A STUDY OF SOME OF THE RELATIONSHIPS BETWEEN EWES AND THE GROWTH OF THEIR LAMBS

By

RODNEY B. HARRINGTON

Bachelor of Science
University of Maine
Orono, Maine
1954

Master of Science
Oklahoma State University
Stillwater, Oklahoma
1957

Master of Science
University of New South Wales
Kensington, New South Wales
1962

Submitted to the Faculty of the Graduate School of
the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
DOCTOR OF PHILOSOPHY
August, 1963

A STUDY OF SOME OF THE RELATIONSHIPS BETWEEN

EWES AND THE GROWTH OF THEIR LAMBS

Thesis Approved:

[illegible]

Thesis Adviser

A. B. Nelson

R D Morrison

Jack R. Harlan

Doyle Chambers

Robert MacVicar

Dean of the Graduate School

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. Joe V. Whiteman, Associate Professor of Animal Husbandry, for his counsel and guidance during the course of this study and in the preparation of this thesis.

Grateful acknowledgement is given to Dr. R. D. Morrison of the Mathematics and Statistics Department for his help in the statistical analysis of the data. Special thanks are tendered to Dr. V. L. Anderson, Director of the Statistical Laboratory at Purdue University for making facilities available for the completion of the statistical analysis of the thesis data.

Special recognition is due the author's wife, Gwenyth, for her assistance and encouragement during the course of these studies.

TABLE OF CONTENTS

Chapter | Page

INTRODUCTION 1

REVIEW OF LITERATURE 4

Factors Influencing or Associated with Lamb Growth Rate . . 5
Ewe Milk Production and Lamb Gain 14

MATERIALS AND METHODS 21

Part I: Repeatability Estimates 21
Part II: Milk Production 28

RESULTS AND DISCUSSION 36

Part I: Repeatability Estimates 36
Analyses of Variance of Birth Weight, 70 Day Weight and Rate of Gain from 70 to 140 Days 36
Influence of Sex 40
Influence of Birth and Rearing Type 41
Influence of Years 42
Interactions 43
Covariables 46
Repeatability Estimates of Birth Weight 48
Repeatability Estimates of 70 Day Weight 50
Repeatability Estimates of Rate of Gain from 70 to 140 Days 51
Repeatability Estimate of Birth Date 53
Conclusions 54

Part II: Milk Production 56
Analyses of Variance of Lamb Gain and Lamb Body Weight 56
Lamb Growth and Ewe Lactation Curves 64
Analyses of Variance of Ewe Milk Production per Lamb Reared 70
Indirect Estimates of Ewe Milk Production Based on Lamb Growth 84
Regression Equations to Predict Ewe Milk Production 88
Conclusions 97

SUMMARY 101

LITERATURE CITED 105

APPENDIX 110

LIST OF TABLES

Table		Page
1	Number of Lambs in the Repeatability Study Assembled According to Sex, Birth and Rearing Type and Year	23
2	Degrees of Freedom and Expected Mean Squares for the Repeatability Estimates	27
3	Summary of the Number of Ewes in the Milk Production Study Assembled According to Year, Age of Ewe and Rearing Type of the Lambs	29
4	Analyses of Variance of Birth Weight	37
5	Analyses of Variance of 70 Day Weight	38
6	Analyses of Variance of Rate of Gain from 70 to 140 Days	39
7	Repeatability Estimates of Birth Weight, 70 Day Weight and Rate of Gain from 70 to 140 Days	49
8	Analyses of Variance and Repeatability Estimate of Birth Date	53
9	Analyses of Variance for Lamb Net Weight Gain from One to Five Weeks of Age 1960-61 Data	57
10	Analyses of Variance for Lamb Net Weight Gain from Six to Ten Weeks of Age 1960-61 Data	58
11	Analyses of Variance for Lamb Body Weight from One to Five Weeks 1961-62 Data	59
12	Analyses of Variance for Lamb Body Weight from Six to Ten Weeks of Age 1961-62 Data	60
13	Correlations Between Total Lamb Net Weight Gain to Different Weeks 1960-61 Data	65
14	Correlations Between Lamb Body Weight to Different Ages 1961-62 Data	66
15	Analyses of Variance of Cumulative Milk Production per Lamb Reared One Through Five Weeks 1960-61 Data	71

LIST OF TABLES (Continued)

Table		Page
16	Analyses of Variance of Cumulative Milk Production per Lamb Reared Six Through Ten Weeks 1960-61 Data.	72
17	Analyses of Variance of Cumulative Milk Production per Lamb Reared One Through Five Weeks 1961-62 Data	73
18	Analyses of Variance of Cumulative Milk Production per Lamb Reared Six Through Ten Weeks 1961-62 Data	74
19	Correlations Between Cumulative Milk Production to Different Weeks 1960-61 Data	82
20	Correlations Between Cumulative Milk Production to Different Weeks 1961-62 Data	83
21	Correlations Between Total Lamb Gain and Cumulative Milk Production to Different Weeks 1960-61 Data	85
22	Correlations Between Lamb Body Weight and Cumulative Milk Production to Different Weeks 1961-62 Data	86
23	Prediction Equations for Estimating Cumulative Ewe Milk Production per Lamb Reared at Different Weeks Based on Lamb Net Weight Gain 1960-61 Data	89
24	Prediction Equations for Estimating Cumulative Ewe Milk Production per Lamb Reared at Different Weeks Based on Lamb Body Weight 1961-62 Data	89
25	Means and Standard Deviations for Cumulative Milk Production per Lamb Reared	91
26	Prediction Equations and Standard Errors for Estimating Cumulative Ewe Milk Production per Lamb Reared at Different Weeks Based on the Rearing Type, Birth Weight and Body Weight of the Lamb 1961-62 Data	93
27	Prediction Equations and Standard Errors for Estimating Cumulative Ewe Milk Production per Lamb Reared at Different Weeks Based on the Rearing Type, Birth Weight and Body Weight of the Lamb 1961-62 Data	94
28	Means and Standard Deviations of Cumulative Milk Production per Lamb Reared on Within Age of Ewe Basis 1961-62 Data .	96

LIST OF TABLES (Continued)

Table Page

29 Partial Regression Coefficients and Standard Errors for Birth Weight in Part I 111

30 Partial Regression Coefficients and Standard Errors for 70 Day Weight. Equations 1 Through 4 in Part I. . . . 112

31 Partial Regression Coefficients and Standard Errors for 70 Day Weight. Equations 5 Through 8 in Part I 113

32 Partial Regression Coefficients and Standard Errors for Rate of Gain from 70 to 140 Days. Equations 1 Through 4 in Part I 114

33 Partial Regression Coefficients and Standard Errors for Rate of Gain from 70 to 140 Days. Equations 5 Through 8 in Part I 115

34 Analyses of Variance for Repeatability Estimates of 70 Day Weight and Rate of Gain from 70 to 140 Days when Data Adjusted for Sex of Lamb, Lamb Birth and Rearing Type, Year Record was Made, Sex by Rearing, Sex by Year and Rearing by Year Interactions, Lamb Birth Date, Lamb Birth Date Squared, Lamb Birth Weight and Lamb Birth Weight Squared 116

35 Analyses of Variance for Repeatability Estimates of Birth Weight, 70 Day Weight and Rate of Gain from 70 to 140 Days When Data Adjusted for Sex of Lamb, Lamb Birth and Rearing Type, Year Record was Made, Sex by Rearing, Sex by Year and Rearing by Year Interactions, Lamb Birth Date and Lamb Birth Date Squared 117

36 Analyses of Variance for Repeatability Estimates of 70 Day Weight and Rate of Gain from 70 to 140 Days when Data Adjusted for Sex of Lamb, Lamb Birth and Rearing Type, Year Record was Made, Sex by Rearing, Sex by Year and Rearing by Year Interactions, and Lamb Birth Weight and Lamb Birth Weight Squared 118

37 Analyses of Variance for Repeatability Estimates of Birth Weight, 70 Day Weight and Rate of Gain from 70 to 140 Days When Data Adjusted for Sex of Lamb, Lamb Birth and Rearing Type, Year Record was Made, Sex by Rearing, Sex by Year and Rearing by Year Interactions 119

38 Analyses of Variance for Repeatability Estimates of 70 Day Weight and Rate of Gain from 70 to 140 Days When Data Adjusted for Sex of Lamb, Lamb Birth and Rearing Type, Year Record was Made, Lamb Birth Date, Lamb Birth Date Squared, Lamb Birth Weight and Lamb Birth Weight Squared 120

LIST OF TABLES (Continued)

Table		Page
39	Analyses of Variance for Repeatability Estimates of Birth Weight, 70 Day Weight and Rate of Gain from 70 to 140 Days When Data Adjusted for Sex of Lamb, Lamb Birth and Rearing Type, Year Record was Made, Lamb Birth Date and Lamb Birth Date Squared	121
40	Analyses of Variance for Repeatability Estimates of 70 Day Weight and Rate of Gain from 70 to 140 Days When Data Adjusted for Sex of Lamb, Lamb Birth and Rearing Type, Year Record was Made, Lamb Birth Weight and Lamb Birth Weight Squared	122
41	Analyses of Variance for Repeatability Estimates of Birth Weight, 70 Day Weight and Rate of Gain from 70 to 140 Days When Data Adjusted for Sex of Lamb, Lamb Birth and Rearing Type and Year Record was Made. .	123
42	Analyses of Variance for Repeatability Estimates of Birth Weight, 70 Day Weight and Rate of Gain from 70 to 140 Days When Data Were in Unadjusted Form	124
43	Partial Regression Coefficients and Standard Errors for Total Lamb Gain 1960-61 Data in Part II	125
44	Partial Regression Coefficients and Standard Errors for Total Lamb Gain 1960-61 Data in Part II	126
45	Partial Regression Coefficients and Standard Errors for Lamb Body Weight 1961-62 Data in Part II	127
46	Partial Regression Coefficients and Standard Errors for Lamb Body Weight 1961-62 Data in Part II	128
47	Simple Correlations Between the Covariables and Net Lamb Gain at One Through Ten Weeks 1960-61 Data Part II . .	129
48	Simple and Partial Correlations Between Covariables and Lamb Body Weight at One Through Ten Weeks 1961-62 Data in Part II	130
49	Within Age of Ewe and Lamb Rearing Type Means at Different Weeks for Lamb Body Weight and Ewe Milk Production (lbs. per week) per Ewe. 1960-61 Data	131
50	Within Age of Ewe and Lamb Rearing Type Means at Different Weeks for Lamb Body Weight and Ewe Milk Production (lbs. per week) per Ewe. 1961-62 Data	132

LIST OF TABLES (Continued)

Table		Page
51	Partial Regression Coefficients and Standard Errors for Cumulative Milk Production per Lamb Reared at One to Five Weeks 1960-61 Data	133
52	Partial Regression Coefficients and Standard Errors for Cumulative Milk Production per Lamb Reared at Six to Ten Weeks 1960-61 Data	134
53	Partial Regression Coefficients and Standard Errors for Cumulative Milk Production per Lamb Reared at One to Five Weeks 1961-62 Data	135
54	Partial Regression Coefficients and Standard Errors for Cumulative Milk Production per Lamb Reared at Six to Ten Weeks 1961-62 Data	136
55	Simple Correlations Between the Covariables and Milk Production per Lamb Reared at One Through Ten Weeks 1960-61 Data	137
56	Simple and Partial Correlations Between the Covariables and Milk Production per Lamb Reared at One Through Ten Weeks 1961-62 Data	138

LIST OF FIGURES

Figure		Page
1	Ewe Lactation Curves (lbs. milk per week) and Corresponding Lamb Growth Curves. Ewes Rearing Single Lambs. 1960-61 Data	68
2	Ewe Lactation Curves (lbs. milk per week) and Corresponding Lamb Growth Curves. Ewes Rearing Twin Lambs. 1960-61 Data	68
3	Ewe Lactation Curves (lbs. milk per week) and Corresponding Lamb Growth Curves. Ewes Rearing Single Lambs. 1961-62 Data	69
4	Ewe Lactation Curves (lbs. milk per week) and Corresponding Lamb Growth Curves. Ewes Rearing Twin Lambs. 1961-62 Data	69

INTRODUCTION

A large portion of the commercial sheep industry in Oklahoma and adjacent areas consists of the production of "spring" milk-fed fat lambs. The success of this type of enterprise depends upon the use of ewes that will breed out of season (spring) and the availability of a succulent pasture as a source of cheap feed. The most desirable type of lamb is one that grows rapidly to market weight and possesses sufficient finish to bring a top or near top market price.

Although the lambs are reared under what might be considered to be rather uniform conditions, considerable variation in growth rate of lambs always exists. Since early lamb growth is strongly influenced by milk supply and mothering ability, a knowledge of some of the relationships between ewes and the growth of their lambs would be useful in evaluating the performance of the ewe.

In the evaluation of ewes rearing lambs the question arises as to whether or not one record on the ewe is sufficient information to evaluate the ewe's performance. A repeatability estimate of lamb growth rate as a characteristic of the ewe would give an indication of the reliability of a single record as an index of the ewe's ability to rear a lamb. Such a repeatability estimate of the lamb growth rate as a characteristic of the ewe would be an estimate of the variation in lamb growth rate that is due to permanent differences among ewes.

However, much of the observed variation in the growth rate of the lamb is the result of influences which are not usually considered to be permanent differences among ewes. Examples of such factors are the sex of the lamb, lamb birth and rearing type, age of the ewe, year the record was made and within season time trends. Consequently it would be desirable to adjust the data for these influences before estimating the repeatability of lamb growth rate.

Although a repeatability estimate of lamb growth rate would give an estimate of the variability due to permanent differences among ewes it would not shed much light on the relationship of the milk production of the ewe and the growth of her lamb or the factors influencing the milk production of the ewe. A good milk supply is essential for the early development of the lamb until the lamb is able to utilize other sources of nutrients. Evidence from the literature indicates that the milk production of the ewe and the growth of the lamb are highly correlated. Thus it may be possible to estimate the milk production of the ewe indirectly based on the growth of the lamb. Evidence from the literature also indicates that the level of milk production of ewes of the "non-milk" breeds is relatively minor after 10 weeks.

Based on this information it would appear that the 70 day weight of the lamb would be a useful index of the ewe's ability to raise a lamb. Likewise the birth weight of the lamb would be an indication of the pre-natal influence of the ewe on lamb growth. Rate of gain after the lamb has reached 70 days of age would also give an indication as to whether or not the influence of permanent differences among ewes extends beyond the period of their maximum lactation when the lamb is no longer dependent upon its dam's milk supply as its main source of nutrients.

The purpose of this study was twofold. The first was to estimate the repeatability of lamb birth weight, 70 day weight and rate of gain from 70 to 140 days as characteristics of the ewe and to see what influence the adjustment of the data for influences not generally considered to be permanent differences among ewes have on the repeatability estimates calculated from the adjusted data. The second purpose was to investigate some of the relationships between the cumulative milk production of the ewe and the growth of her progeny at weekly intervals during the first 10 weeks of her lactation and to calculate prediction equations to estimate the milk production of the ewe based on the growth of her lamb.

REVIEW OF LITERATURE

Many factors are known to contribute to the variation in rate of gain among lambs. Some of these factors are genetic, others are environmental and both contribute in varying degrees to the variation in lamb gain over a particular period. Not all of these factors are independent and in some cases may interact with each other in the expression of their association with rate of gain. Consequently, when considering the importance of a particular source of variation in lamb gain it is necessary to consider what other sources of variation are included in the equation since the magnitude of association of one factor may be dependent on the other factors present in the model. The number of observations in the study is another important aspect to consider. The sampling error associated with small samples is notoriously large and sometimes leads to conflicting or inconsistent results.

Many research workers have investigated some of the factors that are known to influence lamb growth rate. The literature can be roughly divided into two general classes on the basis of whether or not the milk production of the ewe was considered. In this review, the literature concerning the relationship of the milk production of the ewe with lamb growth will be reviewed in a separate section following a general consideration of the other factors known to influence or be associated with lamb gain.

Factors Influencing or Associated with Lamb Growth Rate

Bonsma (1939) investigated several sources of variation in lamb growth rate using data collected on 168 Merino and Merino crossbred lambs. He noted that the crossbred lambs were generally superior to the purebred Merino lambs in rate of gain and that the lambs from crossbred ewes gained faster than those from other groups. The male lambs were significantly ($P < .05$) heavier than females at 12 weeks of age, but when considered on an equal birth weight basis the difference due to sex disappeared. Birth weight had a profound effect upon subsequent rate of growth. He reported a correlation of 0.41 between birth weight and body weight at 12 weeks. He also divided the lambs into three groups based on date of birth. These groups consisted of lambs born prior to June 15, lambs born between June 15 and July 15, and lambs born after July 15. There was a tendency for the later lambs to be lighter. Although the difference due to birth date was not great he felt that date of birth should be considered as a separate source of variation associated with gain. The correlation between the body weight of the ewe and the lamb birth weight was 0.49. Mature ewes reared heavier lambs than maiden ewes. In general Bonsma's statistical analysis consisted of looking at each of these sources of variation separately rather than considering them all simultaneously.

