ram lambs in this trial was satisfactory.

Throughout the trial period all ram lambs gained weight. Under the mating system adopted, a consistent and continued decline in the live weights of ram lambs from the mating group was not observed. However, under different conditions, live weight loss might be expected and it has led various authors (e.g. Clarke *et al.*, 1966; McDonald, 1974) to suggest that ram lambs should not be used with very large numbers of ewes and especially over a prolonged mating interval. Also to ensure the best opportunity to regain any loss in weight, the animals need to be well fed before, during and especially after the mating season.

Observations on semen quality following the use of the ram lamb for flock mating showed that recovery from mating exhaustion occurred shortly after removal from the flocks. It was apparent that ram lambs were more exhausted when more ewes exhibited oestrus. In this trial, mating exhaustion occurred early in the mating period. Thus, it can be suggested that when ram lambs are joined with ewes a system should be devised that will allow multiple mating. Any effect of stress on semen quality and fertility will probably be less when "group-mating" rather than "single-sire" mating is practised.

Breeding from Booroola Merino crossbred ram lambs did not appear to have an adverse effect on semen characteristics (semen motility, sperm concentration and percentage of live sperm) and mating ability when measured later at two-tooth age. The three semen characteristics and mating ability (pen - libido test) of two-tooth rams from the previously mated group were similar to those not used as ram lambs, so that there was no depressive or enhancement effect recorded at the two year age.

Finally, breeding from ram lambs can be recommended where suitable husbandry and management exists. This implies a suitable mating system. If satisfactory procedures are utilized, ram lambs can be exploited most efficiently; any adverse effects on their body development, mating ability and semen production should not be expected (at least at two-tooth stage).

SECTION II

A STUDY
OF THE
FOOT "CONDITIONS"
IN
BOORoola MERINO CROSSBRED
AND
PERENDALE SHEEP

* * * * *

CHAPTER SIX

REVIEW OF LITERATURE

A - INTRODUCTION

In this review three "conditions" of the feet of sheep will be considered; these being foot scald, footrot, and abnormal shape of the hoof. Various factors predispose animals to be affected by these "conditions" and identifying some which are important may assist in deciding husbandry methods or selection criteria to reduce the effect of these "conditions" on productivity.

These three foot "conditions" are interrelated and one subsequently leads to the other (Barber, 1979). Footrot commences as an interdigital dermatitis (scald) which gradually extends under the axial wall and then the sole of the hoof. The overlying horn becomes separated as a result of the inflammatory destruction of its epidermal matrix resulting in abnormal shape of the infected foot. On the other hand, misshapen hooves may act as a predisposing factor for infection with footrot and scald.

Footrot is by far the most important disease in sheep compared with other foot diseases (e.g. foot abscess and scabby mouth). Its cost to production may be considerable in some situations, but where other conditions apply it may not cause significant economic loss.

Almost all sheep affected with foot diseases show some degree of lameness.

Sheep foot diseases (e.g. footrot) do not usually cause the death of affected sheep, unless they are neglected. Ewes that suffer from footrot may not lactate, in consequence lambs may die. Foot diseases may precipitate pregnancy toxæmia in ewes in late pregnancy (Barber, 1979).

Footrot as well as other abnormal foot "conditions" in sheep may cause severe losses of body condition and hence of both live- and carcass weight. This is important in breeding flocks, as ovulation rates of ewes are related to liveweight at, and prior to, mating. Rams affected with footrot may be unable to serve ewes, or their semen may be of poor quality; either or a combination of these circumstances may impair both fertility and fecundity.

Foot "conditions" may cause marked deterioration in the quality and quantity of wool (Symons, 1978). The fleece may become tender and even develop a "break" in the wool. This is likely to result in a significant reduction in price per kilogram for the wool.

B - DEFINITION

Footrot

"Footrot is a contagious disease of the sheep's foot characterised by separation of a large portion of the hoof from the soft tissues due to a spreading infection immediately beneath the horn" (Beveridge, 1941).

Many authors (e.g. Belschner, 1956; Moore, 1957; Barber, 1979)

have described the infection as commencing in the interdigital skin, and horn separation is often seen first in the angle of the heels, but later extends forward under the planter surface and walls. In uncomplicated cases there is little suppuration. Both digits of the foot are invariably affected. Each sheep usually has more than one, but rarely all four feet affected by the "condition". Footrot is a flock disease and under suitable environmental conditions may spread rapidly until almost all of the flock becomes infected.

Footrot can be differentiated from other foot diseases because of the separation of the horn, the minimal swelling and suppuration, the characteristic odour, the general bilateral involvement of the digits, and under suitable conditions the rapid spread of the infection to involve other sheep in the flock. In extreme cases sheep may walk on their knees due to extreme pain in their feet.

The major causative organism of footrot in sheep is *Bacteroides nodosus* in association with other micro organisms. This organism can survive in the feet of chronically infected sheep for several years, but it can remain alive under moist conditions for up to 10 days and it is rapidly killed by sunlight and drying.

More details on the pathological conditions and the mechanism involved in footrot infection may be found in Egerton *et al.* (1969), Skerman and Cairney (1972), Cooper (1973) and Skerman *et al.* (1981).

Scald

This is a term applied to a "condition" of the feet of sheep in

which there is an inflamed "scalded" appearance of the skin between the claws, with some exudation of serious fluid, soft tissues, especially around the heels, but not extending very far (Belschner, 1956; Skerman, 1976). There are two recognised entities of foot scald "conditions". They are:

- (a) Ovine interdigital dermatitis, which is caused by *Fusobacterium necrophorum* (Parsonson *et al.*, 1967). This is a mild self limiting infection in which the skin between the claws of the hoof becomes reddened and swollen. It occurs under moist, wet conditions and clears up spontaneously when the weather improves. Lameness is neither common nor severe (Anon., 1982).

- (b) Non-progressive footrot (Benign footrot) which is caused by some strains of *Bacteroides nodosus* (Thomas, 1962; Egerton *et al.*, 1969; Skerman, 1976). This "condition" results in severe inflammation of the skin between the claws. A high proportion of the flock may show varying degrees of lameness. There is little or no underrunning of the horn of the hoof. It occurs under wet conditions and recovery takes place when the weather improves. It is easily cured by formalin footbath treatment.

Further details on the pathology of the disease and the causative

bacterial development are contained in Murnane (1933), Thomas (1962), Egerton *et al.* (1966), Parsonson *et al.* (1967), Roberts *et al.* (1968), Anon., (1969), Egerton *et al.* (1969) and Egerton (1979).

Abnormal shape of the hoof

"Conditions" of abnormal shape of the hoof may occur as a result of the footrot infection or it may occur as a result of other environmental factors (e.g. nature of the ground surface). All malformations of the hoof may be regarded as "abnormal shape" and this may have some importance in predisposing the animal to footrot.

C - PREDISPOSING FACTORS

Foot scald, footrot, and abnormal shape of hoof vary widely according to locality, climate, season, management and source of breed of sheep (Skerman, 1976).

The micro-organisms which cause footrot and scald can survive inside the foot for years and, when warm wet weather occurs, the spread of these organisms from one sheep to others in the flock may be rapid. Thus dense pastures, high stocking rates, high soil moisture, and generally favourable conditions will play an important role in transmitting the organisms (Barber, 1979). The infection may be picked up in railway trucking yards or on stock routes through districts where the infection is common.

As an example of the effect of the above factors, the incidence

of footrot in the south-east and south-west of Australia is much higher than in its northern parts. Such variation in the incidence of footrot between the two regions was attributed to higher rainfall in the south of Australia and drier season in the north (Fitzpatrick, 1961).

Parsonson *et al.* (1967) observed a higher incidence of ovine interdigital dermatitis (scald) during winter than during summer. However, the district under observation by Parsonson *et al.* (1967) had a predominantly winter rainfall and it was possible that the prevalence of both scald and footrot was increased by wet underfoot conditions rather than the cold temperatures during winter. Belschner (1956) concluded that footrot is active in a mob of sheep when the seasonal conditions are favourable and infection is spread over the pasture and is rapidly picked up by healthy sheep when predisposing factors exist.

It is believed that physical damages to the interdigital space or to the hoof might lead to infections (Beveridge, 1934; Belschner, 1956; Roberts *et al.*, 1968; Cross, 1978). As possible examples of physical damage, both Beveridge (1934) and Roberts *et al.*, (1968) referred to sheep walking on stones, stubble or thistles, friction between the digits, or penetration of the digits by barley grass seed. Such physical damage has been simulated experimentally by either scarifying or incising the interdigital skin (Parsonson *et al.*, 1967; Egerton *et al.*, 1969), or skin-horn (Cross, 1978). These conditions successfully predisposed the animals' feet to infection by footrot and scald organisms.

Graham and Egerton (1968) and Cross (1978) stressed the importance of warmth in the transmission of the organisms which cause scald and footrot. Further, Barber (1979) has reported that long, misshapen hooves harbour pus, mud, faeces and dead tissue and this may be attractive to footrot and scald organisms.

In contrast, when hot dry weather conditions occur, footrot and scald are rare and affected sheep frequently recover spontaneously. These "conditions" are also uncommon on hill pastures where stocking rates and soil pH are low (Barber, 1979; Norman and Hohenboken, 1979).

Sheep of all ages are susceptible to footrot and other foot diseases, although it is usually of less consequence in lambs (Roberts *et al.*, 1968; Quinlivan and Lindsay, 1971; Misra and Singh, 1976). Rams are often severely affected and the condition is more difficult to cure in them (Thomas, 1962). Foot diseases were observed more often in ewes close to lambing than in dry sheep (Roberts *et al.*, 1968) and in lambing ewes the infection was largely confined to the hind feet.

Although Moore (1957) generally had assumed that black horn is higher in resistance to footrot than lighter coloured horn, several early reports (Murnane, 1933; Moore, 1957) have suggested there is no difference in resistance to footrot of different breeds of sheep. This was emphasized in a report from India (Misra and Singh, 1976). They studied lambs of Coimbatore, Corriedale and their crosses, and found that there was no significant difference in the incidence of

the footrot in the lambs of the different genetic groups. However, other reports emphasize breed differences in the resistance to footrot (Beveridge, 1941; Skerman, 1976; Barber, 1979; Norman and Hohenboken, 1979).

Beveridge (1941) and Barber (1979) have suggested that Merinos and Corriedale are more susceptible to footrot than either crosses with British breeds or the pure British breeds such as the Suffolk, Dorset Horn, Romney and Cheviot. The Romney is purported to be more resistant than most other British breeds. Norman and Hohenboken (1979) observed the incidence of footrot on 400 ewes from eight crossbred groups (North Country Cheviot, Dorset, Finn or Romney sires x Suffolk or Columbia-type dams) on seven occasions. They found that breed of the ewe's dam was a significant source of variation in footrot incidence in two of the seven scoring periods, but neither breed (Columbia nor Suffolk) tended to rank consistently above the other for apparent susceptibility. Also they noticed a lack of consistency in ranking for breed of the ewe's sire, because in only the last scoring period did the Finn sheep have significantly higher scores than other breeds. Variation in footrot scores among progeny of individual sires was also noted and found to be significant for all breeds except the Romney in at least one sampling period and/or birth year. However, the effect of sires within breeds and years was not significant in any scoring period. According to the above results, Norman and Hohenboken (1979) concluded that no consistent footrot score differences could be attributed to breed of the ewe's dam, breed of the ewe's sire or age of the ewe, but ewes on irrigated pastures generally had a higher incidence of footrot than ewes on hill pastures.

Information about estimates of heritability and repeatability of different sheep foot "conditions" is not available. But Norman and Hohenboken (1979) calculated the repeatability of footrot in sheep bred on irrigated and hill pastures to be 0.02 and 0.00 respectively.

D - TREATMENT AND CONTROL

An understanding of the nature of the foot diseases and the characteristics of the causative organisms permits several approaches to control and treatment. These are foot care, the use of topical and parenteral antibacterials, eradication and vaccination. More details on these methods may be obtained from Skerman and Cairney (1972), Cooper (1973), Barber (1979), Cross and Parker (1981a, b) and Tweddle (1981).

The best approach in the long term is probably to select for animals showing any natural immunity to infection (Skerman, 1976; Norman and Hohenboken, 1979). Unfortunately, little is known of natural resistance to footrot and scald, or of their heritability estimates, but close attention to hoof conformation and the culling of chronic cases when selecting breeding stock, may assist in breeding an "easy-care" flock.

CHAPTER SEVEN

MATERIALS AND METHODS

A - OUTLINE

The three foot characteristics of abnormal foot shape, foot scald and footrot were assessed by scoring the animal according to standard procedure. The observations were made on Perendale and Booroola Merino crossbred animals born in 1980 and 1981. Table 7.1 shows the general design of the trial, while Table 7.2 shows the details of sires that were used to generate the flocks on which foot characteristics were examined.

The scoring of the foot characteristics was carried out in a farm wool-shed. On all occasions of inspection of the feet two observers made the assessments. Every individual sheep was held so that all its four feet were facing the observer. Every foot of each sheep was carefully inspected before the result was recorded.

B - SCORING SYSTEM

1 - Foot Shape

A scoring system of 1 - 5 was used. The score depended upon the condition of the hoof and the normality of its shape. Extremely bad shape was scored as 1, while feet of good shape scored 5.

The four digits of each animal were thoroughly examined and scored. Each animal was given one score (in the range of 1 - 5) to describe the condition of all its feet, rather than four scores, one

TABLE 7.1 DETAILS OF THE YEAR OF BIRTH OF ANIMALS, NUMBER OF SIRES, NUMBER OF ANIMALS AND DATE OF OBSERVATIONS.

TAG YEAR	BREED	-LAMB		HOGGET		TWO-TOOTH-	
		RAM	EWE	RAM-	EWE-	RAM	EWE
1980	Perendale (7 sires)	9/12/1980 (253)	9/12/1980 (267)		2/7/1981 (262)		23/3/1982 (161)
	(Booroola x Romney) x Perendale (6 sires)	9/12/1980 (321)	9/12/1980 (304)		2/7/1981 (315)		23/3/1982 (273)
	Booroola x Romney (3 sires)	9/12/1980 (66)	9/12/1980 (53)		2/7/1981 (52)		
1981	Perendale (6 sires)	9/12/1981 (291)	9/12/1981 (264)	11/3/1982 (277)			
	(Booroola x Romney) x Perendale (12 sires)	14/12/1981 (361)	14/12/1981 (339)	11/3/1982 (354)			

TABLE 7.2 DETAILS OF THE ORIGIN AND NUMBER OF SIRES USED.