Hazel and Terrill (1945a) reported the results of the analysis of data concerning some of the environmental factors influencing the weaning weight of 2135 Rambouillet lambs reared under range conditions and weaned at approximately 140 days of age. In the analysis the age at weaning and degree of inbreeding of the lamb were considered as covariables and accounted for 5.1 and 6.4 percent of the variation respectively. Ram lambs were

8.3 pounds heavier than ewe lambs and this sex difference accounted for 8.9 percent of the variation in weaning weight. Single lambs were 9.2 and 2.5 pounds heavier than twins reared as twins and twins reared as singles respectively. Lambs reared by two year old ewes were 6.1 pounds lighter than lambs reared by mature ewes. Age of dam and type of birth and rearing accounted for 3.1 and 12.2 percent of the variation in weaning weight. Although the data were collected over a two year period there was no statistically significant difference between years. In all a total of 49.5 percent of the variation in the weaning weight of these lambs was accounted for by the factors studied.

In a subsequent study Hazel and Terrill (1946c) reported the results of the analysis of data collected on these ewe lambs as yearlings. The effects of the factors considered in the previous paper were still in the same direction as at weaning but were considerably smaller although statistically significant ($P < .01$). However there was a considerable reduction in growth rate during the post-weaning period. The influence of year which was unimportant in the weanling traits was a highly significant source of variation ($P < .01$) on the weight of these ewes as yearlings. A total of 28 percent of the variation in yearling weight was accounted for by differences in the degree of inbreeding, birth and rearing type, age of dam and the year the record was made.

In another study Hazel and Terrill (1946a) investigated some of the factors influencing the weaning weight of 478 Columbia, 238 Corriedale, and 366 Targhee lambs. The data were analyzed on a within year basis. The male lambs were significantly ($P < .01$) heavier than the females. Lambs reared as singles were heavier than lambs reared as twins and lambs born as twins and reared as singles. Age of dam effects were also highly significant

($P < .01$) sources of variation in weaning weight. The regressions of weaning weight on weaning age and degree of inbreeding were highly significant ($P < .01$). A total of 33 percent of the variation in weaning weight was accounted for by the variation in the factors studied.

Terrill et al. (1947) reported the results of the analysis of data collected on 406 Columbia and 290 Targhee yearling ewes. In this study the degree of inbreeding, type of birth and rearing, age of dam, and the year the record was made were considered as sources of variation in the yearling weight of these ewes. In general the differences between the various classes were less than the differences that had existed at weaning age. However some inconsistent results were noted within breeds in regard to the influence of type of birth and rearing. The Targhee ewes showed a greater difference as yearlings than as weanling ewes. Another factor which had a significant ($P < .01$) influence on the yearling weight of these ewes was age at shearing. In all a total of 48 percent of the variation in yearling weight was accounted for by these factors.

Sidwell and Grandstaff (1949) analyzed the weaning weights of 1506 lambs representing the lifetime production of 414 Navajo ewes. These data were collected over a ten year period. A highly significant ($P < .01$) difference in the weaning weights of lambs born in different years was noted. Age of dam, which ranged from two to eleven years was also a highly significant ($P < .01$) source of variation in these weaning weights. They noted that the greatest difference in age of dam effect was between the two and three year old ewes, with peak performance in the four to seven year old age groups followed by a decline in production of the eight to eleven year age group. Breed of sire, sex of lamb, and type of birth and rearing were also important sources of variation in this study. Spencer et al. (1942) compared the performance of ewes bred first as lambs with ewes bred first as yearlings. They reported that the lambs reared by the younger ewes were lighter at weaning the first year. However, the ewes bred first as lambs outproduced the ewes bred first as yearlings on a lifetime production basis.

Blackwell and Henderson (1955) studied the variation in the birth weight and weaning weight of sheep under farm flock conditions. Four breeds, Corriedale, Dorset, Hampshire and Shropshire were represented in this study. The data extended over a 28 year period and consisted of 2158 birth weight records and 1295 weaning weight records. Differences due to years, which appeared to fluctuate randomly about a general mean, were a highly significant ($P < .01$) source of variation in these traits. Other significant effects which were reported were sex, type of birth and rearing and the breed of the lamb. The influence of age of dam on the birth and weaning weight of the lambs was curvilinear with the five year old ewes producing the heaviest lambs.

de Baca et al. (1956) reported the results of a study of the factors effecting the weaning weight of 280 lambs. Birth weight was found to be the most important source of variation in weaning weight. Single lambs were 17 pounds heavier than twin lambs but when adjusted for birth weight this difference disappeared. The interaction between the sex of the lamb and type of rearing was non-significant. However, a significant ($P < .01$) breed of sire by breed of ewe interaction was noted in some cases. Bogart et al. (1957) analyzed the birth weights of the same lambs used in the previous study by de Baca and co-workers. Birth type was the most important source of variation in birth weight. The males were consistently heavier than the females but this difference was not statistically significant.

Sidwell (1956) considered some of the aspects of twin versus single lambs of Navajo and Navajo crossbred ewes based on 4537 lambs. He found that years had a highly significant ($P < .01$) influence on total pounds of lamb weaned per ewe. He also noted a highly significant ($P < .01$) rearing by year interaction in these data. However this interaction was not significant when the data were analyzed on a weaning weight per lamb basis.

Hunter (1956) investigated some of the aspects of maternal influence on the size of sheep. He made reciprocal crosses using two breeds (Border Leicester and Welsh Mountain) which differed greatly in mature body size. From the transplantation of ova of these ewes he concluded that the maternal influence on the size of the young at birth was greater in the larger breed. In the analyses of lamb body weight at two and three months of age he reported a significant ($P < .01$) interaction between the breed of ewe and the number of lambs reared. In general, differences in weight due to type of rearing increased up to about four months of age then decreased as the lambs grew older. He stated, "By eight months of age the genotype of the lamb was the most important factor affecting size." However he did note some "carry over" effect due to the maternal influences of the dam.

Harrington _et al_. (1958) estimated the relationships between breed of dam, birth type, sex, rearing type, and birth weight and the body weight at 45, 60, 75, 90, 105, 120 and 135 days of age on 300 crossbred lambs. Birth weight was the most important source of variation in body weight at all ages. Lambs reared as singles were heavier than lambs reared as twins although the difference was not always statistically significant. The difference between males and females tended to increase as the lamb grew older but this was not always significant. These sources of variation accounted for from 59 to 29 percent of the variation in body weight at different ages. The percent of variation accounted for in lamb body weight by these factors declined steadily as the lambs grew older.

Cameron and Hamilton (1961) studied the rate of gain of 144 Shropshire lambs from birth to 140 and 140 days of age. The lambs were weaned at average ages of 10, 15, and 20 weeks. These workers reported that the males gained faster than the females and singles gained faster than twins. The pooled interaction of these effects was non-significant.

Brothers and Whiteman (1961) reported the results of a study involving the effect of weaning on 121 crossbred lambs. An age of dam by sex of lamb interaction was reported which indicated that the male and female lambs of the yearling ewes gained at about the same rate whereas the male lambs gained faster than the female lambs in the older ewe groups.

Shelton and Campbell (1962) analyzed, on a within year basis, the weaning weight data collected on 3414 Rambouillet lambs over a 25 year period. Male lambs grew 7.2 percent faster than female lambs and single lambs grew 4.6 percent faster than twin lambs reared as singles, and 10 percent faster than twin lambs reared as twins. Age of dam effect appeared to be curvilinear with the ewes in the three to seven years of age group weaning the heaviest lambs. They noted a discrepancy between the actual observed differences due to age of dam and adjustment factor for age of dam calculated by least squares methods. They speculated that this discrepancy was due to an age of dam by type of rearing interaction. The regression of weaning weight on age was 0.06. They attributed this low value to a time trend in the data in that as the years advanced the lambs were younger and heavier at weaning. Individual yearly regression coefficients of weight on age ranged from 0.02 to 0.52.

Several workers have investigated some of the genetic aspects of rate of gain and body weight of lambs at different ages. Chapman and Lush (1932) estimated that the genetic variance of birth weight was about 30 percent in a flock of high grade Hampshires. Hazel and Terrill (1945b) calculated two estimates of the heritability of weaning weight in Rambouillet lambs. A heritability estimate of 0.269 ± 0.045 by the paternal half-sib method based on 2183 lambs and an estimate of 0.339 ± 0.077 based on 892 daughter-dam pairs were reported. Hazel and Terrill (1946b) also reported a weighted heritability estimate of 0.17 ± 0.05 for weaning weight of Columbia, Corriedale and Targhee lambs computed by half-sib correlation and daughter-dam regression methods.

Nelson and Venkatchalam (1949) analyzed the data collected on a college sheep flock. They reported heritability estimates of 0.72 and 0.29 for birth weight and weaning weight respectively by the method of intra-sire regression of offspring on parent. The corresponding estimates by paternal half-sib analyses were 0.15 ± 0.17 and 0.42 ± 0.21 for birth weight and weaning weight respectively. Karam et al. (1953) reported a heritability estimate of body weight at 155 days of 0.34 based on 27 sire groups and 593 lambs. Yao et al. (1953) used three methods of estimating the heritability of birth weight in Karakul sheep based on 728 lambs and 207 dams and 22 sires. They reported a heritability of birth weight of 0.18 by the paternal half-sib correlation method, 0.35 by the method of intra-sire regression and 0.25 by the mid-parent regression techniques.

Ragab et al. (1953) calculated heritabilities of 0.34 for birth weight, 0.10 for weaning weight and 0.29 for market weight based on 218, 202 and 165 daughter-dam pairs for birth weight, weaning weight and market weight respectively using data collected on Ossimi sheep in Egypt. Blackwell and Henderson (1955) analyzed the farm flock data collected from 1932 to 1950 at Cornell and reported a heritability of 0.33 for birth weight based on the intra-sire regression of offspring on dam. They also reported a heritability of 0.07 for weaning weight based on the total weight of the first lamb (or lambs) weaned by the ewe and 0.18 for weaning weight when based on intra-sire regression of offspring on dam. They also estimated the repeatability of the total weight of lambs at birth and total weight of lambs weaned as 0.20 and 0.07 as a characteristic of the ewe. These data were adjusted for sex, age of dam, type of birth and rearing and breed of dam prior to estimating these genetic parameters.

Sidwell and Grandstaff (1949) used a similar method of analysis and obtained a repeatability estimate of 0.22 for the weaning weight of lambs of Navajo ewes. Cassard and Weir (1956) reported heritability estimates of 0.09 for birth weight and 0.41 for 120 day weight in Suffolk sheep by the method of offspring dam regression. Hundley and Carter (1956) calculated the heritability of rate of gain from birth to weaning based on 943 crossbred lambs. The heritability estimates for daily gain was 0.37 for the Hampshire sired lambs and 0.04 for the Southdown sired lambs. MacNaughton (1957) analyzed the data collected on 5000 Rambouillet and Canadian Corriedale sheep. He reported intra-year, intra-sire regression heritability estimates for birth weight of 0.33 and 0.45 in the Rambouillet and Corriedale flocks respectively. The heritability of weaning weight was 0.27 in the Rambouillet group and 0.36 in the Corriedale Group. He also calculated repeatability estimates of birth weight of 0.27 and 0.36 in the Rambouillet and Corriedale flocks respectively. The corresponding repeatability estimates for weaning weight were 0.25 in the Rambouillet and 0.30 for the Corriedales.

Vesely and Slen (1961) collected data over a 12 year period on Rommelet ewe lambs and reported a heritability estimate of weaning weight at approximately 140 days of 0.28 based on 694 daughter-dam pairs. Harrington et al. (1962) reported the results of analyzing the data on 671 crossbred lambs. Using the half-sib correlation method they calculated the heritability estimates of 0.11, 0.38 and 0.35 for rate of gain from birth to 50 pounds, 50 to 90 pounds and birth to 90 pounds respectively. Shelton and Campbell (1962) compared several estimates of the heritability of weaning weight of 3440 range Rambouillet lambs when the data were adjusted for different combinations of known sources of variation. By the half-sib correlation method they estimated the heritability of weaning weight to be 0.32 on the unadjusted data. Adjustment of the data gave only slight improvement on this estimate. When the intra-sire regression method was used the resulting heritability of weaning weight was 0.14. They considered this latter estimate to be more indicative of the true genetic situation.

An estimate of the heritability of date of lambing of 0.30 was published in the 66th annual report of the Kentucky Agricultural Experiment Station (1953). The corresponding repeatability estimate based on 166 ewes was 0.43. The data for this study were collected on Southdown and Hampshire ewes.

Ewe Milk Production and Lamb Gain

The estimation of the milk production of ewes of the "non-milk" breeds is a laborious task. Fuller and Klienheinz (1904) observed that the milk yield of the ewe was more than twice as great when estimated by weighing the lamb before and after nursing as compared to hand milking. The method of estimating milk production by weighing the lamb before and after nursing has been used extensively by other research workers. In general these workers have estimated the milk production of the ewe for a 24 hour period at weekly intervals during the lactation period. These estimates were then used to calculate the cumulative milk production of the ewe during her lactation which were then correlated with lamb gain. Recently McCance (1959) has shown that by the injection of PPE (posterier pituitary extract) it is possible to milk the ewe completely dry by hand milking. The injection of PPE did not appear to have any harmful effect on the ewes' subsequent production. However he did not correlate this method of estimating milk production with lamb gain. Some workers have critized the method of estimating milk production by weighing the lamb before and after nursing because it is also a function of the capacity and appetite of the lamb rather than a true measure of the ewe's milk production.

Ritzman (1917) reported the results of feeding whole milk and skim milk on lamb growth. He concluded that the chief advantage of whole milk was its capacity to promote fattening simultaneously with growth. He also noted that the quantity of milk produced by the ewe had a great effect on the rate of gain of her lamb. Neidig and Iddings (1919) likewise concluded that the greatest factor influencing the rate of growth of the lamb is the amount of milk it receives.

Bonsma (1939) correlated the milk yields of 70 Merino ewes with the gain of their lambs during the corresponding period. He reported correlations of 0.882 during the first two weeks of lactation, 0.784 for the second through fifth week, 0.516 for the fifth to eighth week, 0.397 for the eighth through eleventh week and 0.812 for the entire 11 week lactation period between lamb gain and milk production. He also noted a correlation of 0.317 between birth weight of the lamb and the milk production of the ewe. There was also a highly significant ($P < .01$) correlation of 0.512 between the body weight of the ewe and the amount of milk produced. Using the first lactation (two year old ewes) as a base of 100 he found the comparative increases in the 2nd, 3rd and 4th lactation to be 120, 125 and 136 respectively.

Other workers have also correlated lamb gain and milk production over varying periods of time. Shrewsbury et al. (1943) reported a correlation of 0.89 between lamb gain and cumulative milk production to eight weeks of age based on 130 ewes rearing single lambs. Whiting et al. (1952) used data collected on 40 mature range ewes to calculate a correlation of 0.63 between the weight of the lamb at seven weeks and the average daily milk production of the ewe over the same period. The correlation between weaning weight of the lamb at five months and the average daily milk of the ewe to seven weeks was 0.65. They stated that the correlation between the average daily milk production of the ewe to seven weeks and the gain of the lamb from seven weeks to weaning was not significant.

Guyer and Dyer (1954) collected data on 151 Hampshire lambs over a two year period. They reported correlations of 0.71 and 0.86 between total milk production to nine weeks and lamb birth weight and lamb gain respectively.

A correlation of 0.65 between lamb gain and birth weight was also reported but when milk production was held constant the correlation dropped to 0.11. These workers found no significant correlation between ewe body weight taken in early pregnancy with subsequent milk production. Female lambs consumed more milk than male lambs but in general did not gain as fast thus indicating that the females made less efficient use of the milk consumed. However these lambs did receive supplemental feed during the lactation study; hence the difference in the relative efficiency of the male and female lambs may have been due to differences in the amount of supplemental feed consumed. Burris and Baugus (1944) reported correlations ranging from 0.80 to 0.90 between lamb gain and the milk production of 18 Hampshire ewes rearing single lambs. They also reported correlations of 0.74, 0.50 and 0.47 between milk production and ewe body weight, lamb birth weight and udder size at lambing respectively. The average daily gain of the lamb was correlated with ewe weight (0.67), lamb birth weight (0.61) and udder width (0.54). Munro (1955) found a correlation of 0.54 between total milk production at six weeks and the body weight of the ewe based on data collected on 40 Scottish Blackface ewes.

Wallace (1948) accounted for 96 percent of the variation in 112 day weight of 23 lambs by the differences in the amount of milk and supplemental feed consumed by the lamb. He also reported correlations of 0.92, 0.83, 0.71 between milk production and lamb gain over periods from birth to four, eight, twelve and sixteen weeks respectively. He suggested that it might be possible to use the gain of the lamb at some early age as an estimate of the milking ability of the ewe.

Wallace also stated that the level of nutrition of the ewe during the last six weeks of pregnancy has a profound effect upon subsequent milk production. Thomson and Thomson (1953) also reported that the level of nutrition of the ewe during pregnancy has a great effect upon her milk production. Lambs transferred at birth from ewes on a low plane of nutrition were able to take advantage of the increased milk production of these high plane ewes. Lambs from high plane ewes transferred to low plane ewes did very poorly and suffered a high rate of mortality. In this study twin lambs were lighter at weaning than single lambs in all groups except the lambs of ewes which were on a low plane of nutrition during pregnancy and lactation in which case the average weight of the twins and the singles was the same at weaning. This would tend to indicate that in order to get an expression of the rearing effect it is necessary to have an adequate milk supply. Guyer and Dyer (1954) reported that ewes fed on a high plane of nutrition produced more milk than the low plane ewes. Whiting et al. (1952) noted that the milk production of the ewe was influenced by the level of protein intake during pregnancy and lactation. McCance and Alexander (1959) reported that the onset of lactation may be delayed up to 12 hours after parturition when the ewes were poorly fed during pregnancy. The well-fed ewes in their study had ample milk at parturition or a few hours earlier.

Barnicoat et al. (1949, 1956) conducted an extensive investigation of the milk production of ewes in New Zealand. Lactation records on 200 Romney ewes were collected over a five year period. They reported that the level of milk production of the ewe was greatly influenced by her general health and level of nutrition. Six year old ewes produced 16 percent more milk than two year old ewes. Ewes rearing twins produced about 33 percent more milk than ewes rearing single lambs. Within a lambing season there was considerable effect due to the date of lambing on the ewes' milk production. They noted that ewes lambing early in the season and those lambing late in the season produced less milk than those lambing during the middle of the season. They attributed this to differences in the quantity and quality of the forage available during lactation. Correlations between milk production and lamb gain were the highest during the fourth to sixth week period (0.68 to 0.98). The authors concluded that the results of one lactation is sufficient indication of a ewe's lifetime production. Indirect estimates of milk production based on lamb gain were in close agreement with actual yields.

Hunter (1956) studied the maternal influence on the size of sheep. He reported that the amount of milk consumed by the lamb during the first half of the lactation had a great effect upon lamb gain but had considerable less effect on gain during the second half of the lactation. The total milk production of the ewe was affected by the date of lambing with the milk production of late lambing ewes being less than those lambing earlier in the season.

Owen (1957) collected data over a three year period on 181 Hill sheep rearing single lambs. Correlations between lamb gain and milk production ranging from 0.78 to 0.87 based on gain from birth to two weeks and 0.68 to 0.73 on gain from birth to 10 weeks. Correlations between lamb birth weight and total milk production to 10 weeks were about 0.40 on a within age of dam basis and about 0.27 on an across age of dam basis. The correlation between ewe weight and milk production to 10 weeks averaged about 0.67. He also noted a correlation of 0.70 and 0.87 between total milk production to 10 weeks and total production from birth to two weeks and birth to four weeks respectively. He calculated a ratio of about five to one between the milk production of the ewe and the gain of her lamb. He then used this ratio to estimate the milk production of the ewe indirectly based on the gain of her lamb. He stated that the following criterion for estimating milk production must be fulfilled: (1) the lamb must be weighed when gain and milk production are highly correlated, (2) the lamb should be weighed during an age period when growth is nearly linear, (3) the age of the lamb and its birth weight must be known and (4) the variation in date of lambing should not be too great in order to avoid within season time trends.

Alexander and Davies (1959) studied the relationship of the milk production of the ewe to the number of lambs born and reared. The results showed that the milk yield of the ewe was greatly influenced by the number of lambs suckled but not by the number of lambs born. Ewes rearing single lambs which were born as twins produced about the same amount of milk as ewes rearing single lambs born as singles.

Owing to the difficulty of estimating milk production in the ewe very few estimates of the heritability and repeatability of this trait have been calculated. Barnicoat et al. (1956) reported a repeatability of 0.388 based on four consecutive lactations of 19 ewes. Owen (1957) reported a repeatability of 0.422 ± 0.052 based on 278 daughter-dam pairs in which one record was estimated indirectly based on lamb gain. He also reported a heritability of 0.50 for milk production based on 147 daughter-dam pairs. Two estimates of the heritability and repeatability have been made on Italian Sheep. Bettini (1952) in a study involving 796 lactations reported a repeatability of 0.44 based on two successive lactations. He also reported a heritability of 0.61 for length of lactation and a heritability of 0.34 for milk production on a lifetime average basis. Mason and Dassat (1954) analyzed the data from 442 lactations of 150 Langhe ewes and reported a repeatability of 0.69 for uncorrected successive lactations. When these data were adjusted for years, age of dam, date of lambing and the number of lambs born, the repeatability was 0.43.

MATERIALS AND METHODS

This study was composed of two parts. Part I was concerned with the estimation of the repeatability of birth weight, 70 day weight and rate of gain from 70 days to 140 days as characteristics of the individual ewes' production. Several repeatability estimates were made after the effects of various combinations of known sources of variation in these traits were removed by statistical means. Part II was concerned with the estimation of the milk production of the ewe and its relationship with lamb weights or gains. Estimates of milk production were made on each ewe at weekly intervals from one to ten weeks.

Part I: Repeatability Estimates

The data used in this portion of the study were obtained from the experimental sheep flock (Project S-908) at the Fort Reno Livestock Research Station. The lambs were born between October 15 and December 1 during the years 1955 through 1960.

The dams of the lambs were grade Rambouillet and Rambouillet x Panama-Rambouillet ewes which were purchased as yearlings during April and May 1955 in the Del Rio, Texas area. All the lambs were sired by purebred Dorset rams which were purchased from private breeders in Oklahoma. The ewes were first bred as yearlings in late May, June and early July 1955. Subsequent matings of these ewes commenced in late May each year and lasted for approximately 40 days.

The flock was managed according to the usual practices of the commercial sheep producers of Oklahoma. The ewes were fed grain at the rate of about a pound a day for one and one-half to two and one-half months after lambing. During the winter months the ewes were grazed on wheat pasture and received supplemental alfalfa hay during inclement weather. After lambing the ewes were divided into two groups—one group made up of ewes that were not rearing lambs and another group made of ewes rearing lambs. The latter group was moved to a wheat pasture area when the lambs were about 10 days of age. Starting with the 1956-57 lamb crop the ewes rearing twins were separated from the ewes rearing singles in the wheat pasture area by a partition fence and were feed grain about one month longer. All other management of the ewes rearing lambs was similar. The lambs were self-fed a creep feed mixture consisting of two parts cracked milo grain and one part chopped alfalfa hay of good quality.

Birth date, birth weight, sex, and type of birth and rearing were recorded for each lamb within a few hours after the lamb was born. Each lamb was identified by a number which was usually the same as its dam's number. Commencing in the 1956-57 lambing season each lamb was identified by a number which was the same as that of its dam. Twin lambs both received the same number as their dam; however, one of the pair's number was preceded by a bar (-). The number was stamped on a metal ear tag and also paint branded on the back of the lamb. All lambs were docked during the first week after birth. The ram lambs were castrated between one and four weeks of age.

The lambs were weighed to the nearest one-half pound at birth in the 1955-56 season and to the nearest one-tenth of a pound in subsequent seasons.

The lambs were weighed again in late November or early December when the older lambs in the flock were approximately 40 to 45 days of age. Subsequently the lambs were weighed at approximately two week intervals until they reached a market weight of about 90 pounds.

The distribution of the lambs used in this study according to sex, type of rearing and year are presented in Table 1.

TABLE 1.

NUMBER OF LAMBS IN THE REPEATABILITY STUDY ASSEMBLED ACCORDING TO SEX, BIRTH AND REARING TYPE, AND YEAR

Sex	Rearing Type[a]	Year						
		1955	1956	1957	1958	1959	1960	Total
Male	SS	21	44	48	47	36	13	209
	TS	6	4	3	4	6	1	24
	TT	11	36	24	35	69	19	194
Female	SS	19	48	31	50	39	21	208
	TS	3	2	1	4	4	2	16
	TT	8	35	21	51	47	16	178
Total		68	169	128	191	201	72	829

[a]SS = single reared as single
TS = twin reared as single
TT = twin reared as twin

The weights of the lambs were adjusted to a constant age of 70 days by the linear interpolation method as described ty Taylor and Hazel (1955). The calculation of rate of gain from 70 days to 140 days was done by adjusting the lamb weight to a constant age of 140 days, subtracting the adjusted 70 day weight and dividing by 70. In some cases the lambs had reached market weight (approximately 90 pounds) prior to 140 days of age. In such cases rate of gain was calculated by subtracting the 70 day weight from 90 pounds and dividing by number of days between the lamb's age at 90 pounds and 70 days of age.

The least squares method of obtaining constants was used to contend with the multiple classification and unequal subclass numbers as outlined by Anderson and Bancroft (1952). Each observation of a 70 day weight or rate of gain from 70 days to 140 days was considered to be the sum of the influences or effects of the other variables as represented by the following model.

$$Y_{ijkl} = M + S_i + R_j + T_k + (SR)_{ij} + (ST)_{ik} + (RT)_{jk}$$
$$+ D_1X_1 + D_2X_1^2 + W_1X_2 + W_2X_2^2 + e_{ijkl}$$

where

Y_{ijkl} = the 70 day weight or rate of gain from 70 to 140 days of the lamb

M = a constant for all lambs; the mean

S_i = a constant for the i^{th} sex (wether or ewe lamb)

R_j = a constant for the j^{th} type of birth and rearing (single reared as single, twin reared as a single, and twin reared as a twin)

T_k = a constant for the k^{th} year

$(SR)_{ij}$ = a constant for the ij^{th} interaction between the i^{th} sex and j^{th} birth and rearing type

$(ST)_{ik}$ = a constant for the ik^{th} interaction between the i^{th} sex and the k^{th} year.

$(RT)_{jk}$ = a constant for the jk^{th} interaction between the j^{th} birth and rearing type and the k^{th} year

D_1 = a constant for the linear effect of the lamb's birth date X_1, a covariable

D_2 = a constant for the quadratic effect of the lamb's birth date squared, X_1^2, a covariable

W_1 = a constant for the linear effect of the lamb's birth weight X_2, a covariable

W_2 = a constant for the quadratic effect of the lamb's birth weight squared X_2^2, a covariable

e_{ijkl} = error or failure of the above constants to estimate the 70 day weight or the rate of gain from 70 to 140 days of the lamb.

The same model was used for the estimation of the influences of these sources of variation on birth weight except that the constants W_1 and W_2 were not included.

Since the normal equations obtained by least squares methods were not independent, the restrictions were made that the

$$\sum S_i = \sum R_j = \sum T_k = \sum (SR)_{ij} = \sum (ST)_{ik} = \sum (RT)_{jk} = 0 \ .$$

Thus the constants obtained for each classification were expressed as deviations from a zero mean for each class.

Previous work by Harrington _et al._ (1958), Brothers (1961), and Harrington _et al_. (1962) had indicated that the effect of breed of dam for these ewes was negligible; consequently, it was not included in the model.

The constants derived by the solution of these equations were used to calculate the individual lamb deviation from a zero mean in the following manner:

$$e_{ijkl} = Y_{ijkl} - [\, M + S_i + R_j + T_k + (SR)_{ij} + (ST)_{ik} + (RT)_{jk}$$

$$+ D_1X_1 + D_2X_1^2 + W_1X_2 + W_2X_2^2 \,].$$

These e_{ijkl} values were considered to be normally and independently distributed with mean zero and variance σ_e^2. Each e_{ijkl} value was then considered to be made up of two components, a component due to the differences among dams and a component due to the differences among the lamb progeny of the same dam. That is, let

$$e_{ijkl} = E_{mp}$$

then

$$E_{mp} = M + D_m + d_{mp}$$

where

E_{mp} = the adjusted value of p^{th} lamb of the m^{th} ewe

M = the mean with an expected value of zero

D_m = the effect of the m^{th} ewe

d_{mp} = error or failure of the lambs from the same ewe to respond the same.

This model is a simple single classification with unequal subclass numbers and was analyzed as outlined by Snedecor (1956). The expected mean squares and degrees of freedom are presented in Table 2.

TABLE 2.

DEGREES OF FREEDOM AND EXPECTED MEAN SQUARES FOR THE REPEATABILITY ESTIMATES

Source of Variation	Degrees of Freedom	Expected Mean Square
Among Ewes	175	$\sigma_d^2 + 3.7086\sigma_D^2$
Lambs within Ewes	$(477)^a - R^b$	σ_d^2

[a]In the case of twin lambs one lamb from each pair was randomly discarded which resulted in 477 degrees of freedom.

[b]Where R is the number of degrees of freedom lost by fitting the regression equation.

In the case of a dam having twin lambs, one of the adjusted lamb records was discarded at random in order that the data could be kept on a half-sib basis. The estimates of repeatability of the traits were calculated as follows:

$$\text{Repeatability} = \frac{\sigma_D^2}{\sigma_D^2 + \sigma_d^2}$$

which is a special case of the intraclass correlation. This method of adjusting the data and then calculating the repeatability estimates assumes that the ewe effect is not correlated with or does not interact with any of the sources of variation which were used to adjust the data.

Several repeatability estimates of 70 day weight and rate of gain from 70 to 140 days were calculated. These various repeatability estimates were obtained by deleting one or more of the covariables and/or interaction effects from the original model which has been described. The various equations used to adjust the data were as follows:

Equation	Sources of Variation Included in the Data Adjustment									
1	Sex	Rear	Year	SxR	SxY	RxY	BD	BD^2	BW	BW^2
2	Sex	Rear	Year	SxR	SxY	RxY	BD	BD^2	-	-
3	Sex	Rear	Year	SxR	SxY	RxY	-	-	BW	BW^2
4	Sex	Rear	Year	SxR	SxY	RxY	-	-	-	-
5	Sex	Rear	Year	-	-	-	BD	BD^2	BW	BW^2
6	Sex	Rear	Year	-	-	-	BD	BD^2	-	-
7	Sex	Rear	Year	-	-	-	-	-	BW	BW^2
8	Sex	Rear	Year	-	-	-	-	-	-	-
9	Raw Data Unadjusted									

Equation 1 was the general model which has been described. In cases of equations 2, 4, 6, 8 and 9 estimates of the repeatability of birth weight were also calculated.

Part II: Milk Production

The milk production data in this portion of the study were collected over a two year period on Dorset X Western crossbred ewes which are part of the experimental sheep flock (S-908) at the Fort Reno Livestock Research Station. These ewes were saved as replacements from the 1956, 1957, 1958 and 1959 lamb crops. They were sired by purebred Dorset rams and their dams were the grade Rambouillet and RPR ewes described in part I of this study. These one-half Dorset ewes were chosen for the milk production study primarily because they represented four age groups which were genetically similar. The lambs from these ewes were sired by purebred Dorset, Hampshire, Suffolk, and Rambouillet rams. A summary of the number of ewes in this milk production study according to year, age of ewe and type of rearing of their lambs (single or twin) is presented in Table 3.

TABLE 3.

SUMMARY OF THE NUMBER OF EWES IN THE MILK PRODUCTION STUDY ASSEMBLED ACCORDING TO YEAR, AGE OF EWE AND REARING TYPE OF THE LAMBS

Lamb Rearing Type	Age of Ewe	Year 1960-61	Year 1961-62
	1	11	0
	2	10	16
Singles	3	10	13
	4	10	8
	5	0	9
	1	0	0
	2	5	3
Twins	3	9	6
	4	10	10
	5	0	11

The management of the ewes and lambs was similar to that described in Part I. However they were grazed in a separate wheat pasture area and the ewes rearing singles and the ewes rearing twins were not separated as in Part I. The ewes were fed supplemental hay (good quality alfalfa and some prairie hay) as well as a daily ration of grain throughout the period of the study. The lambs had access to a creep ration which was the same as described in part I. All the lambs were docked during the first week after birth. The ram lambs were castrated between one and six weeks of age.