PERENDALE SIRES		INVERMAY RES. CENTRE BOORoola-ROMNEY SIRES		TARA HILL BOORoola SIRES	
(1)	752/78	(1)	314	(1)	81
(2)	772/78	(2)	320	(2)	212
(3)	768/78	(3)	413	(3)	230
(4)	765/78	(4)	115		
(5)	778/78	(5)	119		
(6)	906/78	(6)	102		
(7)	844/78				
	Joined with Perendale ewes in 1980.		Joined with Perendale ewes in 1980.		Joined with Romney ewes in 1980.
(8)	81/76	(7)	196/80		
(9)	813/79	(8)	137/80		
(10)	943/79	(9)	155/80		
(11)	982/79	(10)	158/80		
(12)	929/79	(11)	177/80		
(13)	843/79	(12)	191/80		
	Joined with Perendale ewes in 1981.	(13)	126/80		
		(14)	139/80		
		(15)	152/80		
		(16)	144/80		
		(17)	134/80		
		(18)	132/80		
			Joined with Perendale ewes in 1981.		

† These sires were generated from the matings between the three Tara Hill Booroola sires with Romney ewes in 1980.

for each of its digits.

2 - Foot Scald and Footrot

A score of 0 - 4 was used. The score depended upon the number of feet which had scald (0 = no feet affected; 4 = all feet with scald). A similar system was used to rank footrot with a score of 0 - 4. These showed the number of affected digits.

3 - Reading the Scores

Each foot characteristic was separately inspected and separately scored in the order of foot shape, scald and footrot.

C - ANALYSIS OF DATA

Data (scores) on feet characteristics (foot shape, foot scald and footrot) were analysed, after transformation to the logit scale, using techniques developed by A.R. Gilmour (at Massey University). Significance tests were based on analysis of deviance.

The general form of the linear model used to describe the data is given below. Depending upon the circumstances, the model and sub-models thereof were used.

$$y_{ijkl} = \mu + \alpha_i + \beta_j + S_k + (S\alpha)_{ik} + (S\beta)_{jk} + e_{ijkl}$$

Where

$$y_{ijkl} = \text{the } l^{\text{th}} \text{ record taken on } i^{\text{th}} \text{ year, } j^{\text{th}} \text{ breed} \\ \text{and } k^{\text{th}} \text{ sex of animals.}$$

μ = the general mean.

α_i = the fixed effect of i^{th} year.

β_j = the fixed effect of j^{th} breed.

γ_k = the fixed effect of k^{th} sex.

$(\alpha\gamma)_{ik}$ = the interaction effect between i^{th} year and k^{th} sex.

$(\beta\gamma)_{jk}$ = the interaction effect between j^{th} breed and k^{th} sex.

e_{ijkl} = the residual effect peculiar to l^{th} record on the ijk^{th} individual. Residual effects were assumed to be independently and identically distributed with mean zero and after transformation of the data, common variance.

Techniques used in the analysis were able to estimate the sire effect (within breed) which was included in the residual effect.

Appendices I and II show the data recorded in 1980 and 1981 respectively. These data are from the computer print-out.

In the following chapter abbreviations for levels of significance are:

NS	=	non significant or $P > 0.05$
*	=	$P < 0.05$
**	=	$P < 0.001$
***	=	$P < 0.001$

D - HERITABILITY ESTIMATION

Heritability of each foot characteristic (foot shape, foot scald and footrot) score was estimated using the following equation (Falconer, 1975, page 175).

$$h^2 = 4 \times r_I$$

where

$$h^2 = \text{the estimated heritability.}$$

$$r_I = \text{the estimated intraclass correlation.}$$

E - REPEATABILITY ESTIMATION

Feet of 97 (Booroola x Romney) x Perendale rams were scored twice (a.m. and p.m.) on 10 March 1982 for the incidence of abnormal foot shape, foot scald and footrot. The feet were scored by two observers at each time separately and randomly.

Two techniques, to estimate the intraclass correlation (r_I) of foot shape, were used. Firstly, r_I was estimated on the underlying scale using a mixed logit model for threshold characters implemented in REG (Gilmour, 1983). Secondly, r_I was estimated on the observed

scale basis of usual analysis of variance, as indicated by the following equation.

$$r_I = \frac{\sigma_s^2}{\sigma_s^2 + \sigma_e^2} \quad (\text{Falconer, 1975})$$

CHAPTER EIGHT

RESULTS

A - REPEATABILITY AND HERITABILITY

Appendices IV and V give data for foot scald and footrot scores. The repeatability of each of these characteristics was not calculated because of their low incidence.

Appendix III gives the data of foot shape scores. Tables 8.1 and 8.2 show the analysis of deviance and analysis of variance of foot shape scores respectively, on which estimation of repeatability of foot shape was based.

The repeatability (or intraclass correlation) of foot shape estimated on the basis of the logit scale was 0.73, and when estimated on the basis of analysis of variance was 0.63.

Table 8.3 shows the heritability estimates of foot characteristics of the different classes of sheep.

B - FOOT SHAPE

Average foot shape score is shown in Appendices VI, VII, VIII, IX and X for all classes and breeds of animals involved in the trial. Perendale sheep showed higher average foot shape score than (Booroola x Romney) x Perendale ((Boor. x Rom.) x Per.) and Booroola x Romney (Boor. x Rom.) sheep. On one occasion (9/12/1981), (Boor. x Rom.) x Per. showed higher average foot shape score than did Perendale

TABLE 8.1 ANALYSIS OF DEVIANCE OF FOOT SHAPE SCORE ON WHICH ESTIMATION OF REPEATABILITY WAS BASED.

SOURCE OF VARIATION	D.F.	DEVIANCE
TIME (a.m. v p.m.)	2	7.24 *
OBSERVERS	2	3.80 NS
OBSERVER x TIME	2	0.74 NS
RESIDUAL	768	690.16

$$r_I = 0.73$$

(Note: The degrees of freedom are twice what might be expected because the trait was analysed as a double threshold trait.)

TABLE 8.2 ANALYSIS OF VARIANCE OF FOOT SHAPE SCORE ON WHICH ESTIMATION OF REPEATABILITY WAS BASED.

SOURCE OF VARIATION	D.F.	MS	F-RATIO
TIME (a.m. v. p.m.)	1	3.528	20.36 ***
OBSERVERS	1	0.3118	1.80 NS
OBSERVER x TIME	1	0.0232	0.133 NS
ANIMALS	96	1.3594	7.84 ***
RESIDUAL	288	0.1732	

$$\sigma_e^2 = 0.1732$$

$$\sigma_e^2 + 4\sigma_s^2 = 1.3594$$

$$\sigma_s^2 = 0.29655$$

$$\text{since } r_I = \frac{\sigma_s^2}{\sigma_e^2 + \sigma_s^2}$$

$$\therefore r_I = \frac{0.29655}{0.1732 + 0.29655} = 0.63129$$

TABLE 8.3 ESTIMATES OF HERITABILITY OF SHEEP FOOT CHARACTERISTICS AT DIFFERENT AGES.

FOOT CHARACTERISTIC	AGE OF ANIMAL	HERITABILITY
FOOT SHAPE	LAMB	0.170 or 0.165†
	HOGGET	0.347 or 0.330†
	TWO-TOOTH	0.204 or 0.257†
FOOT SCALD	LAMB	0.523
	HOGGET	0.012
	TWO-TOOTH	0.451
FOOTROT	LAMB	0.228
	HOGGET	0.340
	TWO-TOOTH	0.02

† The first figure was estimated using the 5, 4 and <4-type of scores of foot shape in the analysis of deviance on which estimates of heritability were derived, while the second figure was estimated using only 5 and 4-type of scores in the analysis.

lambs (Appendix IX).

Tables from 8.4 to 8.9 present the analyses of deviance of foot shape scores for lambs, hoggets and two-tooth sheep born in 1980 and 1981.

1 - Year

At lamb-age, there were highly significant differences ($P(\chi^2) < 0.001$) in foot shape scores between 1980 and 1981. These significant differences persisted up to hogget-age of sheep, when they were reported to be significant at ($P(\chi^2) < 0.001$).

2 - Breed

There were highly significant differences ($P(\chi^2) < 0.001$) in foot shape scores between Perendale lambs compared with both (Boor. x Rom.) x Per. and Boor. x Rom. lambs born in 1980 and 1981. Furthermore, in 1980-born lambs, foot shape scores of (Boor. x Rom.) x Per. differed significantly ($P(\chi^2) < 0.001$) compared with Boor. x Rom. Using only 5 and 4 as foot shape scores in the analysis of deviance (Table 8.5), foot shape scores of Perendale lambs born in 1981 did not differ significantly from those of (Boor. x Rom.) x Per. lambs.

Significant differences ($P(\chi^2) < 0.001$) were found in hogget foot shape scores of 1980-born Perendale compared with Boor. x Rom., while there were no significant differences in foot shape scores between 1980-born Perendale and both (Boor. x Rom.) x Per. and Boor. x Rom. On the other hand, highly significant differences ($P(\chi^2) < 0.001$) were reported between Perendale and (Boor. x Rom.) x Per. hoggets

born in 1981.

In 1980-born two-tooth rams, there were significant differences ($P(\chi^2) < 0.001$) in foot shape scores between Perendale and (Boor. x Rom.) x Per.

3 - Sex

For lambs born in 1980 and 1981, there were no significant differences in foot shape scores between ram lambs and ewe lambs. But using only 5 and 4 as foot shape scores in the analysis of deviance (Table 8.5) of the same lambs, there were significant differences at ($P(\chi^2) < 0.05$) in foot shape scores between the two sexes.

Interaction between sex and year did not significantly affect the lamb foot shape scores. Also, there was no significant effect of interaction between sex of lamb and sheep's genetic make-up on foot shape scores.

4 - Sire Effect

Figures 8.1 and 8.2 show the predicted breeding values of the sires based on foot shape scores of progeny born in 1980 and 1981 respectively. These figures show the variability among the breeding values of the different sires, which emphasizes the significant differences in the foot shape scores due to sire effect at lamb age ($P(\chi^2) < 0.001$) and hogget age ($P(\chi^2) < 0.001$). But, two-tooth sheep foot shape scores showed no significant effect of sire.

TABLE 8.4 ANALYSIS OF DEVIANCE OF LAMB FOOT SHAPE SCORE
(5, 4 AND <4-TYPE OF SCORES).

SOURCE OF VARIATION	D.F.	DEVIANCE
1980 v 1981	2	41.66 ***
1980 Per. v (Boor. x Rom.) x Per.; Boor. x Rom.	2	63.54 ***
1980 (Boor. x Rom.) x Per. v Boor. x Rom.	2	30.23 ***
1981 Per. v (Boor. x Rom.) x Per.	2	18.95 ***
SEX	2	5.27 NS
SEX x YEAR	2	0.07 NS
SEX x Per. v (Boor. x Rom.) x Per.; Boor. x Rom., 80	2	3.73 NS
SEX x Per. v Boor. x Rom., 80	2	0.20 NS
SEX x Per. v (Boor. x Rom.) x Per., 81	2	0.61 NS
RESIDUAL	116	203.82

TABLE 8.5 ANALYSIS OF DEVIANCE OF LAMB FOOT SHAPE SCORE
(5 AND 4-TYPE OF SCORES).

SOURCE OF VARIATION	D.F.	DEVIANCE	
1980 v 1981	1	22.26	***
1980 Per. v (Boor. x Rom.) x Per.; Boor. x Rom.	1	50.08	***
1980 (Boor. x Rom.) x Per. v Boor. x Rom.	1	22.76	***
1981 Per. v (Boor. x Rom.) x Per.	1	2.37	NS
SEX	1	4.03	*
SEX x YEAR	1	0.02	NS
SEX x Per. v (Boor. x Rom.) x Per.; Boor. x Rom., 80	1	3.75	NS
SEX x Per. v Boor. x Rom., 80	1	0.17	NS
SEX x Per. v (Boor. x Rom.) x Per., 81	1	0.58	NS
SIRE VARIANCE)		94.49)	***
)	58) 138.98	
RESIDUAL)		44.49)	

TABLE 8.6 ANALYSIS OF DEVIANCE OF HOGGET FOOT SHAPE SCORE
(5, 4 AND <4-TYPE OF SCORES).

SOURCE OF VARIATION	D.F.	DEVIANCE
1980 v 1981	2	62.91 ***
1980 Per. v (Boor. x Rom.) x Per.; Boor. x Rom.	2	2.21 NS
1980 (Boor. x Rom.) x Per. v Boor. x Rom.	2	12.56 ***
1981 Per. v (Boor. x Rom.) x Per.	2	30.40 ***
RESIDUAL	58	148.05

TABLE 8.7 ANALYSIS OF DEVIANCE OF HOGGET FOOT SHAPE SCORE
(5 AND 4-TYPE OF SCORES).

SOURCE OF VARIATION	D.F.	DEVIANCE
1980 v 1981	1	62.81 ***
1980 Per. v (Boor. x Rom.) x Per.; Boor. x Rom.	1	1.22 NS
1980 (Boor. x Rom.) x Per. v Boor. x Rom.	1	12.31 ***
1981 Per. v (Boor. x Rom.) x Per.	1	30.18 ***
SIRE VARIANCE)	79.53)	***
RESIDUAL)	29)	95.86
	16.33)	

TABLE 8.8 ANALYSIS OF DEVIANCE OF TWO-TOOTH RAM FOOT SHAPE SCORE (5, 4 AND <4-TYPE OF SCORES).

SOURCE OF VARIATION	D.F.	DEVIANCE
1980 Per. v (Boor. x Rom.) x Per.	2	39.86 ***
RESIDUAL	22	40.31

TABLE 8.9 ANALYSIS OF DEVIANCE OF TWO-TOOTH RAM FOOT SHAPE SCORE (5 AND 4-TYPE OF SCORES).