The milk production of a ewe was estimated for a 24 hour period at weekly intervals based on the milk consumption of her lamb(s) by weighing the lamb(s) immediately before and after nursing. The problem of preventing the lambs from nursing between weighing times was handled in the manner described by Owen (1957) in that a light canvas cover was placed over the ewe's udder which effectively prevented the lamb from nursing but caused the ewe little or no discomfort. The udder cover was constructed in such a way as to allow it to be partially removed from the ewe during the nursing period and give the lamb easy access to the udder. The use of the udder cover circumvented the necessity of penning the lambs and ewes separately which has been observed by several workers (Barnicoat et al. 1949, 1956; Guyer and Dyer, 1954; Munro 1955) to cause distress both to the ewe and the lamb.

The frequency of the nursing times during the 24 hour period was governed by two considerations. The first was that the time period between nursings should not be too long so as to avoid undue udder pressure in the ewe and also allow the lamb to consume all the milk that had accumulated between nursings. The second consideration was that the ewes and lambs should be handled as little as possible in order that the ewes could have a maximum amount of grazing time. Fewer milkings would also cause less distress to the ewes and lambs during the milking period. These two factors resulted in a compromise in that when the lambs were young and up to about four or five weeks of age they were allowed to nurse five times during the 24 hour period. From about five to eight or nine weeks the lambs nursed four times during the 24 hour period. After the lamb reached eight or nine weeks of age the number of nursing times was reduced to a minimum of three. It was noted that after the lambs were about two weeks old they could easily consume all the milk available.

Immediately prior to putting on the udder cover at the beginning of the 24 hour recording period the lambs were allowed an opportunity to nurse. Consequently no preliminary nursing period was made. Owen (1957) also observed that the disturbance of gathering insured that the lamb took advantage of this time to nurse. In the case of ewes rearing twins both lambs were allowed to nurse simultaneously.

The lambs were weighed to the nearest one-tenth of a pound before and after nursing. In the 1960-61 season a set of ordinary milk scales equipped with a canvas pouch was used but proved to be slow and awkward after the lambs weighed more than 20 pounds. In the 1961-62 season a set of platform dial scales, which read to the nearest one-tenth pound, were equipped with a walk-in crate and were much more efficient. Speed in weighing the lambs was considered to be essential in order to avoid weight loss due to defecation or urination. Before each nursing the lambs were aroused and moved about which generally prevented any untimely weight losses during the nursing period.

In order not to put too much stress on the young lambs, they were at least four days old before any milk production record was made on their dams. Consequently most of the ewes were started on test when their lambs were between four and eleven days of age. Both the milk production of the ewes and the weight of the lambs were adjusted to a constant age. These constant ages started at one week and continued at weekly intervals through 10 weeks. A modification of the linear interpolation method was used to adjust the milk production and body weight of the lambs to a constant age. By using this modified method, the actual age of the lamb did not deviate from the adjusted age by more than four days. If the lamb was less than a week old when the first record was made the two weights bracketing the adjusted age were used to estimate the weight for the day. A similar procedure was used to estimate the weekly milk consumption. If the lamb was more than a week old when the first record was made then the average daily gain of the lamb from birth to its actual age was multiplied by seven and added to the lamb's birth weight to obtain its seven day weight. In subsequent weeks the weights bracketing the adjusted age were used to estimate the corresponding weight of the lamb. The estimate of the daily milk production of the ewe, based on the milk consumption of her lamb(s) during a 24 hour period, was multiplied by the number of days since the previous record was made to obtain an estimate of the total milk production for that period. This estimate was then adjusted to an estimate of the milk production of the ewe for the appropriate weekly period. In the case of milk production the estimate of the weekly production was added to the previous week's accumulated total to obtain the cumulative milk production to that date.

The body weight and condition (degree of finish) of the ewe was also measured or estimated. The degree of finish or condition of the ewe was estimated by a subjective score which ranged from one to nine with one being very thin and nine being very fat based on the degree of finish over the back, loin, rump and ribs of the ewe. In the 1960-61 season only one estimate of the body weight and condition of the ewe was available. This was taken about three weeks prior to lambing. During the 1961-62 season the ewes were weighed and scored at weekly intervals during the lactation period. In the analyses the ewe weight and condition score taken at the time nearest to the adjusted age were used as covariables.

As noted in table 3 the number of ewes per age of ewe group varied within years. There was also a disproportionality in the number of male and female lambs, twins and singles and also the number of lambs within a breed of sire group. The method of least squares analysis as outlined by Anderson and Bancroft (1952) was used to contend with this multiple classification and unequal subclass numbers. The cumulative total milk consumption for each week by the individual lamb was considered to be the sum of the influences or effects of the other variables as represented in the following model:

$$Y_{ijkmn} = M + S_i + R_j + A_k + B_m + (SR)_{ij} + (SA)_{ik} + (RA)_{jk} + E_1X_1 + E_2X_1^2$$

$$+ C_1X_2 + C_2X_2^2 + D_1X_3 + D_2X_3^2 + W_1X_4 + W_2X_4^2 + WTX_5 + e_{ijkmn}$$

where

Y_{ijkmn} = the cumulative milk consumption of the lamb to any particular week

M = a constant for all lambs, the mean

S_i = a constant for the i^{th} sex (wether or ewe lamb)

R_j = a constant for the k^{th} rearing type (single or twin)

A_k = a constant for the k^{th} age of ewe

B_m = a constant for the m^{th} lamb sire breed, (Dorset, Hampshire, Suffolk, or Rambouillet)

$(SR)_{ij}$ = a constant for the ij^{th} interaction effect between the i^{th} sex and j^{th} rearing type

$(SA)_{ik}$ = a constant for the ik^{th} interaction effect between the i^{th} sex and k^{th} age of ewe

$(RA)_{jk}$ = a constant for the interaction between the j^{th} rearing type and the k^{th} age of ewe

E_1 = a constant for the linear effect of the ewe's body weight X_1, a covariable

E_2 = a constant for the quadratic effect of the ewe's body weight squared X_1^2, a covariable

C_1 = a constant for the linear effect of the ewe's condition score X_2, a covariable

C_2 = a constant for the quadratic effect of the ewe's condition score squared X_2^2, a covariable

D_1 = a constant for the linear effect of the lamb's birth date X_3, a covariable

D_2 = a constant for the quadratic effect of the lamb's birth date squared X_3^2, a covariable

W_1 = a constant for the linear effect of the lamb's birth weight X_4, a covariable

W_2 = a constant for the quadratic effect of the lamb's birth weight squared X_4^2, a covariable

WT = a constant for the linear effect of the lamb's body weight or net weight gain to a particular week X_5, a covariable

e_{ijkmn} = error, or failure of the above constants to estimate the total milk consumed by the lamb to any particular week.

The constants referred to in the above model are actually partial regression coefficients.

Since the normal equations obtained by least squares methods were not independent the restrictions were made that the

$$\sum S_i = \sum R_j = \sum A_k = \sum B_m = \sum (SR)_{ij} = \sum (SA)_{ik} = \sum (RA)_{jk} = 0.$$

Thus the constants or partial regression coefficients obtained for each classification were expressed as deviations from a zero mean for each class.

The model presented was the more general case for the 1961-62 season. In the 1960-61 season the quadratic effects E_2 and C_2 were not considered as covariables. Also in the 1960-61 season the effects of D_1 and D_2 were not considered as covariables.

In the analyses of the data for 1960-61 season lamb net weight gain X_5 was used whereas in the 1961-62 season X_5 was the body weight of the lamb.

In order to investigate the influences of these factors on lamb growth, X_5 was taken as a dependent variable. Thus it was possible to use the same general model that has been described for the milk production analysis. The only changes necessary were to delete the rows and columns in the matrix that were associated with the milk consumption of the lamb and reanalyze the data with either lamb body weight or net lamb gain at the various weeks as the dependent variable.

RESULTS AND DISCUSSION

This section is composed of two parts. Part I consists of the repeatability estimates of birth weight, 70 day weight and rate of gain from 70 to 140 days. The corresponding analyses of variance are discussed first followed by a discussion of the repeatability estimates which were calculated from the adjusted data. In part II the results of the milk production study are presented and discussed. The analyses of variance of lamb growth are presented first followed by the analyses of variance of the ewe milk production data and finally the prediction equations for estimating milk production indirectly based on the growth of the lamb.

Part I: Repeatability Estimates

Analyses of Variance of Birth Weight, 70 Day Weight and Rate of Gain from 70 to 140 Days

The analyses of variance for birth weight, 70 day weight and gain from 70 to 140 days are presented in tables 4, 5 and 6. The corresponding coefficients of determination (R^2) are also presented in these tables. Because of the disproportionality of the sub-class numbers and correlations among some of the variables, the data in this study were non-orthogonal. Henderson (1953) and Harvey (1961) have discussed the problem of the estimation of the sums of squares associated with the various effects in the non-orthogonal case. Because of this non-orthogonality, the sums of squares associated with any particular effect are dependent upon the other factors present in the analyses. As a result

TABLE 4.

ANALYSES OF VARIANCE OF BIRTH WEIGHT

Source of Variation	d.f.	Mean Squares Equation 2	Equation 4	Equation 6	Equation 8
Total	828	10.80	10.80	10.80	10.80
Sex (S)	1	31.41**	63.11**	114.43**	109.20**
Rear (R)	2	241.00**	238.02**	309.29**	315.51**
Year (Y)	5	70.45**	63.96**	162.18**	153.37**
S x R	2	0.69	0.56	---	---
S x Y	5	0.96	0.96	---	---
R x Y	10	4.77*	4.52*	---	---
Birth Date	1	2.38	---	2.82	---
Birth Date Squared	1	1.83	---	2.25	---
Error	801	2.16	2.23[a]	2.19[b]	2.25[c]
R^2		0.464	0.446	0.447	0.430

* P < .05

** P < .01

df for Error

a 803

b 818

c 820

TABLE 5
ANALYSES OF VARIANCE OF 70 DAY WEIGHT

Source of Variation	d.f.	Mean Squares							
		Equation 1	Equation 2	Equation 3	Equation 4	Equation 5	Equation 6	Equation 7	Equation 8
Total	828	85.1	85.1	85.1	85.1	85.1	85.1	85.1	85.1
Sex (S)	1	864.7**	1,860.1**	930.2**	1,881.5**	917.7**	3,151.7**	1,197.9**	3,365.5**
Rear (R)	2	3,214.4**	9,544.7**	3,971.4**	10,332.5**	3,616.9**	11,426.8**	4,050.2**	11,804.5**
Year (Y)	5	241.5**	907.7**	461.9**	1,170.6**	337.2**	1,782.3**	792.3**	2,324.6**
S x R	2	139.6**	102.6	77.2	68.0	---	---	---	---
S x Y	5	45.8	39.6	53.9	46.0	---	---	---	---
R x Y	10	54.0*	79.3*	70.6*	92.3*	---	---	---	---
Bth Date	1	16.1	59.4	---	---	18.2	68.1	---	---
Bth Date Sq.	1	27.2	71.6	---	---	29.8	81.4	---	---
Bth Wt.	1	607.9**	---	540.8**	---	663.8**	---	576.5**	---
Bth Wt. Sq.	1	37.3	---	39.0	---	43.4	---	40.3	---
Error	799	29.1	41.1[a]	31.8[a]	45.8[b]	29.7[c]	41.6[d]	32.4[d]	42.8[e]
R^2		0.672	0.533	0.639	0.522	0.656	0.517	0.632	0.502

* P < .05

** P < .01

df for Error
a 801
b 803
c 816
d 818
e 820

TABLE 6

ANALYSES OF VARIANCE OF

RATE OF GAIN FROM 70 TO 140 DAYS

Source of Variation	d.f.	Mean Squares							
		Equation 1	Equation 2	Equation 3	Equation 4	Equation 5	Equation 6	Equation 7	Equation 8
Total	828	0.00827	0.00827	0.00827	0.00827	0.00827	0.00827	0.00827	0.00827
Sex (S)	1	0.16731**	0.23371**	0.15204**	0.22700**	0.45038**	0.71536**	0.38467**	0.63565**
Rear (R)	2	0.00988	0.02247*	0.02724*	0.00889	0.01635	0.02464*	0.03034*	0.01861
Year (Y)	5	0.02269**	0.03572**	0.01549*	0.01763*	0.06841**	0.07578**	0.05067**	0.03959**
S x R	2	0.00119	0.00039	0.00114	0.00094	---	---	---	---
S x Y	5	0.00203	0.00257	0.00233	0.00297	---	---	---	---
R x Y	10	0.00653	0.01126	0.00907	0.01413	---	---	---	---
Bth Date	1	0.06371**	0.05431**	---	---	0.06355**	0.05290**	---	---
Bth Date Sq.	1	0.07048**	0.06184**	---	---	0.07051**	0.06050**	---	---
Bth Wt.	1	0.00214	---	0.00118	---	0.00279	---	0.00132	---
Bth Wt. Sq.	1	0.02489*	---	0.02602*	---	0.03042*	---	0.03019*	---
Error	799	0.00634	0.00667[a]	0.00671[a]	0.00729[b]	0.00631[c]	0.00677[d]	0.00672[d]	0.00734[e]
R^2		0.261	0.220	0.215	0.145	0.249	0.191	0.197	0.122

* $P < .05$

** $P < .01$

df for Error

a 801

b 803

c 816

d 818

e 820

of this situation it is not possible to get an unbiased estimate of the sums of squares associated with error by the usual methods of partitioning the total sums of squares. To overcome this difficulty of a biased error term the method of fitting constants, which has been described by Henderson (1953) and Harvey (1961), was used to obtain the sums of squares for error. These constants are presented in appendix tables 29 through 33. The sums of squares associated with any particular effect were computed by the utilization of the inverse matrix. This method has been explained in some detail by Harvey (1961). Harvey also stated that in dealing with a fixed model, i.e. the case where all the factors are fixed effects, the sums of squares associated with any particular comparison are tested for significance by using the error mean square as the denominator for F.

Influence of Sex:

The effect of the sex of the lamb was a highly significant ($P < .01$) source of variation in birth weight, 70 day weight, and gain from 70 to 140 days in this study. This difference due to sex was evident in all the equations used to analyze these traits. Hazel and Terrill (1945a), Blackwell and Henderson (1955) and Shelton and Campbell (1962) have also noted that the sex of the lamb was an important source of variation in lamb growth at various ages. Guyer and Dyer (1954), de Baca et al. (1956), Bogart et al. (1957) and Harrington et al. (1958) have reported inconsistent results in regard to the significance of sex at different ages in lamb growth; however, these latter workers were dealing with a much smaller number of lambs than were included in this study or the previous studies mentioned.

Influence of Birth and Rearing Type:

The effect of birth type and rearing in this study was estimated as the variation due to the differences among three classes: lambs born as singles and reared as singles, lambs born as twins and reared as singles and lambs born as twins and reared as twins. Therefore, there were two degrees of freedom associated with type of birth and rearing. In the case of the analyses of variance of birth weight in table 4, there are also two degrees of freedom associated with rearing even though the effect of rearing should have no effect on birth weight. As mentioned in the materials and methods section the same model was used to analyze birth weight as was used for the other traits, hence there are two degrees of freedom for birth type or in this case birth and rearing type. Normally, however, the birth weight of lambs is analyzed on the basis of birth type only, i.e. singles or twins. Nevertheless there may be some justification for this birth and rearing type classification at birth in that the health and vigor of the lamb may have some predisposing cause as to whether or not it survives. Venkatchalam <u>et al</u>. (1949) noted that lambs that deviated greatly from the mean birth weight of the breed had a significantly greater mortality rate than other lambs. They also noted that the incidence of death loss was 15 percent higher among twin lambs.

The effect of birth and rearing type on birth weight and 70 day weight as shown in tables 4 and 5 was highly significant ($P < .01$). However, in the analysis of rate of gain from 70 to 140 days presented in table 6 the effect of birth and rearing was significant ($P < .05$) in equations 2, 3, 6 and 7 only and non-significant in the other equations. This inconsistency tends to demonstrate that the magnitude of an effect which is non-orthogonal to the other factors in the analysis is dependent to some extent upon the other factors present. Harrington *et al.* (1962) in a separate study of lamb gain from 50 to 90 pounds, using part of these data reported that lambs reared as twins tended to gain as fast or faster than lambs reared as singles during this period. Hazel and Terrill (1946b) noted that although the difference in the yearling weight of range sheep due to type of rearing was highly significant ($P < .01$), this difference was less than in these same sheep measured at weaning. Hunter (1956) reported that the difference in lamb weight due to rearing type tended to increase up to about four months and then decreased as the lambs grew older. Consequently, if growth in older lambs is measured on a rate of gain basis from, say 70 to 140 days, rather than as body weight at 140 days, an entirely different interpretation of the influence of rearing may be obtained.

Influence of Years:

In this study the effects of years and age of dam were completely confounded thus the classification called years in the model is in fact a combination of year to year variation and any effects due to the increasing age of the ewes. The effects of this year classification were highly significant ($P < .01$) in all the equations used in the analysis of birth weight, 70 day weight, and gain from 70 to 140 days. Sidwell and Grandstaff (1949), Blackwell and Henderson (1955) and Sidwell (1956) have reported that differences due to years have a highly significant effect on lamb growth. Likewise these workers have reported that age of dam was an important source of variation in lamb growth at various ages. It would be a matter of speculation to say whether years or age of dam differences contributed the most to variation in this study. However, it would seem that the influence of years would probably have a greater effect on rate of gain from 70 to 140 days than age of dam since lamb growth during this period is much more dependent upon the quantity and quality of feed available than the milk supply of the ewe. Barnicoat et al. (1956), Brothers and Whiteman (1961) and Cameron and Hamilton (1961) have reported that lambs may be weaned at 70 days of age or less without any serious adverse effect upon their subsequent gain provided there is sufficient good quality feed available.

Interactions:

In the analyses of birth weight the sex by rearing type interaction was non-significant. The constants or partial regression coefficients for this interaction (Appendix Table 29) indicated that the difference between the wether and ewe lambs born and reared as singles was greater than the corresponding differences between the wether and ewe lambs born as twins and reared as singles or twins. In the analyses of 70 day weight the sex by rearing type interaction was significant ($P < .01$) in equation 1 but non-significant in the other equations. The constants (Appendix Table 30) indicated that the wether lambs born and reared as singles were considerably heavier than the ewe lambs born and reared as singles, whereas in the case of the lambs born and reared as twins the ewe lambs were somewhat heavier than the wethers. The wether lambs born as twins and reared as singles were slightly heavier than the corresponding ewe lambs. The sex by rearing type interaction was non-significant in the analyses of rate of gain from 70 to 140 days. The constants (Appendix Table 32) were small, but the wether lambs consistently gained faster than the ewe lambs. The difference between the sexes tended to be smaller in the twins reared as twins than in the singles reared as singles group. de Baca et al. (1956) reported that this interaction was non-significant in the analysis of the 120 day weaning weight of the crossbred lambs in their study. Bogart et al. (1957) also reported that the sex by birth type interaction was non-significant in their analysis of lamb birth weight.

The sex by year interaction was non-significant in all of the analyses of birth weight, 70 day weight and rate of gain from 70 to 140 days. When the appropriate constants for birth weight were added together the difference between the sexes tended to be greater during the later years. It should be remembered that age of dam and years are completely confounded in this study. Consequently any trend across years could be due to the increasing age of the ewes. A similar trend was noted in the analyses of 70 day weight, although there tended to be greater year to year fluctuations in the difference in the weight of the wether and ewe lambs. In the analyses of rate of gain from 70 to 140 days, the wether lambs gained faster than the ewe lambs in all years but the differences from year to year tended to be small. Brothers and Whiteman (1961) reported a significant ($P < .05$) interaction between age of dam and sex following the weaning of the lambs in their study. No other estimates of this interaction were found in the literature.

The rearing by year interaction was consistently significant in the analyses of birth weight and 70 day weight in this study but non-significant in the analyses of rate of gain from 70 to 140 days. The constants for the birth weight analyses (Appendix Table 29) indicated that the differences between lambs born as singles and lambs born as twins tended to increase in later years. A similar trend was noted in the differences between twins reared as singles and twins reared as twins. In the analyses of 70 day weight singles reared as singles were consistently heavier than twins reared as twins with this difference tending to increase in the later years. The corresponding differences between twins reared as singles and twins reared as twins showed a similar trend. The constants derived in the analyses of rate of gain from 70 to 140 tended to be small and varied from year to year with no apparent trend. These results would indicate that seasonal variation may have a greater influence on 70 day weight and rate of gain from 70 to 140 days than on birth weight. However age of dam and years are confounded in this study thus year to year changes are the result of a combination of age of dam and seasonal influences as well as the genotype of the lamb. Sidwell (1956) noted that the effect of the interaction between the number of lambs reared and years on the total weight of the lambs weaned was highly significant ($P < .01$). However when this interaction was considered on an individual lamb weaning weight basis it was non-significant. Hunter (1956) reported in a study of reciprocal crosses of two breeds differing in mature size that the interaction between rearing and breed of ewe was highly significant ($P < .01$) in the analyses of two and three month body weight of the lambs. Thomson and Thomson (1953) noted that in cases of ewes on a low plane of nutrition the single and twin lambs averaged about the same weight. The single lambs reared by ewes in a high plane of nutrition were heavier than the corresponding twin lambs. Thus it would appear that if the lambs were underfed in some years and not in others that it would be possible to develop a rearing by year interaction. Since age of dam was confounded with years in this present study and if young ewes have a lower milk supply than older ewes, the resulting differences in 70 day weight between single and twin lambs would be less with the young ewes than with the older ewes. In this study the ewes aged from two to seven years from 1955 to 1960 and thus there was considerable variation among the ewes as to their age when rearing the lambs which were included in this study.

Covariables:

The birth date of the lamb and the birth date squared were considered as covariables in this analysis. The influence of birth date on the weight of the lamb at birth and 70 days was non-significant. The influence of birth date both linear and quadratic had a highly significant ($P < .01$) effect on gain from 70 to 140 days. The lambs in this study were born between October 15 and November 30 thus there was about 45 days difference between the oldest and youngest lambs in the flock. By using the coefficients calculated for these effects in Equation 1 and plotting the relationship between gain and birth date, it was observed that the lambs born during the last week of October gained the fastest with the lambs born late in the season gaining at slightly slower rate than those born early in the lambing season. Bonsma (1939), Barnicoat (1949, 1956) and Hunter (1956) have also noted within season time trends in lamb gain. This can be most likely attributed to variation in the quantity and quality of forage available.

In the analysis of 70 day weight and rate of gain from 70 to 140 days lamb birth weight and birth weight squared were considered as covariables. The effect of birth weight on 70 day weight was highly significant $(P < .01)$ as a linear function but had practically no curvi-linear effect. The opposite situation was observed in the relationship between birth weight and gain from 70 to 140 days in that the curvi-linear or quadratic effect of birth weight was highly significant $(P < .01)$ but with very little linear effect. When the data were plotted for birth weight and 70 day weight there was a nearly linear increase in 70 day weight with the increase in birth weight. In the case of rate of gain from 70 days to 140 days the heavier lambs at birth tended to gain slightly faster than the lighter lambs. There is a large amount of literature on the linear relationship between birth weight and subsequent lamb growth but none on any curvi-linear relationship between birth weight and subsequent lamb growth. Phillips and Dawson (1940), de Baca et al. (1956) and Harrington et al. (1958) have reported that birth weight is closely associated with subsequent lamb gain.

The coefficients of determination (R^2) which were calculated in this analysis are presented in tables 4, 5, and 6. The coefficients calculated in the analysis of the birth weight data indicated that from 43 to 46 percent of the variation could be accounted for by the variables studied. In the case of 70 day weight from 50 to 67 percent of the variation could be accounted for by the variables studied. The coefficients of determination calculated in the analysis of gain from 70 to 140 days ranged from 0.12 to 0.26.

Repeatability Estimates of Birth Weight

The method used to calculate the repeatability estimates in this study was similar to the method used by Sidwell and Grandstaff (1949), Blackwell and Henderson (1955) and MacNaughton (1956). The method consists of adjusting the data for known sources of variation and then partitioning the remaining variation into that among ewes and the variation between lambs by the same ewe. This method assumes that there is no interaction or correlation between ewe effects and the factors used in adjusting the data. In most studies the data are adjusted for differences due to the sex of the lamb, the year the record was made, the age of the ewe and type of birth and rearing.

In this study repeatability estimates were calculated for birth weight, 70 day weight and gain from 70 to 140 days using the same equations that were used in the analyses of variance. These repeatability estimates are presented in table 7 along with the repeatability estimates calculated on the unadjusted data. The analyses of variance calculations used in obtaining these estimates are presented in appendix tables 34 through 42.

The repeatability estimates for birth weight which are presented in table 7 are rather consistent ranging from 0.351 to 0.369 with the exception of the estimate of 0.195 for the adjusted data. In the analyses of variance of birth weight in table 4 the effects of sex, type of birth (rearing) and years were highly significant effects which should be relatively independent of the ewe effect. Consequently the repeatability estimates on the adjusted data should be somewhat higher than in the unadjusted data. A comparison of equations 4 and 8 in table 7 indicates

TABLE 7
REPEATABILITY ESTIMATES OF BIRTH WEIGHT,
70 DAY WEIGHT AND GAIN FROM 70 to 140 DAYS

Equation	Sources of Variation Included in the Data Adjustment										Repeatability[a]		
											Bth. Wt.	70 day Wt.	Gain
1	Sex	Rear	Year	SxR	SxY	RxY	BD	BD^2	BW	BW^2	---	0.121	0.074
2	Sex	Rear	Year	SxR	SxY	RxY	BD	BD^2	--	---	0.351	0.221	0.109
3	Sex	Rear	Year	SxR	SxY	RxY	--	---	BW	BW^2	---	0.120	0.103
4	Sex	Rear	Year	SxR	SxY	RxY	--	---	--	---	0.362	0.210	0.136
5	Sex	Rear	Year	---	---	---	BD	BD^2	BW	BW^2	---	0.154	0.077
6	Sex	Rear	Year	---	---	---	BD	BD^2	--	---	0.352	0.235	0.104
7	Sex	Rear	Year	---	---	---	--	---	BW	BW^2	---	0.149	0.108
8	Sex	Rear	Year	---	---	---	--	---	--	---	0.369	0.234	0.137
9	Raw Data Unadjusted										0.195	0.166	0.111

[a]The corresponding analyses of variance and standard errors for the repeatability estimate are presented in appendix tables 34 through 42.

that adjusting the data for the interactions considered has a negligible effect on the repeatability estimate (0.362 versus 0.369). There was a slight reduction in the repeatability of birth weight when the data were adjusted for birth date which may be seen by comparing equations 2 and 6 or 4 and 8. A repeatability of birth date was calculated in the data in this study (see table 8) and found to be 0.05, which would indicate that birth date was slightly correlated with the ewe effect. Thus the adjustment of the data for birth date would tend to reduce the repeatability estimate slightly even though birth date was not a significant factor in the variation of birth weight. The repeatability estimate of 0.369 in equation 8 agrees with the repeatability estimate of 0.36 for birth weight in Corriedales reported by MacNaughton (1956) on data adjusted in a similar manner. His corresponding estimate for birth weight for the Rambouillets was 0.27.

Repeatability Estimates of 70 Day Weight

The repeatability estimates of 70 day weight which are presented in table 7 vary considerably from equation to equation depending upon what factors were used to adjust the data. The repeatability estimates calculated from equations 1, 3, 5 and 7 which all involve birth weight effects range from 0.120 to 0.154 and are less than the estimate 0.166 from the unadjusted data. In equations 2, 4, 6 and 8 which do not involve the adjustment of the data for birth weight the estimates ranged from 0.210 to 0.235. Since birth weight differences were correlated with ewe differences then when the data were adjusted for birth weight a reduction in the repeatability estimate should be expected. Adjusting the data for the interaction effects resulted in a slight reduction in the repeatability estimates. It may be recalled from the analyses of variance of 70 day weight that there was a significant ($P < .05$) rearing by year interaction. Since years and age of dam were confounded some of the difference due to age of dam influences might be associated with differences among ewes. This would be due to the fact that all the ewes did not have records in all years which allows for some variation in the average age of the ewes for the records included in the study.

Adjusting the 70 day weight of the lamb for birth date influence had almost no effect on the resulting repeatability estimate. Evidently the relationships between birth date and 70 day weight and birth date and the ewe effect tended to cancel each other. Sidwell and Grandstaff (1949) reported a repeatability estimate of 0.22 for weaning weight. MacNaughton (1956) calculated repeatability estimates of weaning weight of 0.25 and 0.30 on Rambouillet and Corriedale data respectively. Blackwell and Henderson (1955) reported a repeatability estimate of 0.07 based on the total weight of lambs weaned. Although the repeatabilities reported in the literature for weaning weight were calculated when the lambs were somewhat older than the 70 day weight of lambs in this study, the estimate of 0.234 for 70 day weight in equation 8 is similar to the estimates reported by Sidwell and Grandstaff (1949) and MacNaughton (1956).

Repeatability Estimates of Rate of Gain From 70 to 140 Days

The repeatability estimates for rate of gain from 70 to 140 days, which are presented in table 7 ranged from 0.074 to 0.137 when data were adjusted and 0.111 in the unadjusted data. The lowest estimates of the repeatability of lamb gain were obtained when the data were adjusted for both birth weight and birth date (equations 1 and 5 in table 7). Each of these effects had about the same influence on the repeatability as seen by comparing equations 2 and 3 or 6 and 7. The analyses of variance for gain from 70 to 140 days has shown that the birth date of the lamb has a highly significant effect on the gain of the lamb during this period. Also birth date is correlated with the ewe effect (see table 8). Therefore when the data were adjusted for birth date some of the ewe effect was also removed. Likewise birth weight is correlated with both gain and the ewe effect causing a reduction in the repeatability estimate when the data were adjusted for differences in birth weight. Adjusting the data for the interactions had practically no effect on the resulting repeatability estimates. The highest repeatability estimate of 0.137 was obtained when the data were adjusted for differences in sex, rearing type and year effects only. No estimates of the repeatability of gain from 70 to 140 days were found in the literature. However the method of measurement of this trait is such that the part-whole relationship between growth prior to 70 days and the gain of the lamb after 70 days tends to be reduced. This would likewise tend to partition the effects of the maternal influence between the two growth periods.

In general when comparing the repeatability estimates of birth weight, 70 day weight and gain from 70 to 140 days there is a steady decline in the magnitude of the estimates as the lambs grow older which would tend to reflect a decline in maternal influence. This decline in maternal influence is also demonstrated in the various heritability estimates reported in the literature. Paternal half-sib correlation heritability estimates for birth weight are generally much lower than the daughter-dam regression estimates of the heritability of birth weight (Nelson and Venkatchalam, 1949; Yao *et al*. 1953). The heritability estimates of weaning weight at approximately 140 days by these two methods of estimating heritability are generally in closer agreement (Hazel and Terrill, 1945a; Yao *et al*. 1953).

Repeatability of Birth Date

A repeatability estimate of 0.05 for the birth date of the lamb was calculated from the data for the ewes included in this study. The analysis of variance and the resulting repeatability of birth date are presented in table 8.

TABLE 8.

ANALYSIS OF VARIANCE AND THE REPEATABILITY ESTIMATE OF BIRTH DATE

Source of Variation	d.f.	Mean Square[a]
Total	652	114.5
Among Ewes	175	129.52
Birth Date Within Ewes	477	108.51
Repeatability = 0.050 Standard Error = 0.033		

[a]See table 2 in Materials and Methods Section for Expected Mean Squares.

This repeatability estimate for birth date was considerably smaller than the estimate of 0.43 reported at Kentucky (Anonymous, 1953). The Kentucky data were collected over a 21 year period based on the seasonal lambing of Southdown and Hampshire ewes. However no information was given as to the date that the rams were put with the ewes or the duration of the breeding season. The grade Rambouillet and Rambouillet x Panama-Rambouillet ewes in this study were bred in the spring during a rather short breeding season. Consequently, if the ewes were cycling normally at this time, it would be more of a matter of chance for the cycle of a ewe to coincide with the start of the breeding season from season to season.