SOURCE OF VARIATION	D.F.	DEVIANCE
1980 Per. v (Boor. x Rom.) Per.	1	32.46 ***
SIRE VARIANCE)	21.96)	***
)	11)	31.15
RESIDUAL)	9.19)	

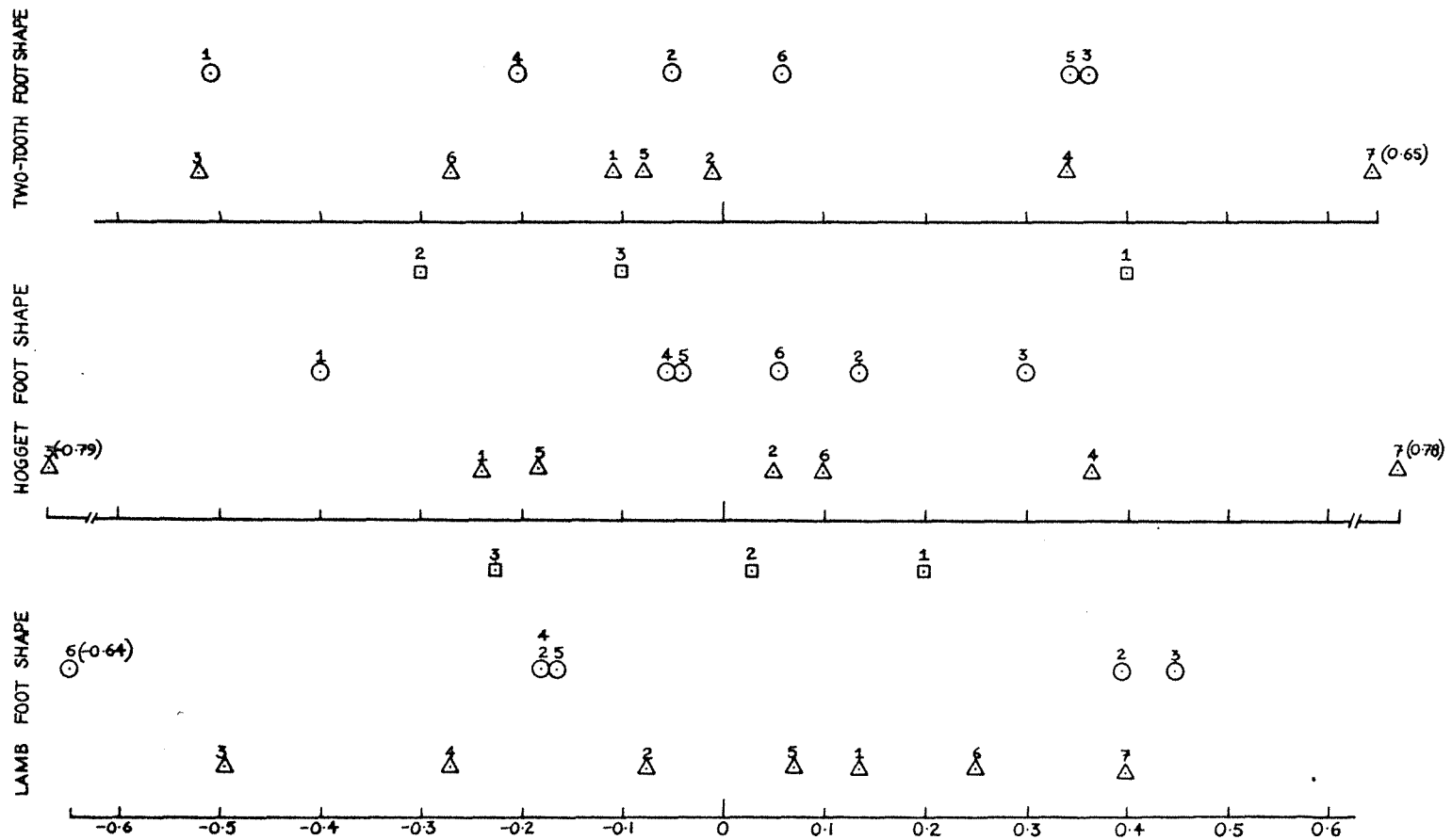


FIG 8-1 PREDICTED BREEDING VALUES OF SIRES BASED ON FOOT SHAPE SCORES OF PROGENY BORN IN 1980. (VALUES CALCULATED FROM DATA AT LAMB, HOGGET AND TWO-TOOTH AGES). Δ PERENDALE SIRES; ○ BOORoola X ROMNEY SIRES; □ BOORoola SIRES.

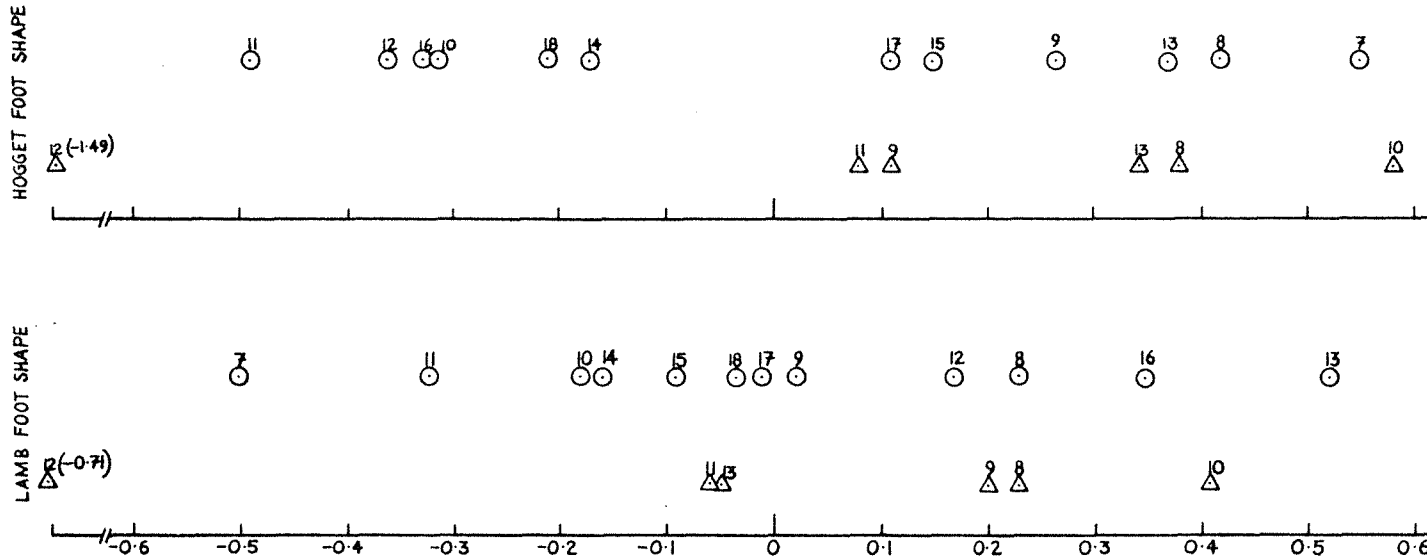


FIG 8-2 PREDICTED BREEDING VALUES OF SIRES BASED ON FOOT SHAPE SCORES OF PROGENY BORN IN 1981, (VALUES CALCULATED FROM DATA AT LAMB AND HOGGET AGES). Δ PERENDALE SIRES; \circ BOORoola X ROMNEY SIRES.

C - FOOT SCALD

The number and percentage of animals with foot scald as well as the number and percentage of feet with scald in all classes and breeds of sheep which were used in the trial, are indicated in Appendices VI, VII, VIII, IX and X. It was evident that Perendale sheep had the lowest incidence of scald compared with Booroola crosses of 1980 and 1981.

Tables 8.10, 8.11 and 8.12 present the analyses of deviance of foot scald scores of 1980- and 1981-born lambs, hoggets and two-tooth sheep respectively.

1 - Year

Table 8.10 indicates that there was no significant difference in foot scald between lambs born in 1980 compared with lambs born in 1981. In contrast, Table 8.11 shows highly significant difference ($P(x^2) < 0.001$) in foot scald incidence between hoggets born in 1980 compared with hoggets born in 1981.

2 - Breed

In 1980-born lambs, significant differences ($P(x^2) < 0.001$) were reported in foot scald scores between Perendale sheep compared with (Boor. x Rom.) x Per. and Boor. x Rom. sheep, while significant differences in foot scald scores could not be detected between (Boor. x Rom.) x Per. and Boor. x Rom. lambs born in the same year.

Table 8.11 reveals that in 1980-born hoggets, there were highly significant differences ($P(x^2) < 0.001$) in foot scald scores between

Perendale and both (Boor. x Rom.) x Per. and Boor. x Rom. But such differences could not be found between the Booroola crosses.

There were no significant differences in foot scald scores between Perendale rams and (Boor. x Rom.) x Per. rams born in 1980 at two-tooth age.

3 - Sex

Table 8.10 indicates that highly significant differences ($P(\chi^2) < 0.001$) were found in foot scald scores between ram lambs and ewe lambs of all genetic make-up born in 1980 and 1981. However, in 1981-born Perendale lambs no incidence of foot scald could be observed in both sexes (Appendix IX).

Sex x Year interaction did not have significant effect on the incidence of foot scald in lambs. Also, there were no significant effects of Sex x Breed interactions on foot scald incidence in lambs born in 1980.

4 - Sire Effect

Figures 8.3 and 8.4 show the predicted breeding values of the sires based on foot scald scores of progeny born in 1980 and 1981 respectively. Also, these figures reveal the variability among the breeding values of the different sires, which emphasizes the significant differences in the foot scald scores due to the sire effect at lamb age ($P(\chi^2) < 0.001$) (Table 8.10), and at two-tooth age ($P(\chi^2) < 0.001$) (Table 8.12). But, there was no significant sire effect on foot scald incidence in hoggets (Table 8.11).

TABLE 8.10 ANALYSIS OF DEVIANCE OF LAMB FOOT SCALD SCORE.

SOURCE OF VARIATION	D.F.	DEVIANCE	
1980 v 1981	1	3.21	NS
1980 Per. v (Boor. x Rom.) x Per. ; Boor. x Rom.	1	32.01	***
1980 (Boor. x Rom.) x Per. v Boor. x Rom.	1	0.79	NS
¹⁹⁸¹ SEX	1	23.17	***
SEX x YEAR	1	0.07	NS
SEX x Per. v (Boor. x Rom.) x Per. : Boor. x Rom., 80	1	1.73	NS
SEX x Per. v (Boor. x Rom.) x Per., 80	1	0.00	NS
SIRE VARIANCE)	34.57)		***
)	48)	104.28	
RESIDUAL)	69.71)		

TABLE 8.11 ANALYSIS OF DEVIANCE OF HOGGET FOOT SCALD SCORE.

SOURCE OF VARIATION	D.F.	DEVIANCE	
1980 v 1981	1	69.07	***
1980 Per. v (Boor. x Rom.) x Per.: Boor. x Rom.	1	69.57	***
1980 (Boor. x Rom.) x Per. v Boor. x Rom.	1	0.10	NS
1981 SIRE VARIANCE)	3.27)		NS
))		
)	24)	41.38	
RESIDUAL)	38.11)		

TABLE 8.12 ANALYSIS OF DEVIANCE OF TWO-TOOTH RAM FOOT SCALD SCORE.

SOURCE OF VARIATION	D.F.	DEVIANCE	
1980 Per. v (Boor. x Rom.) x Per.	1	0.06	NS
SIRE VARIANCE)	5.85)		*
))		
)	11)	20.69	
RESIDUAL)	14.84)		

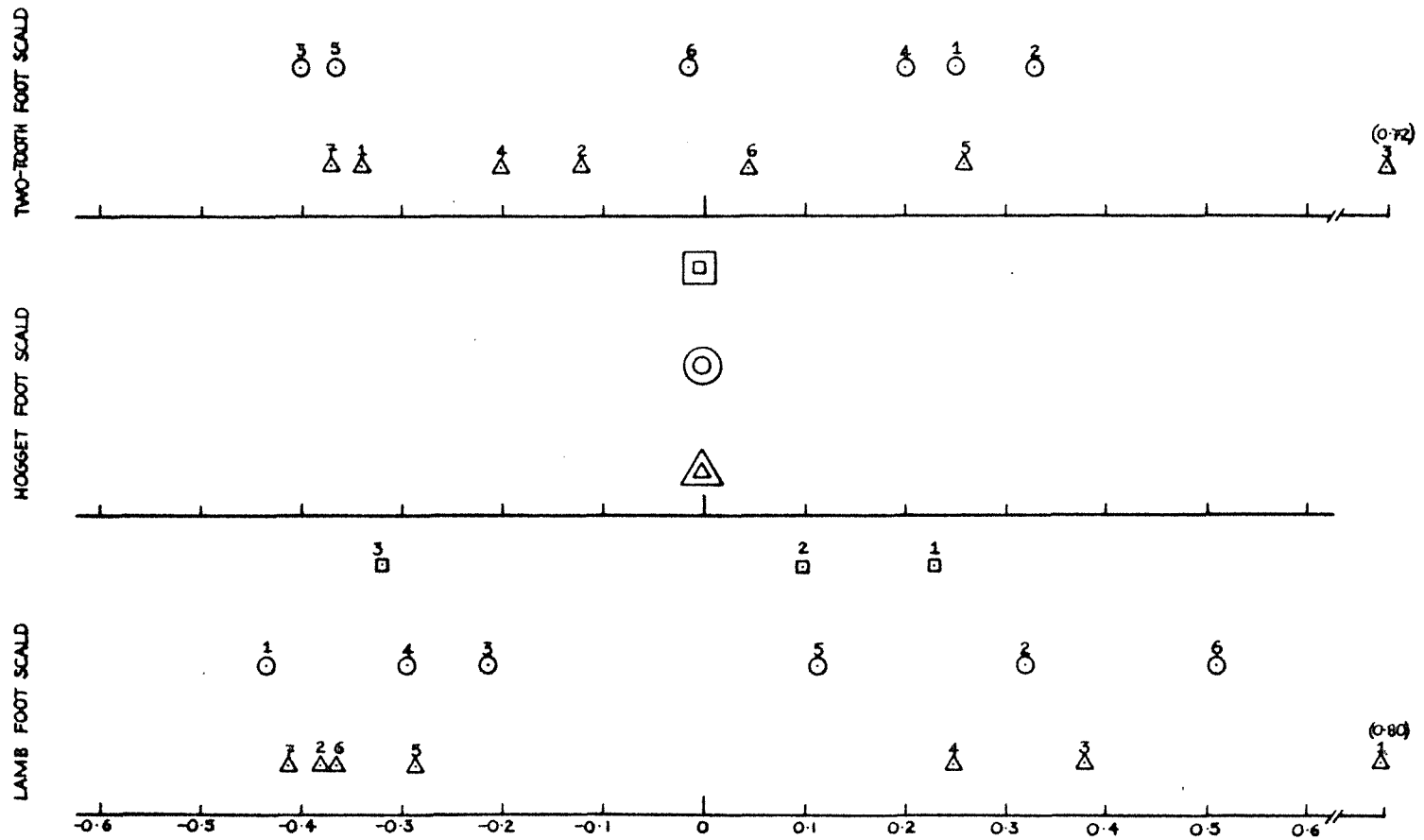


FIG 8-3 PREDICTED BREEDING VALUES OF SIRES BASED ON FOOT SCALD SCORES OF PROGENY BORN IN 1980, (VALUES CALCULATED FROM DATA AT LAMB, HOGGET AND TWO-TOOTH AGES). Δ PERENDALE SIRES; ○ BOORoola X ROMNEY SIRES; □ BOORoola SIRES.