Conclusions

In the analyses of the factors influencing lamb growth in part I of this study several were observed to be important. Since birth weight, 70 day weight and rate of gain from 70 to 140 days represented different stages of growth in the lamb's life, the influence of the sources of variation were not necessarily the same. The sex of the lamb had a highly significant ($P < .01$) influence on lamb growth at these different periods. Lamb birth and rearing type was also highly significant ($P < .01$) in the analyses of birth weight and 70 day weight. In the analysis of rate of gain from 70 to 140 days birth and rearing type did not appear to have as great an influence on lamb growth as it did in the earlier periods. Year differences, which were confounded with age of dam in this portion of the study, were a highly significant source ($P < .01$) of variation in lamb growth during these periods. The first order interactions between these main classes, sex, birth and rearing type and years were less conclusive. The sex by rearing and sex by year interactions appeared to be unimportant. However the rearing by year interaction may be an important factor in the analyses of birth weight and 70 day weight. Since age of dam and years were confounded it was not possible to determine which of these factors might have the greatest influence on this interaction. Within season time trends (as estimated by birth date of the lamb) were unimportant in the analyses of birth weight and 70 day weight. In the case of rate of gain from 70 to 140 days birth date and birth date squared were major sources of variation in the rate of gain of these lambs during this period and under systems of management similar to this study. The influence of lamb birth weight, when considered as a covariable, had a highly significant ($P < .01$) linear relationship with 70 day weight but the non-linear (quadratic) relationship was unimportant. However, birth weight squared was a significant ($P < .05$) source of variation in the analysis of rate of gain from 70 to 140 days.

The repeatability estimates calculated from the adjusted data varied considerably depending upon what factors were considered in the adjustment of the data. These changes were dependent upon whether or not the source of variation used in adjusting the data was also associated with among ewe differences. When the data were adjusted for differences in the sex and rearing type of the lamb and the year the record was made, the repeatability estimates for birth weight, 70 day weight and rate of gain from 70 to 140 days were 0.369, 0.234 and 0.137 respectively. The repeatability estimates for birth weight were in general agreement with the estimates found in the literature. The repeatability estimates for 70 day weight was similar to the results reported for weaning weight by other workers. The repeatability estimates in this study were rather low consequently it would be desirable to have more than one record available in evaluating the ewe's performance.

Part II: Milk Production

Analyses of Variance of Lamb Gain and Lamb Body Weight

In the 1960-61 milk production season lamb growth was measured on a net weight gain basis, i.e., body weight minus birth weight. In the 1961-62 season lamb growth was measured on a body weight basis. These measures of lamb growth were taken at weekly intervals from one through ten weeks. The analyses of variance for the 1960-61 season are presented in tables 9 and 10. The 1961-62 analyses are presented in table 11 and 12. The corresponding partial regression coefficients for the variables considered in the analyses are presented in appendix tables 43 through 46.

In general the difference between the sexes increased as the lambs grew older. Although the males were heavier than the females at all ages during both seasons this difference was non-significant except during the eighth, ninth and tenth weeks of the 1960-61 season. Harrington et al. (1958) also noted that the male lambs were heavier than the females and the difference increased as the lambs grew older. Guyer and Dyer (1954) reported that male single lambs gained slightly faster than the females from birth to nine weeks, whereas the female twin lambs gained slightly faster than the males but the differences in rate of gain due to sex were not statistically significant.

The analyses of variance in tables 9 through 12 indicate that single lambs were significantly ($P < .01$) heavier than the twin lambs at all ages in both seasons. In general the difference between rearing types from one to ten weeks increased as the lambs grew older. Guyer and Dyer (1954), Barnicoat et al. (1949,1956), Hunter (1956) and Doney and Munro (1962) have

TABLE 9

ANALYSES OF VARIANCE FOR LAMB NET WEIGHT

GAIN FROM ONE TO FIVE WEEKS OF AGE 1960-1961 DATA

Source of Variation	d.f.	Mean Squares Week 1	Week 2	Week 3	Week 4	Week 5
Total	87	1.4	5.1	10.0	15.0	20.9
Sex (S)	1	0.3	0.5	0.9	2.1	4.2
Rearing Type (R)	1	7.5**	37.1**	71.7**	116.9**	164.2**
Age of Dam (D)	3	3.8**	16.5**	32.4**	43.0**	58.8**
Breed of Sire	3	0.5	3.6	6.5	11.6	22.6*
S x R	1	0.9	1.1	0.5	0.9	1.5
S x D	3	2.4	3.9	4.1	2.2	2.4
R x D	2[a]	0.5	2.5	5.2	11.6	15.4
Dam Body Weight	1	0.8	1.1	2.1	8.3	9.9
Dam Condition Score	1	0.2	0.9	2.6	2.4	2.9
Birth Weight	1	4.2*	17.2**	25.6**	25.5*	36.8**
Birth Weight Squared	1	3.4*	13.1**	17.5*	14.7	20.8
Error	69	0.8	1.9	3.2	4.8	6.5
R^2		0.551**	0.713**	0.745**	0.747**	0.752**

[a]There were no twin lambs in the yearling ewe group

* $P < .05$

** $P < .01$

TABLE 10

ANALYSES OF VARIANCE FOR LAMB NET WEIGHT

GAIN FROM SIX WEEKS TO TEN WEEKS OF AGE 1960-61 DATA

Source of Variation		d.f.	Mean Squares				
			Week 6	Week 7	Week 8	Week 9	Week 10
Total		87	24.3	28.1	33.3	37.8	50.3
Sex	(S)	1	14.9	31.0	55.4*	83.2**	78.3*
Rearing Type	(R)	1	188.7**	214.6**	258.0**	320.0**	410.6**
Age of Dam	(D)	3	57.7**	62.1**	67.2**	78.7**	110.6**
Breed of Sire		3	31.8**	40.3**	45.6**	50.3**	52.0**
S x R		1	1.6	8.6	10.4	12.1	16.0
S x D		3	2.2	3.1	2.1	3.6	6.6
R x D		2[a]	18.5	22.0	28.6	40.6	52.5
Dam Body Weight		1	12.9	14.8	24.9	32.1	35.5
Dam Condition Score		1	0.6	0.5	0.4	0.0	0.4
Birth Weight		1	39.4*	54.1**	61.1**	74.0**	86.8**
Birth Weight Squared		1	20.3	30.6	32.3	38.7	42.6
Error		69	7.8	9.6	11.3	14.1	17.3
R^2			0.746**	0.730**	0.732**	0.740**	0.727**

[a] There were no twin lambs in the yearling ewe group

* $P < .05$

** $P < .01$

TABLE 11

ANALYSES OF VARIANCE FOR LAMB BODY

WEIGHT FROM ONE TO FIVE WEEKS OF AGE 1961-62 DATA

Source of Variation	d.f.	Mean Squares				
		Week 1	Week 2	Week 3	Week 4	Week 5
Total	106	6.4	12.0	19.5	27.8	35.3
Sex (S)	1	1.2	4.4	11.4	14.7	13.8
Rearing Type (R)	1	26.8**	79.5**	207.8**	384.6**	236.1**
Age of Dam (D)	3	1.3	4.4	14.0*	23.0*	30.8
Breed of Sire	3	2.8	5.8	4.9	1.5	2.2
S x R	1	0.5	2.9	4.1	5.8	4.9
S x D	3	0.1	0.6	2.8	6.2	9.6
R x D	3	0.3	1.0	2.4	10.4	12.0
Dam Body Weight	1	1.7	2.2	1.3	0.0	0.1
Dam Body Weight Squared	1	2.0	3.0	2.4	0.1	0.4
Dam Condition Score	1	0.8	0.0	0.8	1.4	1.4
Dam Cond. Score Squared	1	0.4	0.0	0.3	0.4	0.5
Birth Date	1	1.5	0.1	0.5	1.1	1.7
Birth Date Squared	1	1.6	0.7	2.2	6.5	0.3
Birth Weight	1	170.2**	237.0**	287.5**	389.9**	554.5**
Birth Weight Squared	1	0.2	0.6	0.6	0.0	0.9
Error	82	0.8	2.5	5.0	6.9	10.3
R^2		0.897**	0.837**	0.801**	0.805**	0.772**

* $P < .05$

** $P < .01$

TABLE 12

ANALYSES OF VARIANCE FOR LAMB BODY

WEIGHT FROM SIX TO TEN WEEKS OF AGE 1961-62 DATA

Source of Variation		d.f.	Mean Squares Week 6	Week 7	Week 8	Week 9	Week 10
Total		106	42.8	49.8	58.1	68.8	77.8
Sex	(S)	1	9.8	18.0	52.9	76.2	60.7
Rearing Type	(R)	1	560.1**	405.9**	525.8**	789.3**	635.4**
Age of Dam	(D)	3	56.2**	74.3	100.1**	154.3**	145.3**
Breed of Sire		3	2.6	6.4	8.3	18.9	26.9
S x R		1	0.8	4.2	18.1	15.5	11.9
S x D		3	13.7	9.3	12.3	21.6	19.0
R x D		3	21.3	23.1	26.8	24.5	27.7
Dam Body Weight		1	3.1	5.9	0.1	5.6	0.1
Dam Body Weight Squared		1	7.6	6.4	0.4	2.9	0.0
Dam Condition Score		1	0.5	8.1	1.1	1.2	5.0
Dam Cond. Score Squared		1	18.5	15.0	10.6	3.3	3.3
Birth Date		1	8.3	7.3	13.0	5.0	33.6
Birth Date Squared		1	0.1	0.6	1.6	2.8	23.4
Birth Weight		1	553.6**	613.9**	663.6**	764.2**	999.8**
Birth Weight Squared		1	1.9	0.1	1.1	0.3	0.9
Error		82	11.0	16.4	18.9	22.4	28.3
R^2			0.800**	0.742**	0.746**	0.745**	0.716**

* P < .05

** P < .01

reported that lambs reared as singles gain faster than lambs reared as twins during this period.

Age of dam effects were generally highly significant ($P < .01$) at all ages in both seasons. The difference between ages of dams as estimated by the partial regression coefficients in appendix tables 43 through 46 appeared to be greater during the first season than the corresponding ages during the second season. These differences are also presented graphically in figures 1, 2, 3 and 4. The greatest difference between ages was in the comparison of the yearling ewes in the 1960-61 season with the older ewes in the same season. It should be emphasized that in most studies the ewes generally lamb first as two-year olds. Bonsma (1939) and Barnicoat _et al_. (1949, 1956) have indicated that in regard to age of dam effects the difference between the first and second lamb rate of gain tends to be greater than the differences between the second and subsequent lamb rate of gain.

The effect of breed of sire on lamb growth was somewhat different between the two seasons. In the first season breed of sire was non-significant during the first four weeks, but starting with the fifth week the breed of sire effect was a significant ($P < .05$ to $P < .01$) factor in the gain of the lamb. The Hampshire and Rambouillet sired lambs tended to gain the fastest and Dorset sired lambs the slowest during the 10 week period. During the 1961-62 season when lamb growth was measured on a body weight basis the influence of breed of sire was non-significant at all weeks. The partial regression coefficients indicated that the Suffolk and Rambouillet sired lambs were heavier during the early weeks, but the Hampshire sired lambs were the heaviest after the sixth week. In general the Dorset sired lambs were the lightest at all ages up to 10 weeks.

However, the number of lambs in any particular breed of sire group were rather small and since this study was not designed to make breed comparisons it would be unwise to make any definite statements concerning the relative merits of the breeds for the use as sires of fat lambs. However, genetic differences seem to be important. Kean and Henning (1949) in a crossbreeding study have reported that the breed of sire may be an important source of variation in lamb gain.

The first order interactions, sex by rearing, sex by age of dam and rearing by age of dam were non-significant at all ages in both seasons. However, the partial regression coefficients for these did indicate certain trends. In general the difference between the sexes was greater in the singles reared as singles group than in the twins reared as twins group. In the case of sex by age of dam differences, the differences between the sexes tended to be greater in the older ewe groups. The differences between rearing types (singles reared as singles and twins reared as twins) across age of dam tended to be somewhat smaller than the other interactions. However, in the two-year old ewes group the difference between rearing types was somewhat smaller than in the older ewe groups.

In the analyses of variance presented in tables 9 through 12 the covariables, with the exception of lamb birth weight, were non-significant at all ages. In the 1960-61 season lamb birth weight squared was also significant ($P < .05$ to $P < .01$) during the first three weeks. The fact that most of the covariables were significantly correlated with lamb growth but when these same covariables were included in the analysis of variance most of them were non-significant would indicate that they were correlated among themselves. The importance of birth weight as a factor in lamb growth during this early period has also been noted by Guyer and Dyer (1954), Barnicoat et al. (1956), Owen (1957) and Harrington et al. (1958).

The simple correlations between the covariables and net lamb gain for the 1960-61 season are presented in appendix table 47. The covariables considered were the body weight and condition score of the dam, lamb birth weight and lamb birth weight squared. In the 1961-62 season dam body weight squared, dam condition score squared, lamb birth date and lamb birth date squared were also considered as covariables in addition to the ones included in the 1960-61 analyses. In the analyses of the 1961-62 data a different computer program was used which also calculated the partial correlation coefficients between the independent variables and the dependent variable (see appendix table 48). The partial correlations were calculated with all the factors in the model taken into consideration. In general the simple correlations between the covariables and lamb growth were significant ($P < .05$ to $P < .01$) with the exception of dam condition score in the 1960-61 season and lamb birth date and birth date squared in the 1961-62 season. The partial correlations calculated from the 1961-62 season's data were small and non-significant with the exception of lamb birth weight which were highly significant ($P < .01$) and ranged from 0.542 to 0.884.

Coefficients of determination R^2, which estimate the portion of the total variation which is accounted for in lamb growth by the variables included in the model are also presented in tables 9 through 12. These coefficients ranged from 0.551 to 0.752 in the 1960-61 season and from 0.712 to 0.897 in the 1961-62 season. In general the R^2 values were very similar after the first week but there was a slight decline as the lambs grew older.

Simple correlations between net gain at different weeks and between body weight at different weeks are presented in tables 13 and 14. The results in these two tables are very similar which would indicate that net weight gain or body weight at some subsequent age up to ten weeks may be predicted from a previous measurement of the trait with about equal accuracy. Although these correlations were high no tests of significance were made because of the part whole nature of the correlations. The coefficient of determination, r^2 between total gain at two weeks and ten weeks was 0.803. The coefficient of determination, r^2 for body weight over the same period was 0.806. Thus about 80 percent of the variation in total net gain or body weight at ten weeks may be accounted for by the variation in these traits when the lambs are two weeks of age.

Lamb Growth and Ewe Lactation Curves

The mean lactation curves of the ewes and the corresponding growth curves of their lambs according to the number of lambs reared and age of the ewe are presented in figures 1 through 4. These data are also presented numerically in appendix tables 49 and 50. These figures are based on the unadjusted data without regard to the sex or breed of sire of the lamb. In general the growth of the lambs was very linear in both seasons. The greatest difference in rate of gain of lambs occurred between the lambs of the youngest ewes as compared to the lambs of the older ewes within each season. The lactation curves were very similar to those published by Bonsma (1939), Barnicoat *et al.* (1949, 1956), Guyer and Dyer (1954), Hunter (1956) and Owen (1957). In general milk production rose sharply

TABLE 13

CORRELATIONS BETWEEN TOTAL LAMB

NET WEIGHT GAIN TO DIFFERENT WEEKS 1960-61 DATA

	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Week 1	0.924	0.888	0.857	0.847	0.827	0.810	0.796	0.788	0.785
" 2		0.990	0.969	0.961	0.942	0.928	0.913	0.901	0.896
" 3			0.988	0.980	0.964	0.949	0.936	0.922	0.916
" 4				0.993	0.979	0.963	0.952	0.938	0.931
" 5					0.990	0.977	0.962	0.949	0.942
" 6						0.992	0.982	0.970	0.962
" 7							0.991	0.983	0.977
" 8								0.993	0.986
" 9									0.991

TABLE 14.

CORRELATIONS BETWEEN LAMB BODY

WEIGHT TO DIFFERENT AGES 1961-62 DATA

	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Week 1	0.976	0.945	0.927	0.912	0.896	0.884	0.878	0.872	0.856
" 2		0.988	0.976	0.959	0.946	0.934	0.927	0.921	0.898
" 3			0.995	0.983	0.973	0.961	0.954	0.948	0.924
" 4				0.993	0.983	0.972	0.965	0.958	0.937
" 5					0.993	0.983	0.979	0.970	0.955
" 6						0.993	0.989	0.980	0.965
" 7							0.996	0.989	0.975
" 8								0.994	0.984
" 9									0.988

to the second or third week and then gradually declined for the remainder of the lactation. However, because of the method of adjusting the milk production records to a constant age there was a tendency to dampen the peak of the lactation curve. This was brought about by the assumption of a linear change in milk production between the dates that the milk production estimates were actually taken.