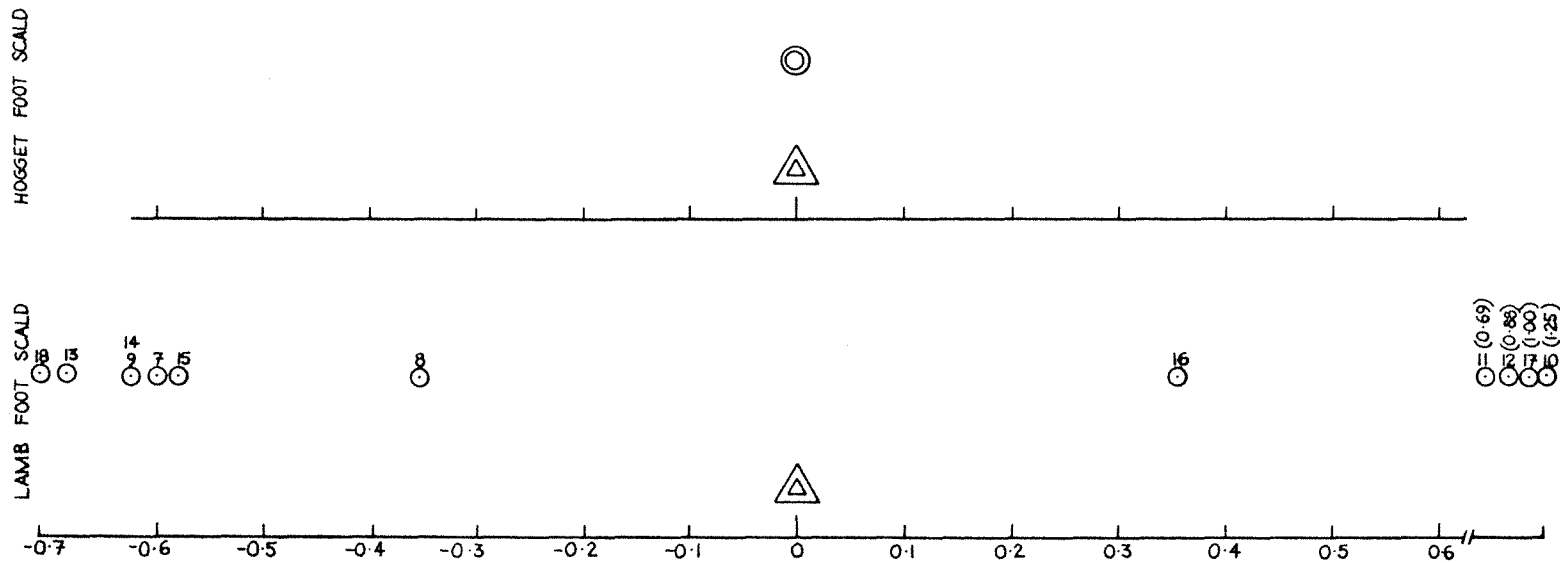


FIG 8.4 PREDICTED BREEDING VALUES OF SIRES BASED ON FOOT SCALD SCORES OF PROGENY BORN IN 1981,
 (VALUES CALCULATED FROM DATA AT LAMB AND HOGGET AGES). Δ PERENDALE SIRES;
 \circ BOORoola X ROMNEY SIRES.

D - FOOTROT

The number and percentage of animals with footrot as well as the number and percentage of feet with footrot in all classes and of different genetic make-up of sheep used in the trial, are given in Appendices VI, VII, VIII, IX and X. Perendale sheep tended to have a lower incidence of footrot than did (Boor. x Rom.) x Per. and Boor. x Rom. sheep.

Tables 8.13, 8.14 and 8.15 present the analyses of deviance of footrot scores of 1980- and 1981-born lambs, hoggets and two-tooth sheep respectively.

1 - Year

Table 8.13 indicates that there was no significant difference in the incidence of footrot in lambs born in 1980 compared with lambs born in 1981. Table 8.14 shows there was no significant difference in footrot incidence in the hoggets born in 1980 compared with hoggets born in 1981. However, Perendale sheep born in 1981 showed no incidence of footrot at both lamb and hogget ages compared with sheep of the same breed born in 1980. (Boor. x Rom.) x Per. lambs showed similar percentages of footrot incidence in both years, but at hogget age they showed a higher incidence of footrot in 1981 than in 1980.

2 - Breed

Table 8.13 indicates that, in 1980-born lambs, significant differences ($P(x^2) < 0.05$) in footrot scores were found between Perendale sheep and both (Boor. x Rom.) x Per. and Boor. x Rom. sheep.

However, there was no significant difference in the incidence of footrot between the Booroola crosses.

Table 8.14 reveals that in hoggets born in 1980, there were highly significant differences ($P(\chi^2) < 0.001$) in footrot scores in Perendale compared with the Booroola crosses. On the other hand, there were no significant differences in footrot scores between (Boor. x Rom.) x Per. and Boor. x Rom.

Table 8.15 shows that highly significant differences ($P(\chi^2) < 0.001$) were found in the incidence of footrot in Perendale two-tooth rams compared with (Boor. x Rom.) x Per. two-tooth rams, born in 1980.

3 - Sex

Table 8.13 shows that there was no significant difference in footrot scores between ram lambs and ewe lambs born either in 1980 or 1981.

There was no Sex x Year interaction on the incidence of footrot in lambs. There were no significant effects of Sex x Breed interactions on footrot scores in lambs born in 1980.

4 - Sire Effect

Figures 8.5 and 8.6 show the predicted breeding values of the sires based on footrot scores of progeny born in 1980 and 1981 respectively. These figures demonstrate the variability between the breeding values of the different sires, which emphasizes the

effects on the incidence of footrot due to sire at lamb age ($P(\chi^2) < 0.001$) (Table 8.1), and at hogget age ($P(\chi^2) < 0.001$) (Table 8.14). There was no significant effect of sire on the incidence of footrot in the two-tooth rams born in 1980 (Table 8.15).

TABLE 8.13 ANALYSIS OF DEVIANCE OF LAMB FOOTROT SCORE.

SOURCE OF VARIATION	D.F.	DEVIANCE	
1980 v 1981	1	0.07	NS
1980 Per. v (Boor. x Rom.) x Per.; Boor. x Rom.	1	7.50	*
1980 (Boor. x Rom.) x Per. v Boor. x Rom.	1	1.58	NS
SEX	1	0.01	NS
SEX x YEAR	1	0.99	NS
SEX x Per. v (Boor. x Rom.) x Per.; Boor. x Rom., 80	1	0.00	NS
SEX x Per. v (Boor. x Rom.) x Per., 80	1	0.01	NS
SIRE VARIANCE)	9.13)		**
)	48)	59.79	
RESIDUAL)	50.66)		

TABLE 8.14 ANALYSIS OF DEVIANCE OF HOGGET FOOTROT SCORE.

SOURCE OF VARIATION	D.F.	DEVIANCE	
1980 v 1981	1	0.34	NS
1980 Per. v (Boor. x Rom.) x Per.; Boor. x Rom.	1	25.65	***
1980 (Boor. x Rom.) x Per. v Boor. x Rom.	1	0.54	NS
SIRE VARIANCE)	31.56)		***
)	24)	53.86	
)			
RESIDUAL)	22.30)		

TABLE 8.15 ANALYSIS OF DEVIANCE OF TWO-TOOTH RAM FOOTROT SCORE.

SOURCE OF VARIATION	D.F.	DEVIANCE	
1980 Per. v (Boor. x Rom.) x Per.	1	15.49	***
SIRE VARIANCE)	0.12)		NS
)	11)	9.11	
)			
RESIDUAL)	9.99)		

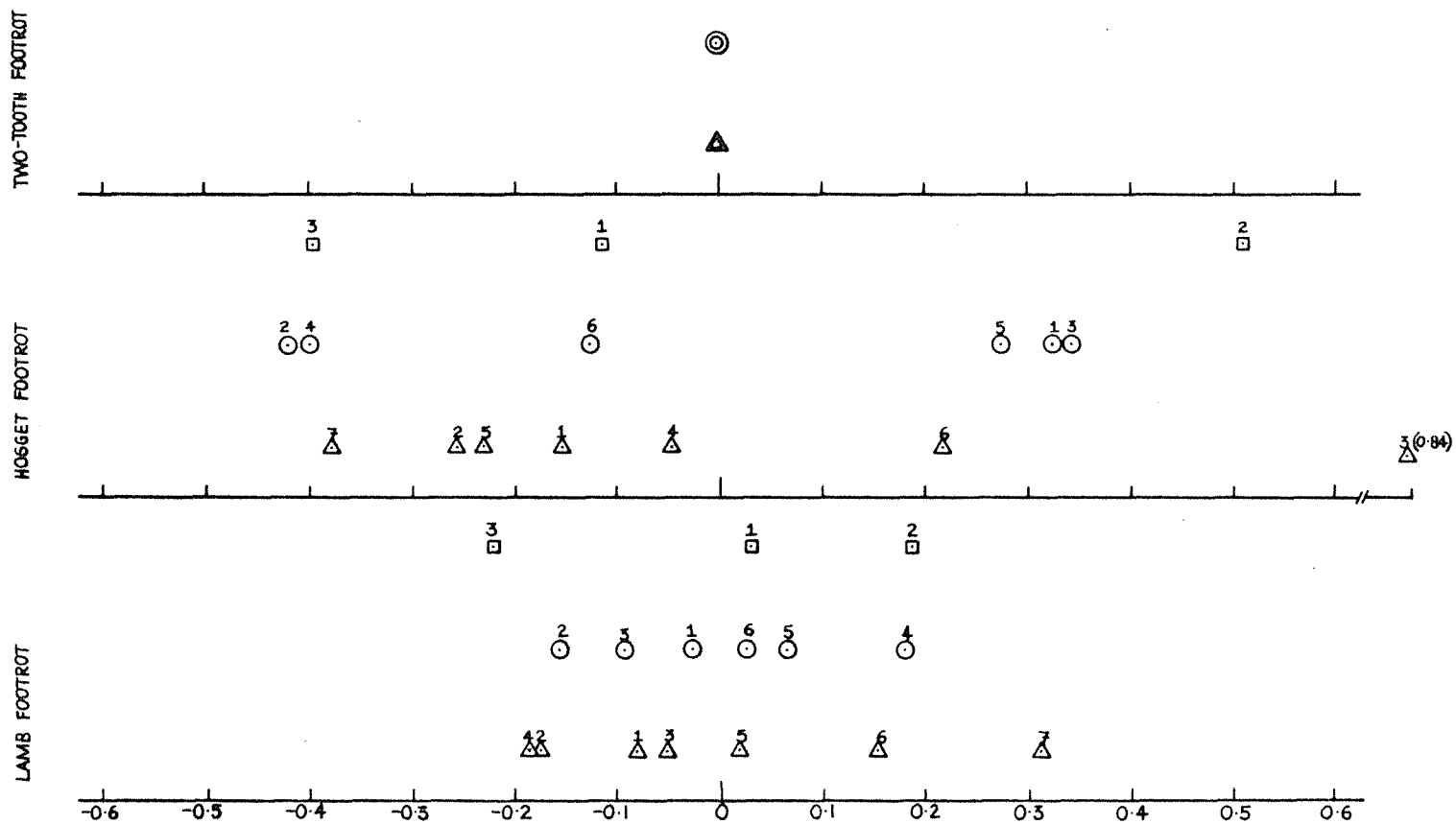


FIG 8.5 PREDICTED BREEDING VALUES OF SIRES BASED ON FOOTROT SCORES OF PROGENY BORN IN 1980, (VALUES CALCULATED FROM DATA AT LAMB, HOGGET AND TWO-TOOTH AGES). Δ PERENDALE SIRES ; \circ BOORoola X ROMNEY SIRES ; \square BOORoola SIRES.

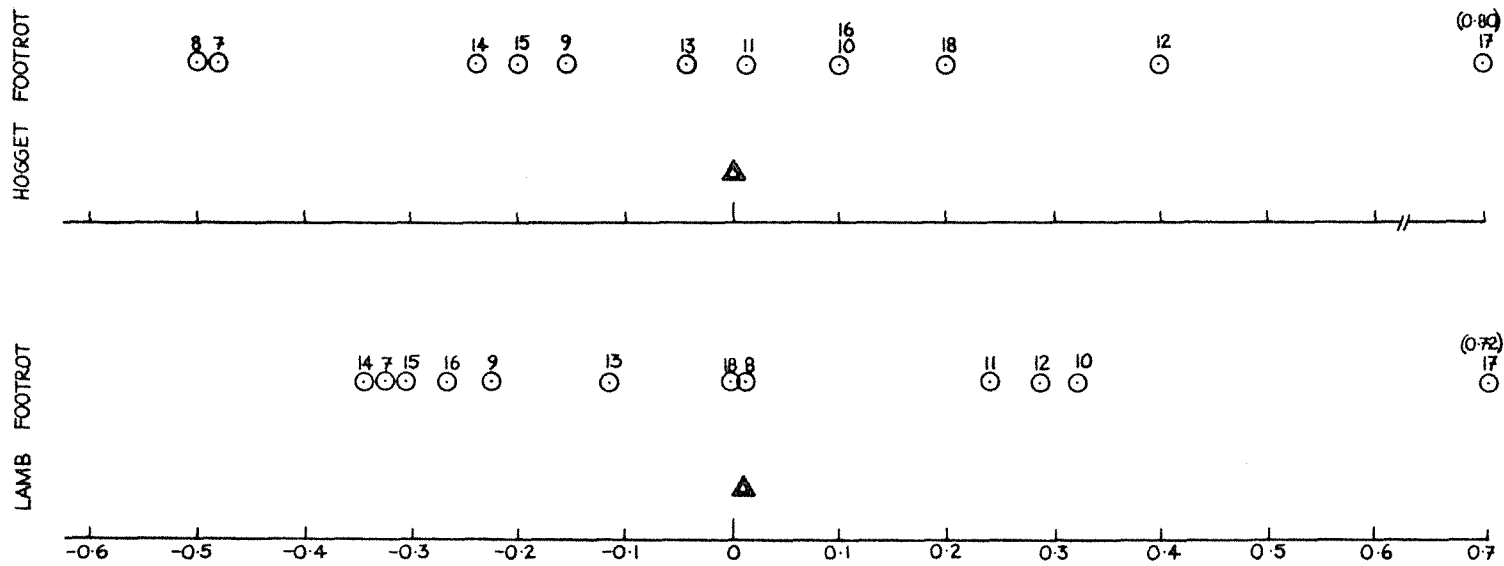


FIG 8.6 PREDICTED BREEDING VALUES OF SIRES BASED ON FOOTROT SCORES OF PROGENY BORN IN 1981, (VALUES CALCULATED FROM DATA AT LAMB AND HOGGET AGES). Δ PERENDALE SIRES; \circ BOORoola X ROMNEY SIRES.

CHAPTER NINE

DISCUSSION AND CONCLUSIONS

A - REPEATABILITY

Both values for estimates of repeatability of foot shape score are reasonably high. This may suggest that, despite the significant variation due to the time of scoring (a.m. and p.m.), there was consistency between the scores of the foot shape which were given by the two observers.

B - EFFECT OF BREED

The results of the trial have revealed generally a higher incidence of abnormal foot shape, foot scald and footrot in Booroola crosses compared with Perendale sheep. The results are in general agreement with the assumption that Merino sheep are more prone to foot diseases than other breeds of sheep, particularly those of British origin (Beveridge, 1941; Barber, 1979; Norman and Hohenboken, 1979). Since the Booroola is to be used in crosses with Romney and Perendale sheep to increase the fecundity of the flock, it should be realized that susceptibility to foot problems might occur and reduce part of the potential level of fecundity.

The significant differences in lamb and hogget foot shape scores between Booroola crosses themselves ((Boor. x Rom.) x Per. and Boor. x Rom.) would emphasize the importance of the proportion of Booroola 'blood' in each cross in contributing to increased abnormal foot shape. As the proportion of British breed 'blood' increased in the crosses

with Booroola, the resistance to foot diseases was enhanced. This is quite evident when comparing (Boor. x Rom.) x Per. with Boor. x Rom. sheep. (Boor. x Rom.) x Per. cross tended to have better feet than Boor. x Rom. cross.

C - EFFECT OF YEAR

Highly significant differences in foot shape scores occurred at both lamb and hogget ages. Differences in foot scald scores occurred only at the hogget age. In contrast, there was no significant difference in the incidence of footrot between the two years' groups of animals.

The climatic conditions in each year may have an important role in the incidence of abnormal foot shape for both lambs and hoggets as well as in the incidence of foot scald in hoggets. The main climatic factor which may have contributed to these differences is the total rainfall. Monthly and annual total rainfall in Tuapaka farm area in each year of trial are given in Appendix XI. The Tuapaka area had a higher annual rainfall in 1980 than in 1981. This difference in annual total rainfall may partly enable some of the between year effects to be explained.

D - EFFECT OF SEX

Results of analysis of foot characteristic scores revealed that ram lambs differed significantly from ewe lambs in the incidence of abnormal foot shape ($P(\chi^2) < 0.05$) and foot scald ($P(\chi^2) < 0.001$), but difference in the incidence of footrot between the two sexes was not

significant. The significant difference in the foot shape score between the two sexes was obtained using only "5 and 4-type" of scores in the analysis (and not for 5, 4 and <4-type of analysis).

The average foot shape grade and the incidence of both foot scald and footrot are given in Appendices VI and IX for 1980- and 1981-born lambs respectively. Ewe lambs had consistently higher average foot shape grade than ram lambs. Ram lambs had a high incidence of foot scald than ewe lambs in 1980 group of animals. Differences in the incidence of footrot between the two sexes were not apparent and consistent.

The results obtained tend to suggest that sex of lambs has an effect on the incidence of abnormal foot shape and foot scald, but not on footrot. Thomas (1962) reported that mature rams were much more susceptible to footrot than mature ewes, but his work did not involve observation on lambs.

Sex x Year and Sex x Breed interactions were not significant for any of the observed foot characteristics. It would appear that neither the year in which the lambs were born nor their breed had an effect on the incidence of the three foot "conditions" observed between ram lambs and ewe lambs.

The general trend of the results observed might indicate that lambs were much more resistant to foot diseases than either hoggets or two-tooth sheep. This observation seems to be in agreement with results reported by Roberts *et al.* (1968; Quinlivan and Lindsay (1971) and Misra and Singh (1976), who found that lambs of either

sex are less prone to foot diseases (notably footrot) than mature sheep.

E - EFFECT OF SIRE

There were considerable variations in the incidence of the foot characteristics over the trial period due to the effects of sires. But sire effect did not seem to significantly influence the incidence of foot scald in hoggets and footrot in two-tooth sheep.

The results indicate that significant variation in the incidence of the three foot characteristics is probably due to both differences between sires of each breed and between sires of different breeds. The ranks of the sires according to their breeding values for each foot characteristic at each age of sheep and in each year (Figures 8.1 to 8.6), do in fact show this to be the case.

The results revealed considerable variation between the breeding values of the sires based on their progeny foot characteristic scores. This variation may indicate that in addition to the environmental effects on each foot characteristic, there were probably genetic effects expressed differently at different ages of the progeny (G.A. Wickham, Pers. Comm.).

It was not possible to estimate the phenotypic correlation of each foot characteristic of the progeny of each sire. However, some idea as to how they are correlated can be obtained by examining the

data given in Appendices I and II. Figures from 8.1 to 8.6 show that, to some extent, there was consistency in the effect of sire within each breed on the incidence of each foot characteristic. In contrast, some sires positively affected the incidence of foot abnormalities by promoting the abnormal foot shape, and a high incidence of foot scald and footrot in their progeny at lamb age. At later ages ⁵ same sires did affect those characteristics negatively. Again, this may lead to the same conclusion that environmental and genetic effects operate differently at different ages.

The obtained results may suggest that sires of different breeds were a major source of variation in the incidence of foot abnormalities. Booroola and crossbred sires contributed more variation in abnormalities compared with Perendale sires over the trial period. The ranking and use of the sires, based on their breeding values, for a low incidence of the three foot abnormalities may be a possible method to enhance the natural resistance of the sheep against foot diseases.

F - HERITABILITY

The results show that estimates of heritability of foot shape, foot scald and footrot were higher at hogget-, lamb-, and hogget-ages respectively compared with other ages of the sheep for the same foot characteristic (Table 8.3). These estimates of heritability may suggest that effects of genetic variation on the incidence of abnormal foot shape, foot scald and footrot were clearly observed at hogget-, lamb-, and hogget ages respectively than at other ages

of sheep.

The size of the heritability estimates for these three foot characteristics may suggest that long-term selection against the incidence of abnormal foot shape, foot scald and footrot may reduce the incidence of these foot abnormalities in future generations. This suggestion has been made previously by Skerman (1976) and Norman and Hohenboken (1979) who did not calculate any estimate of heritability for each foot characteristic. However, the present results are in agreement with their suggestion, by which they emphasized the important role of mass selection to enhance the natural resistance against foot diseases in general and footrot in particular. Since these foot "conditions" are believed to be interrelated and subsequently one leads to the other (Barber, 1979), selection against any of them could result in a decline in their incidence in sheep.

G - GENERAL CONCLUSION

In this study there were clear indications that the incidence of the three foot "conditions" (abnormal foot shape, foot scald and footrot) was highest in the Booroola Merino crosses than in the Perendale sheep. Sires within breed and between breed had an important effect on the incidence of these foot "conditions" observed in their progeny. Sex of the animal also contributed to the variation in the incidence of abnormal foot shape and foot scald, but not of footrot. However, observations on foot "conditions" were only conducted at the lamb age in regard to any effect of sex. Environmental

factors (notably the annual rainfall) have an important effect in promoting the incidence of these foot "conditions". This is evident when breeding from sheep (e.g. Booroola Merinos) which are more susceptible to foot diseases in environments that might predispose to such faults.

Since there was significant variation in the incidence of the foot "conditions" due to between breed and between sire effects, it can be suggested that long-term selection programmes should include selection against these "conditions" and hopefully enhance natural resistance to such foot diseases. Mass selection and/or breeding from the selected sires which show a lower incidence of these foot "conditions", could lead to an increased resistance to foot diseases in future generations. Such predictions are based on the size of the estimates of heritability of the foot "conditions", as well as the predicted breeding values of the sires used in this study. The estimates of heritability and breeding values of the sires lead to the general conclusion that genetic variation in foot characteristics exists between different breeds of sheep and individuals. From the present study it is predicted that there would be a reasonable selection response to "foot problems".

Finally, it does appear that a long-term investigation of the general behaviour of genes which are responsible for the incidence of "foot problems" is required. Information from such work might be very useful in better understanding "foot problems" in sheep especially in wet environments where a high incidence of "foot problems" are likely to lower both the animals' and flock productivity.

APPENDICES

* * * * *

APPENDIX I SUMMARY OF FOOT CHARACTERISTICS DATA OF SHEEP BORN IN 1980.

SERIAL NO.	BREEDS	SEXES	SIRES	TL	LF5	LF4	LF3	LF2	LF1	LS	LR	TH	HF5	HF4	HF3	HF2	HF1	HS	HR	T2-THE	2-THF5	2-THF4	2-THF3	2-THF2	2-THF1	2-THS	2-THR
1	1	1	1	39	33	6	0	0	0	6	1																
2	1	2	1	50	41	9	0	0	0	2	0	47	38	9	0	0	0	2	1	36	28	8	0	0	0	0	1
3	1	1	2	35	30	4	1	0	0	1	0																
4	1	2	2	29	20	9	0	0	0	0	0	30	26	4	0	0	0	1	0	10	8	2	0	0	0	0	0
5	1	1	3	29	21	8	0	0	0	1	0																
6	1	2	3	48	31	17	0	0	0	4	1	47	33	12	2	0	0	6	6	21	13	7	1	0	0	3	1
7	1	1	4	35	23	12	0	0	0	3	0																
8	1	2	4	32	26	5	1	0	0	1	0	32	30	1	1	0	0	0	1	18	17	1	0	0	0	0	0
9	1	1	5	26	23	3	0	0	0	0	0																
10	1	2	5	25	19	6	0	0	0	1	1	26	21	5	0	0	0	5	0	8	6	1	1	0	0	1	1
11	1	1	6	34	31	3	0	0	0	0	1																
12	1	2	6	28	23	5	0	0	0	1	1	28	24	3	1	0	0	1	2	25	18	7	0	0	0	1	1
13	1	1	7	54	46	8	0	0	0	1	2																
14	1	2	7	54	50	4	0	0	0	1	2	52	50	0	0	0	0	2	0	41	40	1	0	0	0	0	0
15	2	1	1	43	33	10	0	0	0	3	1																
16	2	2	1	61	49	11	0	1	0	4	3	57	44	11	1	1	0	15	12	53	21	26	5	1	0	3	6
17	2	1	2	57	35	19	2	1	0	13	1																
18	2	2	2	53	35	17	1	0	0	5	2	54	47	7	0	0	0	16	4	46	25	16	5	0	0	3	8
19	2	1	3	44	33	11	0	0	0	5	1																
20	2	2	3	50	42	8	0	0	0	4	2	51	46	5	0	0	0	16	11	44	30	9	3	2	0	0	4
21	2	1	4	49	32	12	5	0	0	7	2																
22	2	2	4	38	23	15	0	0	0	1	3	42	35	7	0	0	0	13	3	35	17	12	5	1	0	2	3
23	2	1	5	64	37	26	1	0	0	12	3																
24	2	2	5	46	33	11	2	0	0	4	2	49	41	7	1	0	0	17	10	38	26	8	4	0	0	0	4
25	2	1	6	62	27	30	5	0	0	16	4																
26	2	2	6	56	30	22	3	1	0	6	1	62	53	4	4	1	0	25	8	57	33	15	7	1	0	2	0
27	3	1	1	22	10	10	2	0	0	7	1																
28	3	2	1	19	11	7	1	0	0	1	2	19	15	2	2	0	0	8	3								
29	3	1	2	23	10	6	3	4	0	5	2																
30	3	2	2	16	7	6	3	0	0	2	2	16	8	7	1	0	0	7	6								
31	3	1	3	21	7	13	1	0	0	2	1																
32	3	2	3	18	6	10	2	0	0	2	0	17	10	6	1	0	0	3	1								

NOTE

* BREEDS

- 1 = Perendale x Perendale
- 2 = (Booroola x Romney) x Perendale
- 3 = Booroola x Romney

* SEXES

- 1 = Male
- 2 = Female

* SIRES

They have been illustrated in Table 7.2

- * TL = Number of lambs presented for foot inspection
- LF5 = Number of lambs scored as foot shape 5
- LF4 = Number of lambs scored as foot shape 4
- LF3 = Number of lambs scored as foot shape 3
- LF2 = Number of lambs scored as foot shape 2
- LF1 = Number of lambs scored as foot shape 1
- LS = Number of lambs with foot scald
- LR = Number of lambs with footrot

- * TH = Number of hoggets presented for foot inspection
- HF5 = Number of hoggets scored as foot shape 5
- HF4 = Number of hoggets scored as foot shape 4
- HF3 = Number of hoggets scored as foot shape 3
- HF2 = Number of hoggets scored as foot shape 2
- HF1 = Number of hoggets scored as foot shape 1
- HS = Number of hoggets with foot scald
- HR = Number of hoggets with footrot

- * T2-THE = Number of 2-tooth ewes presented for foot inspection
- 2-THF5 = Number of 2-tooth ewes scored as foot shape 5
- 2-THF4 = Number of 2-tooth ewes scored as foot shape 4
- 2-THF3 = Number of 2-tooth ewes scored as foot shape 3

- 2-THF2 = Number of 2-tooth ewes scored as foot shape 2
- 2-THF1 = Number of 2-tooth ewes scored as foot shape 1
- 2-THS = Number of 2-tooth ewes with foot scald
- 2-THR = Number of 2-tooth ewes with footrot

APPENDIX II SUMMARY OF FOOT CHARACTERISTICS DATA OF SHEEP BORN IN 1981.