The relative difference in level of milk production between the age of ewe groups was somewhat less than the relative difference in the corresponding growth rates of their lambs. Ewes rearing twins had a greater initial production but declined at a more rapid rate than the ewes rearing singles. This is also reflected in the within age of ewe ratio of the average weekly milk production of ewes rearing twins and ewes rearing singles (see appendix tables 49 and 50) which varied greatly between age of ewe groups. In some cases the ewes rearing twins produced less milk than the ewes rearing singles during the latter weeks of the lactation period. The cumulative milk production ratio at 10 weeks of ewes rearing twins to ewes rearing singles ranged from 102 for the three year old ewes in the 1960-61 season to 155 for the four year old ewes in the 1961-62 season. No tests of significance were made on these ratios but in general the ewes rearing twins produced about 30 percent more milk during the 10 week lactation period than the ewes rearing singles. The number of ewes in these comparisons varied greatly. In the 1960-61 season there were no twins in the yearling ewe group consequently no estimate could be made of the relative differences in the level of production of ewes rearing twins and ewes rearing singles. In both seasons the number of two year old ewes rearing twins was somewhat smaller than the

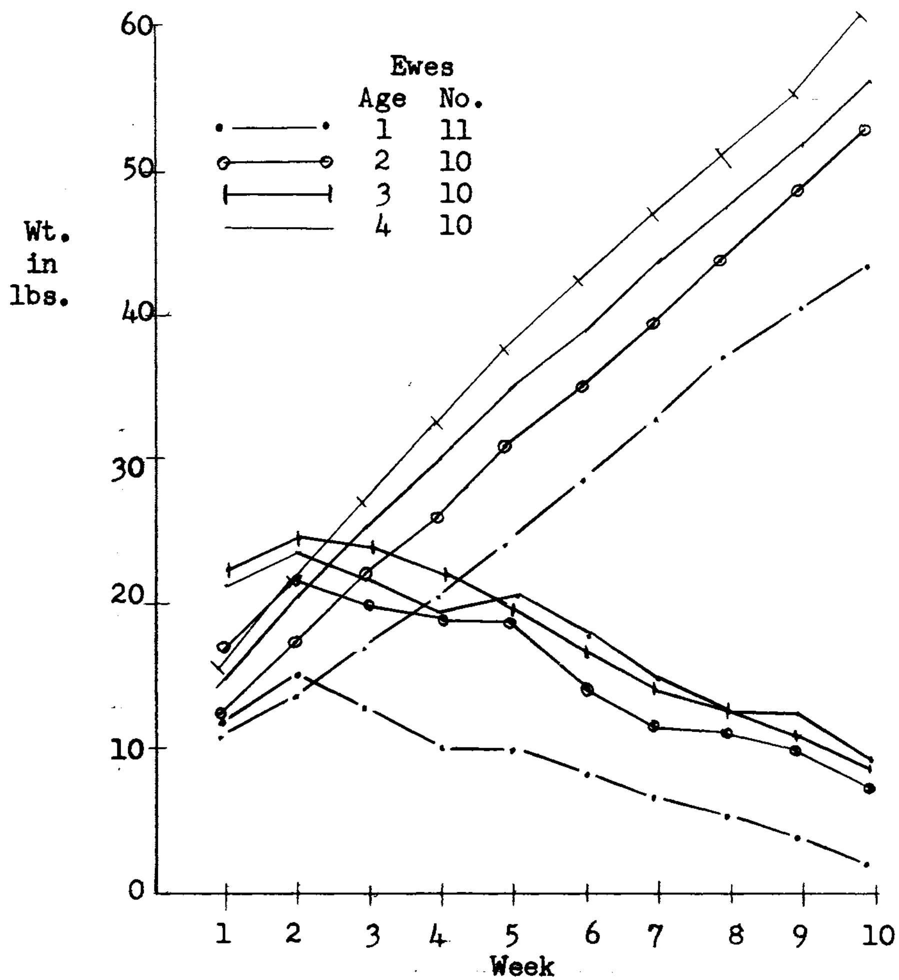

Figure 1. Ewe Lactation Curves (lbs.milk per week) and Corresponding Lamb Growth Curves: Ewe Rearing Single Lambs 1960-61 Data

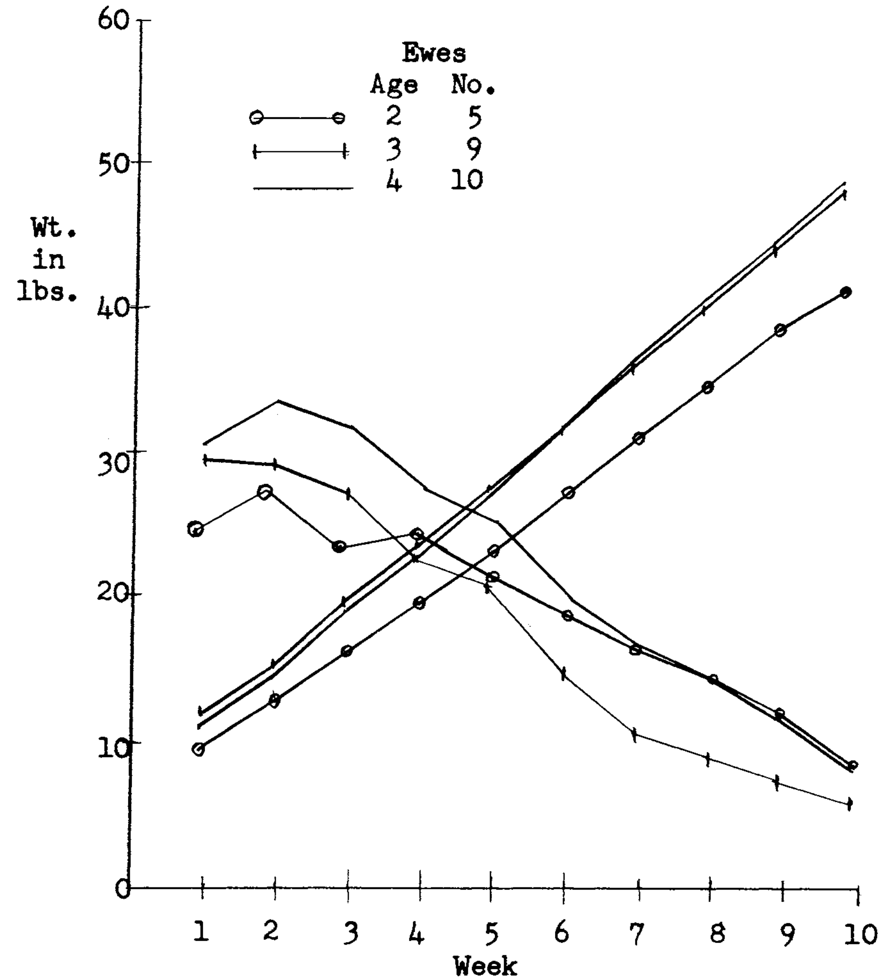

Figure 2. Ewe Lactation Curves (lbs.milk per week) and Corresponding Lamb Growth Curves: Ewe Rearing Twin Lambs 1960-61 Data

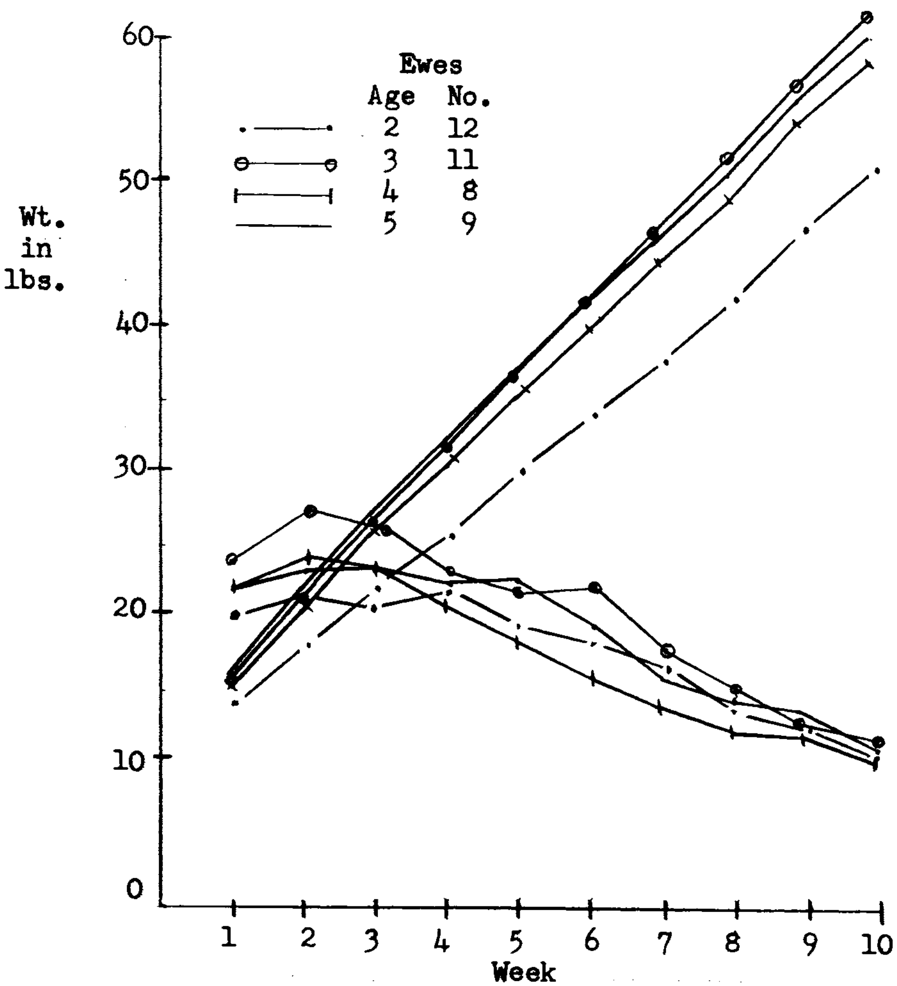

Figure 3. Ewe Lactation Curves (lbs.milk per week) and Corresponding Lamb Growth Curves: Ewe Rearing Single Lambs 1961-62 Data

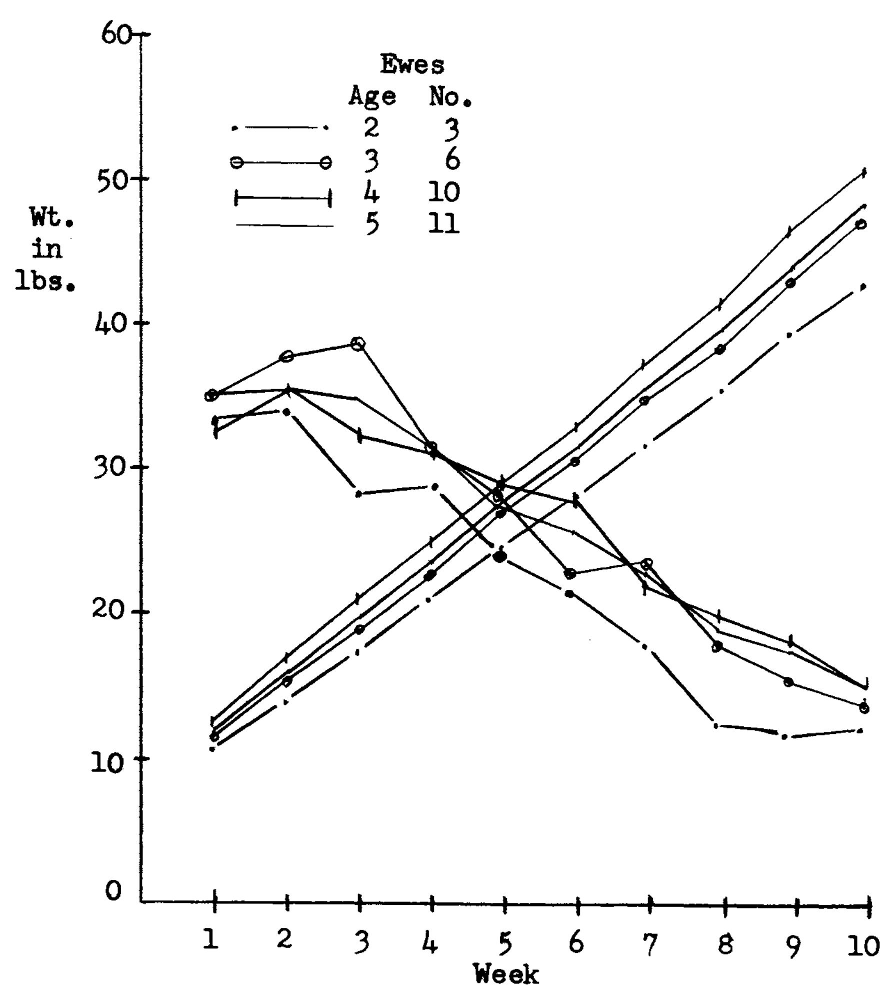

Figure 4. Ewe Lactation Curves (lbs.milk per week) and Corresponding Lamb Growth Curves: Ewes Rearing Twin Lambs 1961-62 Data

number of ewes rearing twins in the older age groups. Barnicoat *et al.* (1956) reported that ewes rearing twins produced about 33 percent more milk than ewes rearing singles during a nine week lactation period. Doney and Munro (1962) reported an increase in total production of the ewes rearing twins of 45 to 55 percent as compared to ewes rearing singles.

Analyses of Variance of Ewe Milk Production Per Lamb Reared

The analyses of variance of ewe milk production per lamb reared are presented in tables 15 through 18. The corresponding partial regression coefficients are presented in appendix tables 51 through 54.

In the 1960-61 season the sex of the lamb was a significant ($P < .05$ to $P < .01$) source of variation in milk production of the ewe during the seventh through tenth week. In the 1961-62 season the influence of the sex of the lamb on the milk production of the ewe was non-significant except at the third week ($P < .05$). However, the partial regression coefficients for sex indicated that the female lambs consumed slightly more milk than the males. In the analyses of lamb growth it was noted that the males grew faster than the females during the lactation period. Since all the lambs had access to creep feed during the lactation period it is not possible to draw any definite conclusions in regard to the relative efficiency of the two sexes in converting milk to gain. Guyer and Dyer (1954) also noted that females consumed more milk than the males. In their study the difference in rate of gain between the sexes was somewhat less than in this study.

The effect of rearing on ewe milk production per lamb reared was significant ($P < .05$ to $P < .01$) during the fifth through eighth week in

TABLE 15

ANALYSES OF VARIANCE OF CUMULATIVE MILK PRODUCTION PER LAMB REARED ONE THROUGH FIVE WEEKS 1960-61 DATA

Source of Variation	d.f.	Mean Squares Week 1	Week 2	Week 3	Week 4	Week 5
Total	87	23.1	93.0	201.8	344.8	520.9
Sex of Lamb (S)	1	4.0	2.2	3.4	21.1	143.3
Lamb Rearing Type (R)	1	0.2	32.3	99.1	262.5	542.8*
Age of Ewe (E)	3	7.2	23.7	54.5	178.5	334.2
Lamb's Sire Breed	3	2.6	7.6	35.7	150.0	244.7
S x R	1	7.0	39.8	50.6	51.1	25.2
S x E	3	1.2	7.1	8.5	3.5	21.8
R x E	2[a]	3.8	17.0	43.5	81.6	127.3
Ewe Body Weight	1	4.6	12.7	26.0	125.9	157.8
Ewe Condition Score	1	0.6	19.6	58.1	67.7	151.1
Lamb Birth Weight	1	4.6	0.2	16.5	5.8	0.0
Lamb Birth Date	1	1.4	4.3	24.8	7.3	0.0
Lamb Gain	1	290.6**	1,065.4**	686.0**	3,786.3**	900.9**
Error	68	9.0	29.5	47.4	78.9	129.0
R^2		0.695**	0.752**	0.817**	0.821**	0.806**
Standard Error of Estimate		3.0	5.4	6.9	8.9	11.4

[a]There were no twin lambs in the yearling ewe group

* $P < .05$

** $P < .01$

TABLE 16

ANALYSES OF VARIANCE OF CUMULATIVE MILK

PRODUCTION PER LAMB REARED SIX THROUGH TEN WEEKS 1960-61 DATA

Source of Variation		d.f.	Mean Squares				
			Week 6	Week 7	Week 8	Week 9	Week 10
Total		87	715.5	929.9	1,153.5	1,408.8	1,649.3
Sex of Lamb	(S)	1	591.3	1,076.5*	1,512.6*	2,251.7*	2,523.1*
Lamb Rearing Type	(R)	1	798.7**	953.4*	1,246.2*	1,045.2	1,036.9
Age of Ewe	(E)	3	700.5	996.0**	1,607.6**	2,116.3**	2,287.1**
Lamb's Sire Breed		3	392.8	644.8*	905.3*	1,284.5*	1,530.7**
S x R		1	0.8	6.6	8.1	266.7	418.9
S x E		3	77.3	195.3	356.9	517.8	561.2
R x E		2[a]	229.7	383.9	689.9	894.8	1,104.9
Ewe Body Weight		1	349.8	527.1	912.5	1,248.6	1,490.7*
Ewe Condition Score		1	129.7	207.9	271.6	175.8	206.6
Lamb Birth Weight		1	8.8	33.5	149.6	322.9	570.9
(Lamb Bth. Wt.)^2		1	13.3	41.0	165.1	371.6	652.4
Lamb Gain		1	5,927.6**	8,169.2**	9,225.4**	11,000.0**	13,933.1**
Error		68	165.7	198.5	287.1	321.3	373.5
R^2			0.819**	0.831**	0.826**	0.822**	0.823**
Standard Error of Estimate			12.9	14.1	16.9	17.9	19.3