SERIAL NO.	BREEDS	SEXES	SIRES	TL	LF5	LF4	LF3	LF2	LF1	LS	LR	TH	HF5	HF4	HF3	HF2	HF1	HS	HR
1	1	1	8	67	40	21	5	1	0	0	0	69	58	11	0	0	0	0	0
2	1	2	8	55	39	11	4	1	0	0	0								
3	1	1	9	47	27	16	4	0	0	0	0	46	36	8	2	0	0	0	0
4	1	2	9	31	23	7	0	1	0	0	0								
5	1	1	10	52	38	8	5	0	1	0	0	49	44	4	1	0	0	0	0
6	1	2	10	37	25	10	2	0	0	0	0								
7	1	1	11	40	20	12	8	0	0	0	0	36	28	7	1	0	0	0	0
8	1	2	11	43	27	12	4	0	0	0	0								
9	1	1	12	50	17	21	6	5	1	0	0	49	19	24	4	2	0	0	0
10	1	2	12	51	20	20	10	1	0	0	0								
11	1	1	13	32	16	12	3	1	0	0	0	28	24	4	0	0	0	0	0
12	1	2	13	48	30	13	3	2	0	0	0								
13	2	1	7	30	17	12	1	0	0	0	0	28	21	7	0	0	0	0	0
14	2	2	7	37	14	21	2	0	0	1	0								
15	2	1	8	31	23	8	0	0	0	2	1	30	21	9	0	0	0	0	0
16	2	2	8	20	13	6	1	0	0	0	1								
17	2	1	9	19	12	6	1	0	0	0	0	18	12	6	0	0	0	0	1
18	2	2	9	22	14	7	1	0	0	0	0								
19	2	1	10	24	11	10	2	1	0	5	2	25	11	8	4	2	0	3	3
20	2	2	10	26	17	8	1	0	0	5	2								
21	2	1	11	39	15	17	6	1	0	8	4	40	16	19	5	0	0	3	4
22	2	2	11	20	15	3	2	0	0	1	0								
23	2	1	12	31	20	9	2	0	0	7	2	28	12	12	3	1	0	0	5
24	2	2	12	23	17	6	0	0	0	2	2								
25	2	1	13	23	20	3	0	0	0	0	0	23	16	7	0	0	0	1	2
26	2	2	13	27	21	5	1	0	0	0	1								
27	2	1	14	33	17	14	2	0	0	1	0	36	18	16	2	0	0	1	2
28	2	2	14	40	25	13	1	1	0	0	0								
29	2	1	15	33	20	13	0	0	0	1	0	33	20	12	1	0	0	0	2
30	2	2	15	26	15	9	2	0	0	0	0								
31	2	1	16	46	33	11	2	0	0	6	1	44	20	21	3	0	0	2	5
32	2	2	16	40	30	9	1	0	0	3	0								
33	2	1	17	22	14	5	3	0	0	6	4	20	12	4	3	1	0	3	6
34	2	2	17	34	21	12	1	0	0	3	3								
35	2	1	18	30	19	10	1	0	0	0	1	29	14	13	2	0	0	0	4
36	2	2	18	24	14	8	2	0	0	0	1								

APPENDIX III CLASSIFICATION OF ABNORMAL FOOT SHAPE INCIDENCE IN 97 (BOORoola X ROMNEY)
X PERENDALE RAMS.

		OBSERVER NO.1										
		Types of Combined Scores at a.m. and p.m. observations										
		5;5	5;4	4;5	5;<4	<4;5	4;4	4;<4	<4;4	<4;<4	Total	
OBSERVER NO.2	Types of Combined Scores at a.m. and p.m. observations	5;5	32	0	5	0	0	1	1	0	1	40
		5;4	3	0	1	0	0	0	0	0	0	4
		4;5	7	0	6	0	0	2	0	0	0	15
		5;<4	0	0	0	0	0	0	0	0	0	0
		<4;5	0	0	0	0	0	0	0	0	0	0
		4;4	7	2	4	0	0	11	0	3	0	27
		4;<4	0	0	0	0	0	0	0	0	0	0
		<4;4	0	0	0	0	0	4	0	0	2	6
		<4;<4	0	0	0	0	0	1	0	1	3	5
		Total	49	2	16	0	0	19	1	4	6	97

APPENDIX IV CLASSIFICATION OF FOOT SCALD INCIDENCE IN
97 (BOORoola X ROMNEY) X PERENDALE RAMS.

			OBSERVER NO.1				
			Types of Combined Scores at a.m. and p.m. observations				
			0;0	0;1	1;0	1;1	Total
OBSERVER NO.2	Types of Combined Scores at a.m. and p.m. observations	0;0	80	1	4	3	88
		0;1	0	0	0	2	2
		1;0	0	0	0	1	1
		1;1	0	0	0	6	6
		Total	80	1	4	12	97

APPENDIX V CLASSIFICATION OF FOOTROT INCIDENCE IN
97 (BOORoola X ROMNEY) X PERENDALE RAMS.

			OBSERVER NO.1				
			Types of Combined Scores of a.m. and p.m. observations				
			0;0	0;1	1;0	1;1	Total
OBSERVER NO.2	Types of Combined Scores at a.m. and p.m. observations	0;0	90	0	3	1	94
		0;1	0	0	0	1	1
		1;0	0	0	0	2	2
		1;1	0	0	0	0	0
		Total	90	0	3	4	97

APPENDIX VI COMPARATIVE RESULTS OF FOOT SCORES OF BOOROOOLA CROSS
AND PERENDALE LAMBS AT TUAPAKA (9/12/1980)
(ANIMALS TAG 1980).

FOOT CHARACTERISTIC	BREEDS		
	STUD PERENDALE	(BOOROOOLA X ROMNEY) X PERENDALE	BOOROOOLA X ROMNEY
Average of Foot Shape Grade (1-5)			
Ram lambs	4.818	4.56	4.196
Ewe lambs	4.782	4.664	4.34
Number and Per- centage of Animals with Scald			
Ram lambs	12; (4.74%)	56; (17.44%)	15; (22.72%)
Ewe lambs	10; (3.74%)	24; (7.89%)	5; (9.43%)
Number and Per- centage of Feet with Scald			
Ram lambs	14; (1.38%)	83; (6.46%)	19; (7.2%)
Ewe lambs	10; (0.936%)	33; (2.71%)	6; (2.83%)
Number and Per- centage of Animals with Footrot			
Ram lambs	4; (1.58%)	12; (3.74%)	4; (6.06%)
Ewe lambs	5; (1.87%)	13; (4.3%)	4; (7.55%)
Number and Per- centage of Feet with Footrot			
Ram lambs	6; (0.6%)	16; (1.246%)	5; (1.89%)
Ewe lambs	5; (0.468%)	15; (1.23%)	4; (1.886%)

NOTE: Percentages of feet either with Scald or with Footrot were calculated by dividing total number of feet with Scald or Footrot on the total number of animals X 4.

APPENDIX VII COMPARATIVE RESULTS OF FOOT SCORES OF BOORoola CROSS
AND PERENDALE EWE HOGGETS AT TUAPAKA (2/7/1981)
(ANIMALS TAG 1980).

FOOT CHARACTERISTIC	BREEDS		
	STUD PERENDALE	(BOORoola X ROMNEY) X PERENDALE	BOORoola X ROMNEY
Average of Foot Shape Grade (1-5)	4.84	4.812	4.557
Number and Per- centage of Animals with Scald	18; (6.87%)	102; (32.38%)	18; (34.61%)
Number and Per- centage of Feet with Scald	21; (2.003%)	145; (11.5%)	27; (12.98%)
Number and Per- centage of Animals with Footrot	8; (3.05%)	49; (15.55%)	10; (19.23%)
Number and Per- centage of Feet with Footrot	8; (0.76%)	65; (5.158%)	13; (6.25%)

APPENDIX VIII COMPARATIVE RESULTS OF FOOT SCORES OF BOOROOOLA CROSS
AND PERENDALE TWO-TOOTH EWES AT TUAPAKA (23/3/1982)
(ANIMALS TAG 1980).

FOOT CHARACTERISTIC	BREEDS	
	STUD PERENDALE	(BOOROOOLA X ROMNEY) X PERENDALE
Average of Foot Shape Grade (1-5)	4.807	4.402
Number and Percentage of Animals with Scald	5; (3.105%)	10; (3.66%)
Number and Percentage of Feet with Scald	4; (0.93%)	14; (1.28%)
Number and Percentage of Animals with Footrot	4; (2.48%)	35; (12.82%)
Number and Percentage of Feet with Footrot	6; (0.93%)	49; (4.48%)

APPENDIX IX COMPARATIVE RESULTS OF FOOT SCORES OF BOORoola CROSS
AND PERENDALE LAMBS AT TUAPAKA (9/12/1981)
(ANIMALS TAG 1981).

FOOT CHARACTERISTIC	BREEDS	
	STUD PERENDALE	(BOORoola X ROMNEY) X PERENDALE
Average of Foot Shape Grade (1-5)		
Ram lambs	4.3711	4.5457
Ewe lambs	4.4924	4.587
Number and Percentage of Animals with Scald		
Ram lambs	0.00	39; (10.80%)
Ewe lambs	0.00	17; (5.014%)
Number and Percentage of Feet with Scald		
Ram lambs	0.00	56; (3.87%)
Ewe lambs	0.00	22; (1.62%)
Number and Percentage of Animals with Footrot		
Ram lambs	0.00	15; (4.155%)
Ewe lambs	0.00	11; (3.24%)
Number and Percentage of Feet with Footrot		
Ram lambs	0.00	18; (1.246%)
Ewe lambs	0.00	14; (1.032%)

APPENDIX X COMPARATIVE RESULTS OF FOOT SCORES OF BOOROOOLA CROSS
AND PERENDALE RAM HOGGETS AT TUAPAKA (11/3/1982)
(ANIMALS TAG 1981).

FOOT CHARACTERISTIC	BREEDS	
	STUD PERENDALE	(BOOROOOLA X ROMNEY) X PERENDALE
Average of Foot Shape Grade (1-5)	4.7119	4.457
Number and Percentage of Animals with Scald	0.00	13; (3.67%)
Number and Percentage of Feet with Scald	0.00	20; (1.41%)
Number and Percentage of Animals with Footrot	0.00	30; (8.47%)
Number and Percentage of Feet with Footrot	0.00	44; (3.107%)

APPENDIX XI TOTAL MONTHLY RAINFALL IN TUAPAKA FARM OVER THE TRIAL PERIOD.†

MONTHS OF THE YEAR	TOTAL RAINFALL (mm)	
	1980	1981
January	85	-
February	33.9	97.1
March	173.6	61.1
April	100.8	31.8
May	40.3	124.1
June	60.4	167.9
July	108.4	133.1
August	117.4	98.8
September	132.4	133.6
October	172.6	82.4
November	163.1	55.9
December	23.3	77.6
TOTAL	1211.2	1063.4

† These meteorological data were obtained from the Geography Department in Massey University.

APPENDIX XII DETAILS OF THE FLOCK MATING PERFORMANCE OF THE BOORoola X ROMNEY CROSSBRED RAM LAMBS.

RAM LAMBS OF MATING GROUP	NO. OF MATING FLOCK	FLOCK SIZE (NO. OF EWES)	NO. OF EWES RADDLED IN EACH MATING PERIOD (P)				TOTAL NO. OF EWES RADDLED	NO. OF EWES RETURNING SERVICE	NO. OF NON-PREGNANT EWES	NO. OF PREGNANT EWES	NO. OF EWES PRESENT AT LAMBING	NO. OF LAMBS DOCKED	NO. OF LAMBS WEANED
			P ₁	P ₂	P ₃	P ₄							
<u>TRAINED</u>													
1	1	140	51		8	59	8	3	48	44	57	56	
2	2	140	54		11	65	3	5	57	50	57	55	
3	3	100	35		10	45	3	6	37	34	41	41	
4	1	140		66		29	48	7	40	38	50	50	
5	2	140		63		16	79	2	61	57	77	76	
6	3	100		45		2	47	3	41	41	62	60	
<u>UNTRAINED</u>													
7	4	140	74		18	92	10	4	77	74	91	90	
8	5	140	61		19	80	13	6	60	52	60	60	
9	6	100	42		10	52	5	4	43	43	56	54	
10	4	140		39		15	54	7	39	37	53	52	
11	5	140		60		10	70	6	59	53	68	67	
12	6	100		40		11	51	6	38	37	52	51	
TOTAL			317	313	76	83	789	128	61	600	560	724	712

APPENDIX XIII NUMBER OF EWES RETURNING TO SERVICE AFTER EACH MATING PERIOD (P) AND FOR EACH RAM LAMB SIRE.

RAM LAMBS OF MATING GROUP	NO. OF MATING FLOCK	NO. OF EWES RETURNING TO SERVICE AFTER EACH MATING PERIOD (P)				TOTAL
		P ₁	P ₂	P ₃	P ₄	
<u>TRAINED</u>						
1	1	4		4		8
2	2	1		2		3
3	3	0		3		3
4	1		28		20	48
5	2		11		5	16
6	3		3		0	3
<u>UNTRAINED</u>						
7	4	8		2		10
8	5	13		0		13
9	6	3		2		5
10	4		3		4	7
11	5		6		0	6
12	6		4		2	6
TOTAL		29	55	13	31	128

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INFLUENCE OF THE THYROID GLAND ON
PITUITARY GONADOTROPHIC ACTIVITY
IN THE RABBIT^{1,2}

J. P. CHU³

*From the Physiological Laboratory, University of Nanking College of Agriculture
and the Department of Physiology, College of Medicine,
National Central University
CHENGTU, CHINA*

A BRIEF review of the literature reveals that the results of previous studies on the relationship between the thyroid and pituitary glands are controversial and confusing. Evans and Simpson (1930) reported that pituitary glands of thyroidectomized young female rats 5 weeks after the operation were less effective than those of normal controls in causing sexual maturity in immature rats. Hohlweg and Junkmann (1933) found that the implantation of hypophyses from thyroidectomized female rats into immature female rats did not cause estrus. Van Dyke and Chen (1935) reported that the concentration of the hormone causing ovulation was reduced in thyroidectomized rabbits. The saline suspension of the anterior hypophysis from a normal animal always caused ovulation, but not so when a similar suspension from a thyroidectomized animal was used. P'an (1940) reported that the gonadotrophic potency of the anterior pituitary gland was decreased following thyroidectomy in both rat and rabbit. In the completely thyroidectomized guinea pig, the animals showed a temporary or prolonged failure of corpus luteum formation, but no obvious abnormalities of the follicles were noted (Williams, Phelps and Burch, 1941). Reineke, Bergman and Turner (1941) found in male goats thyroidectomized at the ages of 5 and 24 days that the gonadotrophic hormone was present in low concentration and that the testes were not stimulated. These results indicate that the gonadotrophic activity of the pituitary gland is greatly decreased by the extirpation of the thyroid gland.

On the other hand, Hammett (1926) claimed that the ovaries of rats thyroidectomized at ages of 23 to 100 days were approximately of the same size by 150 days, but considerably smaller than those of the

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controls. Smith and Engle (1930) observed that the pituitary glands of long-term thyroidectomized female rats (200 days) did not show any difference in gonadotrophic activity from the normal as shown by implantation into immature mice. Van Horn (1933) repeated the experiments and corroborated the results. Leonard and Leonard (1937) found that immature female rats deprived of their thyroid glands for 6 to 8 days showed no significant change in the total number of ovarian follicles as compared with the controls. Smelser (1939) reported that thyroidectomy in rats caused a reduction in weight of the accessory reproductive organs of the adult male and a decrease in sperm production; but there was no decrease in gonadotrophic potency of the hypophysis.

In regard to the cellular changes of the anterior pituitary gland in thyroidectomized rats, many authors (Severinghaus, Smelser and Clarke, 1934; Zeckwer, Davison, Keller and Livingood, 1935; Nelson and Hickman, 1937) have come to the conclusion that the basophiles appear to increase in number and in size, a condition similar to that following castration. However, the enlarged pituitary body in the thyroidectomized rabbit is said to be the result of the hypertrophy of the chromophobe cells, while the eosinophiles may be reduced in number (Bryant, 1930). From the fact that the gonad normally receives a constant supply of the gonad-stimulating hormone from the pituitary gland, any structural changes of the latter might conceivably alter the functional state of the former. Assuming that the gonadotrophic hormone is a complex of active substances, namely, luteinizing hormone and follicle-stimulating hormone, then the shifting of a proper balance of these two hormones would result in varying degrees of sexual abnormality. Greenwood and Chu (1939) reported that the removal of thyroid glands in immature Brown Leghorn pullets did not interfere with the maturation of the sex gland, *i.e.*, the time of laying of the first egg, but the growth of the comb and head furnishings which usually accompanies the onset of sexual maturity was inhibited. It is suggested that the inhibition of the comb growth in the thyroidectomized pullets may be due to the partial impairment of the pituitary gland or the inability of the ovary to produce androgenic substance. The purpose of this study is to determine the possible action of the thyroid on the pituitary-gonad system.

MATERIALS AND METHODS

Female rabbits obtained from a local dealer were used for the experiments. They were kept in the animal house for a few days before being operated upon. The ages of the animals were not known; however, they were mature and sexually active. Thyroidectomy was performed under ether anesthesia. Inasmuch as the rabbit is not very susceptible to infections, aseptic precautions were not necessarily strict. The animals showed no ill effects from the operation.

During the years of 1941 to 1943, 104 female rabbits were completely

thyroidectomized. They were kept separately in wire cages after the operation. A ration consisting of pericarp of wheat and green vegetables was given to all of the experimental and control animals.

The experiments were made in several groups. The nature of the experiment and the number of animals used in each group will be described in the following sections.

RESULTS

Ovarian changes following thyroidectomy in the rabbit. About one month after thyroidectomy, 21 animals were laparotomized and the ovaries examined. It was found that the ovaries of these animals were

TABLE 1. OCCURRENCE OF OVULATION AFTER COITUS IN THYROIDECTOMIZED RABBITS

Animal No.	Days After Thyroidectomy	Frequency of Coitus	Occurrence of Ovulation	Condition of Ovary
R 19	30	3	—	Many large follicles
R 45	84	4	—	Many large follicles
R 48	77	3	—	Many large follicles
R 53	83	4	—	Many large follicles
R 10	50	3	—	Many large follicles
R 67	34	4	—	Many large follicles
R 66	66	5	—	Many large follicles
R 41 ¹	141	3	+	A few large follicles
R 47	155	3	—	Numerous large follicles
R 2 ¹	100	3	+	Rather few large follicles
R 45	148	3	—	Numerous large follicles
R 1	135	4	—	A few large follicles
R 15	25	4	—	Numerous large follicles
R 118	4	4	—	
R 77	53	5	—	Numerous large follicles
R 173	18	—	—	Numerous large follicles
R 77	112	3	—	Numerous large follicles
R 152	53	3	—	Numerous large follicles
R 196	47	2	—	Numerous large follicles
R 197	47	2	—	Numerous large follicles

¹ Thyroid remnants were present.

highly vascular and through their surfaces could be seen many follicles of different sizes. Examination of the ovaries of the normal controls revealed that large follicles were usually infrequent and the ovarian tissues formed a compact mass. It is evident, therefore, that in the absence of the thyroid gland, the growth of the graafian follicles is much enhanced.

Ovulation reaction after coitus. It is well known that the rabbit ovulates only after coitus. Most of the operated animals were mated successfully at various intervals after thyroidectomy. In every case the success and frequency of matings were noted. The animals were then subjected to laparotomy 48 hours later in order to determine the occurrence of ovulation. In this series of experiments, we examined 20 thyroidectomized animals which had mated several times within a brief period. At laparotomy, however, none had ovulated except two animals in which pieces of thyroid remnants were discovered at autopsy. The details of the experiments are summarized in table 1.

We have observed more than 100 normal rabbits in which coitus has been followed by ovulation with but few exceptions. It is thus clear that thyroidectomy in the rabbit prevented the rupture of follicles after mating.

Ovarian reaction to the injection of human pregnancy urine extract. It is possible that the absence of ovulation in the thyroidectomized rabbits may be due to the lowered sensitivity of ovarian response, while the amount of ovulating hormone circulated in the blood is normal. If this is true, the injection of an effective dose of pregnancy urine extract would not induce ovulation. Experiments were performed on 5 thyroidectomized rabbits which were matched by the same number of normal animals. The body weights of these animals were approximately the same. Five mg. of the international standard gonadotrophin dissolved in 1 cc. of physiological saline was injected intravenously. After an interval of 48 hours the animals were laparotomized in order to determine if ovulation had occurred. The results obtained are presented in table 2.

TABLE 2. NUMBER OF RUPTURED FOLLICLES INDUCED BY THE INJECTION OF CHORIONIC GONADOTROPHIN INTO NORMAL AND THYROIDECTOMIZED RABBITS

Experimental Groups	No. of Animals	Dosage	Av. No. Ruptured Follicles	Range	Remarks
Normal	5	mg. 5	2	1-4	One rabbit had not ovulated
Thyroidectomized	5	5	35	18-63	All animals had ovulated

It was found that with the given dosage of urinary gonadotrophin, all of the thyroidectomized animals ovulated readily, but one of the normal animals failed to show any response. Not only was the percentage of ovulation higher in the thyroidectomized group, but also the number of ruptured follicles. In the normal animals the average number of ruptured follicles was 2, while that of thyroidectomized ones was 35. The presence of an overwhelmingly large number of ruptured follicles in the thyroidectomized rabbits resulting from the injection of pregnancy urine extract was partly due to the preëxistence of numerous mature follicles and partly attributed to the high sensitivity of the ovaries. Thus, after the ablation of the thyroid gland, the evidence is not for a lowered sensitivity of the ovary to gonadotrophin. On the contrary, the results obtained suggest an increased sensitivity.

The formation of corpora lutea has been observed by subsequent laparotomies on these animals. In every respect, the appearance of this organ was normal, as also was its secretory function as judged from the progestational changes of the endometrium. This fact is particularly interesting with reference to the question if the ovulating

substance of human pregnancy urine is identical with the luteinizing hormone and whether the latter is essential for the formation and functional maintenance of the corpus luteum. This point will be discussed in some detail. The functional period of the corpus luteum was found to be consistently longer than in normal pseudopregnancy.

Ovarian reaction to the injection of copper acetate. That ovulation in the rabbit can be induced by the injection of copper acetate has been recently discovered by Bischoff (1938). Emmens (1940) found that the ovulation thus produced can be inhibited by simultaneous injection of an anti-serum against the ox pituitary. This indicates that the copper salt itself is not directly concerned in this reaction but in some way excites the hypophysis to liberate the ovulating hormone.

TABLE 3. OVULATION RESPONSE TO THE INJECTION OF COPPER ACETATE INTO NORMAL AND THYROIDECTOMIZED RABBITS

Experimental Groups	Date Exp. Performed	No. of Animals	Dosage	No. of Animals Ovulated	Remarks
Normal	May '42	5	15 (total) <i>mg./kg.</i>	4	One died within 24 hours
	Jan. '43	5	10	2	Two died within 24 hours
Thyroidectomized	May '42	5	15 (total)	0	
	Jan. '43	5	10	0	

Harris (1941) suggests that the effect of copper salts on ovulation in the estrous rabbit is caused by stimulation of some part of the nervous pathways to the hypophysis, particularly from the hypothalamic region. Although the failure of thyroidectomized rabbits to ovulate is undoubtedly not due to the lowered sensitivity of the ovary, it seems possible that the mating reaction was not sufficient to cause the pituitary gland to release its gonadotrophic hormone. Therefore, it was decided to treat the thyroidectomized animals with copper acetate. By this means the nervous fibers passing into the pituitary might be directly stimulated by the copper salt and ovulation induced. Ten thyroidectomized rabbits were used for this experiment. Five of these were tested in May, 1942, and the remainder in January, 1943. On each occasion, the experiments were matched by the same number of normal estrous animals. A single injection of 15 mg. of copper acetate in 1 cc. of physiological saline was given intravenously to the first set of animals; the dosage was then changed to 10 mg. per kilogram of body weight for the second set. Since the body weight of each of the test animals was about 1.6 kg., the size of dosage for both groups of animals was approximately the same. As a rule, the test animals were laparotomized 48 hours after the injection and the ovaries examined. In the normal group, 3 of 10 animals died within

24 hours after the injection. Ovulation occurred in 6 of the 7 surviving animals (table 3). Thus, a fairly high percentage of ovulation was induced in the normal rabbits by the injection of copper acetate.

On the other hand, all of the thyroidectomized animals survived the injection of copper acetate, but none ovulated. From the results of these experiments, it appears to be certain that failure of the thyroidectomized rabbit to ovulate is not due to a lack of excitation from coitus.

Biological characterization of the hypophyseal ovulating hormone in normal and thyroidectomized rabbits. The results of the foregoing experiments do not reveal whether the absence of ovulation in thyroidectomized rabbits is due to a quantitative reduction of the ovulating hormone or to an impairment of the nervous center which conveys

TABLE 4. OVULATION REACTION OF NORMAL ESTROUS RABBITS TO THE INJECTION OF EXTRACT OF PITUITARY GLANDS FROM NORMAL ESTROUS DONOR RABBITS

Recipient Animals	Occurrence of Ovulation	Ovarian Conditions of Recipients
R 79	+	Normal appearance
R 90	-	Normal appearance
R 91	-	Normal appearance
R 77	-	Normal appearance
R 97	-	Normal appearance
R 39	+	Normal appearance
R 179	-	Normal appearance
R 161	-	Normal appearance
R 207	-	Normal appearance
R 164	-	Normal appearance

the nervous impulse to the hypophysis. The sensitivity of the ovary is obviously normal, since the animals responded readily with ovulation to the administration of pregnancy urine extract. It has been reported by van Dyke and Chen (1935) that the injection of suspensions of fresh pituitary into estrous rabbits causes a high percentage of ovulation. We have used the same technique to determine the relative amounts of ovulating hormone in the normal and thyroidectomized rabbits.

The method of preparation of the extract was as follows: Fresh anterior lobes were finely macerated in a test tube and a definite amount of physiological saline was added. The clear solution thus obtained after filtration was intravenously injected. The final concentration of the extracts was so adjusted that 1 cc. of the saline preparation was equivalent to one anterior lobe of the hypophysis. The experiments were divided into four groups which will be described in the following sections.

Percentage of ovulation in normal estrous rabbits injected with pituitary gland extract from normal rabbits. For purposes of comparison

we have performed 10 assays of the extract. The body weights of the test animals were about 1.5 kg. Each animal received intravenously 1 cc. of the saline extract of hypophysis. As a rule, 48 hours after the injection, a laparotomy was performed and both ovaries were carefully examined. Only those in which the follicles had ruptured were considered as positive. The results of the tests are presented in table 4.

It is quite clear from the table that 6 of 10 control animals ovulated within 48 hours after the injection. The ovaries of these animals appeared to be normal, as far as the number of follicles is concerned.

TABLE 5. OVULATION REACTION OF NORMAL ESTROUS RABBITS TO THE INJECTION OF A PITUITARY GLAND EXTRACT FROM THYROIDECTOMIZED RABBITS

Recipient Estrous Animals	Pituitary Thyroidectomized Donors	Time of Autopsy	Occurrence of Ovulation	Ovarian Condition of Recipients
		<i>days</i>		
R 210 ¹	R 108	103	—	Normal appearance
R 92	R 66	69	—	Many large follicles
R 74	R 43	137	—	Many large follicles
R 94	R 68	77	—	Many large follicles
R 87 ¹	R 1	137	+	Normal appearance
R 105	R 5	53	—	Many large follicles
R 107	R 25	67	—	Many large follicles
R 117	R 16	83	—	Many large follicles
R 118	R 15	83	—	Many large follicles
R 104	R 68	47	—	Many large follicles
R 6	R 11	38	—	Several large follicles
R 7	R 5	43	—	Many large follicles
R 192	R 81	113	—	Several large follicles
R 193	R 77	113	—	Many large follicles
R 8	R 4	56	—	Many large follicles

¹ Thyroid tissue identified in the pituitary donor.

Thus, the administration of this dose of pituitary gland extract to 10 estrous animals caused ovulation in 60 per cent.

Percentage of ovulation in estrous rabbits injected with an extract prepared from pituitary glands of thyroidectomized female rabbits. Should the pituitary gland of thyroidectomized rabbits contain an appreciable amount of ovulating hormone, the injection of an extract prepared from them into estrous rabbits would cause ovulation. Fifteen assays of this kind were made. All of the test animals were healthy estrous females; the body weights ranged from 1.3 to 1.5 kg. The same number of thyroidectomized females which were killed at various intervals after the operation, furnished the pituitary gland material for the assay. The results are summarized in table 5.

It was found that among the 15 animals receiving the hypophyseal extract from thyroidectomized rabbits, only one showed a positive reaction. However, thyroid remnants were found in the donor animal. If this case is not taken into consideration, 100 per cent of the test

animals did not ovulate. However, an enormous increase in the number of ovarian follicles in the recipient animals was observed. This indicates that the pituitary gland of thyroidectomized rabbits contained a follicle-stimulating factor which could not be demonstrated in the normal pituitary gland by the same method.

Percentage of ovulation in thyroidectomized animals caused by the injection of an extract of hypophysis from normal animals. In a preceding section, we have shown that the ovaries of the thyroidectomized rabbits are sensitive to the injection of pregnancy urine extract. Since the biological properties of the urinary gonadotrophin are in some respects different from the gonadotrophic factor of the hypophysis, the reactivity of the thyroidectomized rabbit to the injection of fresh extract remained to be determined. Ten thyroidectomized females were injected with saline extract of the normal hypophysis. As determined

TABLE 6. OVULATION REACTION OF THYROIDECTOMIZED RABBITS TO THE INJECTION OF A PITUITARY EXTRACT FROM NORMAL ESTROUS DONORS

Recipient Thyroidectomized Animals	Occurrence of Ovulation	Ovarian Conditions of Recipients
R 48	+	Many ruptured follicles
R 53	+	Many ruptured follicles
R 67	+	Many ruptured follicles
R 47	+	Several ruptured and hemorrhagic follicles
R 15	+	A few ruptured and many hemorrhagic follicles
R 36	-	Follicles few and small
R 68	+	Several ruptured and hemorrhagic follicles
R 71	+	A few ruptured and many hemorrhagic follicles
R 105	+	Many ruptured follicles
R 106	+	A few ruptured follicles

by laparotomy 48 hours after the injection, ovulation occurred in all but one case (table 6).

The percentage of positive responses is thus 30 per cent higher than in the normal group (60%). The results of these experiments point to the fact that the ovary of the thyroidectomized rabbit is obviously very sensitive to the ovulating hormone of the pituitary.

Percentage of ovulation in thyroidectomized rabbits injected with an extract prepared from hypophyses of thyroidectomized females. It has been shown that none of the estrous rabbits ovulated after the injection of an extract from hypophyses of the thyroidectomized animals. This may indicate that the ovulating hormone of the hypophysis is considerably reduced under hypothyroid conditions, but no evidence is available to show its absence. We have also demonstrated that the ovary of the thyroidectomized rabbit is much more sensitive than that of the normal to the injection of pregnancy urine and fresh hypophyseal extract. The use of thyroidectomized animals for the assay might make it possible to detect small amounts of ovulating hormone if it were present in the hypophyses of thyroidectomized rabbits.

TABLE 7. OVULATION REACTION OF THYROIDECTOMIZED RABBITS TO THE INJECTION OF A PITUITARY EXTRACT FROM THYROIDECTOMIZED RABBITS

Recipient Thyroidectomized Animals	Pituitary Thyroidectomized Donors	Time of Autopsy	Occurrence of Ovulation	Ovarian Condition of Recipients
R 161	R 97	<i>days</i> 103	—	Numerous large follicles
R 174	R 71	130	—	Numerous large follicles
R 148	R 105	114	—	Numerous large follicles
R 149	R 106	114	—	Numerous large follicles
R 150	R 148	38	—	Numerous large follicles

Five tests based on this assumption were made. The results obtained were all negative (table 7). For this and other reasons, we are rather inclined to the belief that the hypophysis of the thyroidectomized rabbit does not contain an amount of ovulating hormone sufficient to be detected by these methods.

Effect of replacement therapy with desiccated thyroid. If the observed changes of the ovary in the thyroidectomized rabbits directly result from a condition of hypothyroidism, the administration of desiccated thyroid to such animals should restore the ovarian functions to normal. Thirteen rabbits were given desiccated thyroid by mouth at different times after thyroidectomy—some being fed immediately after operation, while others remained in a hypothyroid condition for a considerable length of time until the ovarian changes had become evident. The dosage was at first 50 mg. per kg. of body weight every other day, but this amount of thyroid was definitely toxic and was finally reduced to 35 mg. per kg. of body weight. Some of these animals receiving the high doses of desiccated thyroid suffered a great loss of body weight which hindered the general health so that they refused to mate when a buck was introduced. Others receiving the lower doses of desiccated thyroid appeared to be healthy and had but little loss of body weight. They mated during the period of thyroid feeding and ovulation was observed in all of the cases (table 8). The ovaries of these animals were normal, being structurally solid with relatively few follicles of different sizes. It may be concluded, there-

TABLE 8. OCCURRENCE OF OVULATION AFTER COITUS IN THYROID-FED-THYROIDECTOMIZED RABBITS

Animal No.	Days after Thyroidectomy	Days of Thyroid Feeding	Dosage of Thyroid per kg.	Frequency of Coitus	Occurrence of Ovulation	Condition of Ovary
			<i>mg/2nd day</i>			
R 120	98	67	35	4	+	Normal
R 123	104	71	35	5	+	Normal
R 205	28	14	35	3	+	Normal
R 195	48	14	35	3	+	Normal
R 207	25	14	35	3	+	Normal
R 217	18	17	35		+	Normal

fore, that the administration of desiccated thyroid to the long-standing thyroidectomized rabbits restores the ovarian functions to normal, while, given shortly after thyroidectomy, prevents the ovarian changes of the hypothyroid type.

The content of ovulating hormone which is present in the hypophyses of these animals was assayed in estrous rabbits. It was found that the hypophyseal extract prepared from those animals fed with high doses of desiccated thyroid was ineffective in causing the rupture of mature follicles, but that the extract prepared from those fed on small doses of thyroid exerted an action on the ovary either by causing it to produce hemorrhagic follicles or to ovulate (table 9). The percentage of positive reactions seemed to be lower than the normal (60%), but this may be attributed to the difficulty of giving

TABLE 9. OVULATION IN ESTROUS RABBITS CAUSED BY INJECTION OF AN HYPOPHYSEAL EXTRACT FROM THYROID-FED-THYROIDECTOMIZED RABBITS

No. of Pituitary Donors	Days after Thyroidectomy	Days of Thyroid Feeding	Occurrence of Ovulation
R 98	30	21	—
R 63	71	68	—
R 117	93	34	—
R 217	40	39	+
R 217	40	39	+
R 120	127	96	Hemorrhagic follicles
R 123	127	96	Hemorrhagic follicles

the animals a physiological dosage of desiccated thyroid. Individual variations may also be a part of the factors involved.

DISCUSSION

The presence of two different gonadotrophic hormones in the anterior hypophysis has been discussed by Fevold (1939). The follicle-stimulating hormone is biologically different from the luteinizing hormone and its chemical properties also differ. The work of Casida (1934), Foster and Fevold (1938), and Foster (1938) indicates that ovulation cannot be induced in rats and in rabbits by the administration of follicle-stimulating hormone unless it is contaminated by traces of luteinizing hormone. This suggests that the factor essential for ovulation may be the luteinizing hormone. In our thyroidectomized rabbits, the formation of the corpora lutea usually followed rupture of the follicles. We have also demonstrated that the thyroidectomized rabbit is deprived of ovulating hormone. This leads us to the belief that the luteinizing hormone of the hypophysis is by no means indispensable for the formation of the corpus luteum. The question arises as to what factor is particularly concerned in governing the formation and functional state of this organ. This has been a question of debate for a long time. But there is every reason to believe that estrogen may be important in the formation and functional

maintenance of the corpus luteum. Robson (1938) has found that when estrogen is injected into the rabbits in which ovulation has been induced after hypophysectomy, active corpora lutea develop. The gonadotrophic factor from pregnancy urine maintains a functional corpus luteum when given immediately after hypophysectomy, but not when a few days are allowed to elapse before its administration. It is suggested, therefore, that normally gonadotrophic hormone indirectly controls the luteal function through the secretion of estrogen which in turn regulates hypophyseal function and not by direct action on the corpus luteum. The results reported by Chu and Lee (1942) give further support to this contention. On the basis of this hypothesis it would follow that after thyroidectomy, large amounts of estrogen must have been made available from the hypertrophied follicles which transformed the ruptured follicles into corpora lutea, despite the absence of luteinizing hormone.

With regard to the content of luteinizing hormone (ovulating hormone) in the anterior hypophysis of thyroidectomized rabbits, our results are not in accord with those reported by van Dyke and Chen (1935). They found that the saline suspension of the pituitary gland from thyroidectomized animals may cause ovulation in estrous rabbits, but that the percentage of positive responses is definitely lower than that caused by the injection of the extracts from normal pituitary glands. This discrepancy may be explained by the different dosage used by them.

The results of the copper acetate injection are of interest. This chemical is supposed to exert its action through the hypothalamus, thereby activating the pituitary gland through the stalk. Inasmuch as the thyroidectomized females failed to ovulate even when the hypothalamus was stimulated by the copper salt, it may be inferred that the absence of ovulation after coitus is not due to the block of impulse to the central nervous system. The results of assays may clarify this point. The hypophyseal extract from the thyroidectomized animals was ineffective in causing ovulation in both estrous and thyroidectomized rabbits. In view of the high ovarian sensitivity of the latter group of animals, it should be possible to detect even a sub-normal amount of the hormone. However, no positive responses were obtained. In considering the results of these experiments, it may be that the pituitary gland of the thyroidectomized rabbit is deficient in ovulating hormone.

Although Hofmeister (1893) was the first to observe an hypertrophy of the follicles in thyroidectomized rabbits, its significance was not explained by him. Enhanced growth of follicles was invariably observed in our thyroidectomized animals. There are at least two possibilities which may bring about such a change, *a*) the content of the follicle-stimulating hormone may have become increased or *b*) its action has been rendered more effective by the removal of the thyroid gland. Evidence thus far obtained favors the former alternative as a

possible interpretation. The reason is that not only do the ovaries of thyroidectomized rabbits develop an extraordinarily large number of follicles, but also there is an increased potency of the pituitary glands in stimulating the growth of follicles in estrous rabbits. While this is most likely the explanation, the second alternative is by no means precluded. It has been shown by Fluhmann (1934), Leonard (1936), and Leonard and Hansen (1936) that thyroidectomy in the rat increases the effectiveness of injected follicle-stimulating hormone. This suggests that the presence of active thyroid may inhibit the ovarian function.

It is known that pituitary glands of castrated animals contain a higher titer of follicle-stimulating hormone than those of normal animals, as does the urine of castrated animals. As reported by previous workers (Severinghaus, *et al.*, 1934; Zeckwer, *et al.*, 1935; Nelson and Hickman, 1937), the cellular changes of the hypophysis in thyroidectomized rats are similar to those in castrated animals and such changes can also be prevented or corrected by estrogen injections (Nelson and Hickman, 1937). On this basis we would expect an increase in amount of the follicle-stimulating hormone in the hypophysis of thyroidectomized animals. This assumption gains support from the results of the present study.

It has been amply demonstrated that the activity of the hypophysis is in some way controlled by the gonad. The interaction between these two glands of internal secretion through their respective hormones has formed a foundation upon which the postulation of sexual periodicity is based. No clear-cut evidence is now available to show what part is taken by the thyroid in the regulation of pituitary gland function. From the results of the present study, we would postulate that, as far as the follicle-stimulating hormone is concerned, the inhibitory action of estrogen on the hypophysis might be indirect through the thyroid. Under the condition of hypothyroidism, the pituitary gland is rich in follicle-stimulating hormone so that the graafian follicles are highly stimulated. As a result of follicular hypertrophy, large amounts of estrogen would be produced and constantly added to the general circulation. Despite the increase in concentration of estrogen in the blood, the mechanism of elaboration of the follicle-stimulating hormone does not seem to be suppressed as evidenced by the results of assays and the persistence of large follicles in the long-standing thyroidectomized rabbits. It appears to be likely that even the presence of a high concentration of estrogen in the thyroidectomized rabbit, is ineffective in checking the enhanced production of the follicle-stimulating hormone.

SUMMARY

In thyroidectomized rabbits, the ovaries contained many more large follicles than in normal controls. However, ovulation did not take place after coitus or after the injection of copper acetate. The

operated animals readily ovulated after the injection of pregnancy urine extract and the ruptured follicles were more numerous than in normal estrous animals.

Fresh hypophyseal saline extracts were prepared from the normal and thyroidectomized rabbits for the assay of the relative amounts of ovulating hormone. It was found that the extract from the normal animals caused ovulation in 60 per cent of the estrous rabbits, whereas extract from thyroidectomized rabbits caused no ovulation but induced the growth of follicles. Furthermore, thyroidectomized females were very sensitive, responding by ovulation to the injection of hypophyseal extract, from normal animals, but they failed to ovulate when injected with an extract similarly prepared from thyroidectomized animals.

It appears that the hypophysis of thyroidectomized rabbits is free of ovulating hormone, whereas the follicle-stimulating hormone may be considerably increased.

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