[a]There were no twin lambs in the yearling ewe group

*P < .05

**P < .01

TABLE 17

ANALYSES OF VARIANCE OF CUMULATIVE MILK

PRODUCTION PER LAMB REARED ONE THROUGH FIVE WEEKS 1961-62 DATA

Source of Variation		d.f.	Mean Squares				
			Week 1	Week 2	Week 3	Week 4	Week 5
Total		106	21.2	77.4	186.8	336.0	515.7
Sex of Lamb	(S)	1	1.3	27.7	185.1*	49.7	14.3
Lamb's Rearing Type	(S)	1	6.3	0.6	13.1	27.5	74.6
Age of Ewe	(E)	3	23.7	147.6**	284.4**	514.0**	884.8**
Lamb's Sire Breed		3	0.4	18.5	50.2	131.6	296.5
S x R		1	9.5	24.8	27.9	61.1	1.6
S x E		3	16.7	17.8	15.9	104.5	87.8
R x E		3	14.8	19.3	29.7	42.8	72.4
Ewe Body Weight		1	12.8	31.9	44.2	5.2	196.5
$(\text{Ewe Body Wt.})^2$		1	15.8	39.6	52.3	15.7	197.5
Ewe Condition Score		1	7.6	2.1	4.5	17.1	1.1
$(\text{Ewe Cond. Score})^2$		1	8.0	5.8	0.7	0.0	0.0
Lamb Birth Date		1	17.9	0.6	5.9	39.1	22.5
$(\text{Lamb Bth. Date})^2$		1	22.9	12.8	10.0	1.7	2.0
Lamb Birth Weight		1	102.0**	344.2**	899.6**	1,167.0**	1,644.5**
$(\text{Lamb Bth. Wt.})^2$		1	9.7	9.2	0.1	0.9	1.9
Lamb Body Weight		1	307.4**	1,692.5**	5,473.2**	8,012.4**	14,135.0**
Error		81	9.9	25.0	42.0	80.6	140.7
R^2			0.642**	0.751**	0.827**	0.816**	0.789**
Standard Error of Estimate			3.1	5.0	6.5	9.0	11.9

* P < .05

** P < .01

TABLE 18

ANALYSES OF VARIANCE OF CUMULATIVE MILK

PRODUCTION PER LAMB REARED SIX THROUGH TEN WEEKS 1961-62 DATA

Source of Variation	d.f.	Mean Squares: Week 6	Week 7	Week 8	Week 9	Week 10
Total	106	723.6	919.2	1,104.5	1,291.5	1,462.9
Sex of Lamb (S)	1	57.4	46.5	47.3	346.8	356.2
Lamb's Rearing Type (R)	1	94.5	1,354.5*	2,633.7**	3,685.3**	6,090.2**
Age of Ewe (E)	3	313.5	564.3	650.2	824.7	1,174.4
Lamb's Sire Breed	3	541.3*	606.6	1,031.1*	1,315.2*	1,737.0*
S x R	1	52.6	246.6	521.6	700.8	308.6
S x E	3	113.3	172.4	185.9	163.8	285.7
R x E	3	206.6	159.8	264.0	448.7	172.3
Ewe Body Weight	1	279.5	233.6	305.2	817.5	1.9
(Ewe Body Wt.)^2	1	269.5	281.4	350.0	897.8	3.1
Ewe Condition Score	1	15.1	55.4	126.5	240.8	231.6
(Ewe Cond. Score)^2	1	33.4	161.5	293.2	433.8	100.4
Lamb Birth Date (BD)	1	9.7	24.7	47.4	102.2	140.6
(Lamb Birth Date)^2	1	32.0	95.1	46.5	69.0	9.2
Lamb Birth Weight	1	1,835.2**	1,426.5**	1,464.0*	1,062.1	360.8
(Lamb Bth. Wt.)^2	1	0.3	2.1	17.1	34.9	15.5
Lamb Body Weight	1	16,322.2**	19,686.0**	20,905.3**	21,614.1**	25,352.0**
Error	81	185.3	286.7	297.2	368.0	464.6
R^2		0.802**	0.774**	0.792**	0.780**	0.755**
Standard Error of Estimate		13.6	16.4	17.2	19.2	21.6

* P < .05

** P < .01

the 1960-61 season. During the 1961-62 season the effect of rearing on ewe milk production per lamb reared was significant ($P < .05$ to $P < .01$) from the seventh through tenth week. It is interesting to note that the influence of rearing was not a significant source of variation on the amount of milk produced by the ewe per lamb reared until into the second half of the lactation period. The partial regression coefficients (appendix tables 51 through 54) indicate that single lambs had received about 30 pounds more total milk per lamb by the eighth week than the twins in the 1960-61 season. In the 1961-62 season this difference was about 20 pounds. Barnicoat et al. (1949, 1956), Guyer and Dyer (1954), Alexander and Davies (1959) and Doney and Munro (1962) have reported that the number of lambs reared is an important factor in the total milk production of the ewe during the lactation period.

The influence of age of ewe was somewhat different in the two seasons. In the 1960-61 season age of ewe was not a significant source of variation in milk production until the sixth through tenth weeks, whereas in the 1961-62 season the influence of age of ewe was significant during the second through fifth weeks only. Since milk production was measured on a per lamb reared basis, it is difficult to interpret the age of ewe influence in these analyses. This is primarily because of the great differences in the number of twin lambs per age of ewe group. Ewes that reared twin lambs produced less milk per lamb than ewes rearing single lambs. Consequently since there were a greater number of ewes rearing twin lambs in the older ewe groups (see table 3 in the materials and methods section) this would tend to bias the age of ewe differences if considered on a milk production per ewe basis. A more appropriate comparison of age of ewe differences on a milk production per ewe basis would be the lactation curves in figures 1 through 4. These figures show the age of ewe differences within the type of rearing of the lamb and are biased only by sex and breed of sire of the lamb differences among the different age groups. Bonsma (1939) used the first lactation of two year old ewes as a base of a 100 and found the comparative increases in pounds of total milk produced in the second, third and fourth lactation to be 120, 125 and 136 respectively. Barnicoat et al. (1949) reported that six year old ewes produced 16 percent more milk than two year old ewes. Owen (1957) worked with ewes rearing single lambs only and reported four year old ewes produced about six percent more milk than three year old ewes.

The influence of the lamb's breed of sire was very similar in both the 1960-61 and 1961-62 seasons. During the 1960-61 season the breed of the lamb's sire was significant ($P < .05$) during the seventh, eighth and ninth week and highly significant ($P < .01$) during the tenth week. During the 1961-62 season the breed of the lamb's sire was significant ($P < .01$) influence on the lactation of the ewe during the sixth through tenth week. Inspection of the partial regression coefficients for total ewe milk production per lamb reared (see appendix tables 51 through 54) indicated that the Dorset sired lambs received more milk during the latter part of the lactation but the lambs did not gain as fast (see appendix tables 43 through 46) as the lambs sired by the other breeds. During the 1960-61 season the Hampshire sired lambs consumed less milk but gained faster whereas during the 1961-62 season the Hampshire sired lambs received more milk and were heavier during the latter part of the lactation. In the 1960-61 season the Suffolk sired lambs received less milk and did not gain as fast as the other lambs. During the 1961-62 season the Suffolk sired lambs received less milk but tended to be heavier at most weeks. Since all the lambs had access to creep feed throughout the lactation period it is not possible to determine whether these inconsistencies between the growth of the lamb within different sire groups and the amount of milk received were due to differences in creep feed consumption or to differences in the ability of the lambs to convert milk to gain. However the influence of the lambs' breed of sire were non-significant until the lambs were old enough to consume effective amounts of creep feed. Thus it could have been that the heavier lambs were depending more on creep feed than their dam's milk production as a source of nutrients. Owen (1957) crossed Welsh Mountain ewes with Suffolk and Welsh Mountain rams. The ratio of the amount of milk consumed to live weight gain of the lamb from birth to ten weeks was 4.13 and 3.37 for the purebreds and crossbreds respectively which would indicate that the crossbreds were slightly more efficient in converting milk to gain, unless other sources of nutrients were important factors in the growth of these lambs. There were only seven lambs in each sire group for this comparison. Other workers have worked with only one sire breed, consequently no other estimates of the effect of the breed of sire of the lamb on milk production of the dam were available. Cartwright and Carpenter (1961) studied the effect of nursing habits on the weight of beef calves. They noted that the crossbred calves nursed more frequently and were generally heavier than the purebred calves. They indicated that the milk production of the dam may be influenced by the genotype of the calf.

The first order interactions, sex by rearing, sex by age of ewe and rearing by age of ewe were non-significant at all weeks in both seasons. The partial regression coefficients for these data indicated that the male twin lambs received more milk than the female twins during the early stages of the lactation whereas in the case of lambs reared as singles the reverse was true. In general the ewe lambs received more milk than the males during the later weeks of the lactation period with the relative differences between the sexes within a rearing type being about the same. The sex of lamb by age of ewe relationships were rather inconsistent but there was a tendency for the ewe lambs in the young age of ewe groups to consume more milk than the males. In the case of the rearing by age of ewe differences there was a general trend for the single lambs to receive more milk per lamb than the twin lambs in the younger age of ewe groups. In general, other research workers have either worked within a rearing type or ignored the possible interactions between these factors.

In the analysis of ewe milk production per lamb reared several covariables were taken into consideration. In the 1960-61 season ewe body weight, ewe condition score, lamb birth weight, lamb birth weight squared and net lamb gain were considered as covariables in the analysis. During the 1961-62 season ewe body weight squared, ewe condition score squared, lamb birth date and lamb birth date squared were also considered as covariables in addition to those included in the 1960-61 analysis. In the 1961-62 season lamb body weight was used instead of net lamb gain. In the analyses of variance of ewe milk production per lamb reared presented in tables 15 through 18 most of the covariables which were considered were unimportant. In the 1960-61 season ewe body weight (with the exception of the tenth week, $P < .05$), ewe condition score, lamb birth weight and lamb birth weight squared were non-significant sources of variation in total ewe milk production per lamb reared. Lamb net weight gain was highly significant ($P < .01$) at all weeks. In the 1961-62 season all the covariables were non-significant with the exception of lamb birth weight and lamb body weight. In the 1961-62 season lamb birth weight was a significant ($P < .05$ to $P < .01$) source of variation in ewe milk production from one through eight weeks. Lamb body weight was highly significant ($P < .01$) at all weeks. The difference in the importance of birth weight between the two seasons may be in part due to the fact that in the 1961-62 season lamb body weight was used instead of the net weight gain of the lamb. Thus in the 1961-62 season birth weight would tend to act as an adjustment on lamb body weight to put it on a net weight gain basis. When the 1961-62 data were reanalyzed using lamb net weight gain instead of lamb body weight as a covariable the results were almost identical with the analyses using lamb body weight except that the partial regression coefficient for birth weight was small and non-significant.

The simple correlations between the covariables and ewe milk production for the 1960-61 season are presented in appendix table 55. In the 1960-61 season the correlations of ewe body weight and ewe condition score with ewe milk production were non-significant. In the 1961-62 season the simple correlations (see appendix table 56) of ewe body weight, body weight squared, ewe condition score and condition score squared with ewe milk production per lamb reared were significant ($P < .05$ to $P < .01$) at most weeks but the corresponding partial correlations were small and non-significant. Part of the difference in these simple correlations between season may be due to the time of measurement. In the 1960-61 season the ewes were weighed and scored about three weeks prior to the beginning of lambing whereas in the 1961-62 season the ewes were weighed and scored at each week during the lactation. The simple correlations of lamb birth weight and birth weight squared with ewe milk production were highly significant in the 1960-61 season. In the 1961-62 season the simple correlation between lamb birth weight and total ewe milk production at different weeks were also highly significant. However, the partial correlations between lamb birth weight and total milk production were somewhat smaller and declined during the latter part of the lactation. In the 1961-62 season both the simple and partial correlations of lamb birth date, lamb birth date squared, and birth weight squared with milk production were small and non-significant. The simple correlations between the net weight gain of the lamb and total milk production per lamb reared at different weeks were highly significant ($P < .01$) during the 1960-61 season. Both the simple and partial correlations between lamb body weight and total milk production of the ewe per lamb reared were highly significant ($P < .01$) at all weeks in the 1961-62 season.

Bonsma (1939), Burris and Baugus (1955) and Owen (1957) have reported that ewe body weight was significantly correlated with her milk production. However, Barnicoat *et al*. (1949), and Guyer and Dyer (1954) reported that the correlation between ewe body weight and her level of milk production was non-significant in their data. No estimates of the correlations between the condition of the ewe as estimated by a condition score were found in the literature. However, numerous workers have reported that the level of nutrition of the ewe has a profound effect upon the amount of milk produced during the lactation period. Bonsma (1939), Burris and Baugus (1955) and Owen (1957) reported significant correlations ranging from about 0.30 to 0.70 between lamb birth weight and milk production of the ewe. Most of these workers have considered these covariables one at a time in its relationship with the milk production of the ewe but as noted in this study although certain variables may be significantly correlated with milk production there is no assurance that they will all be important sources of variation in the milk production of the ewe when they are all considered simultaneously in the analyses.

The coefficients of determination, R^2 are also presented in tables 15 through 18. These coefficients ranged from 0.695 to 0.831 in the 1960-61 season and from 0.542 to 0.827 in the 1961-62 season. These coefficients tended to be the highest during the third through sixth week of lactation.

The standard errors of estimate for the ewe cumulative milk production per lamb reared are also presented in the analyses of variance tables 15 through 18. These standard errors of estimate give an indication of the range of error in estimated cumulative milk production of the ewe per lamb reared. These standard errors of estimate increased steadily from week to week during the lactation period. During the third through seventh week these standard errors of estimate were approximately 13 to 14 percent of the unadjusted means (see table 46) during the 1960-61 season and from 11 to 13 percent of the unadjusted means in the 1961-62 season.

Simple correlations were calculated between total milk production per lamb reared at different weeks and are presented in tables 19 and 20. The result of the two seasons are very similar although the corresponding correlations tend to be slightly higher in the first season. The correlation

TABLE 19

CORRELATIONS BETWEEN CUMULATIVE

MILK PRODUCTION TO DIFFERENT WEEKS 1960-61 DATA

	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Week 1	0.922	0.899	0.847	0.802	0.774	0.763	0.754	0.746	0.742
" 2		0.976	0.939	0.914	0.894	0.884	0.874	0.866	0.860
" 3			0.982	0.958	0.938	0.929	0.918	0.906	0.898
" 4				0.990	0.975	0.968	0.958	0.947	0.938
" 5					0.994	0.989	0.981	0.971	0.964
" 6						0.997	0.991	0.983	0.977
" 7							0.997	0.992	0.987
" 8								0.998	0.995
" 9									0.999

TABLE 20

CORRELATIONS BETWEEN CUMULATIVE MILK PRODUCTION TO DIFFERENT WEEKS 1961-62 DATA

	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Week 1	0.873	0.800	0.764	0.737	0.721	0.715	0.697	0.685	0.675
" 2		0.964	0.935	0.910	0.899	0.885	0.865	0.847	0.830
" 3			0.976	0.950	0.938	0.921	0.905	0.889	0.873
" 4				0.984	0.970	0.955	0.942	0.927	0.912
" 5					0.992	0.981	0.969	0.956	0.942
" 6						0.994	0.985	0.974	0.963
" 7							0.995	0.986	0.978
" 8								0.996	0.990
" 9									0.997

between total milk production at two weeks and ten weeks were 0.86 and 0.83 for the 1960-61 and 1961-62 seasons respectively. Thus it would appear that total milk production as early as the second week might be used as an index of a ewe's total production during the lactation. Owen (1957) reported correlations of 0.70 and 0.87 between total milk production at two and four weeks respectively with total milk production at 10 weeks. The corresponding correlations in this study were somewhat higher than those reported by Owen.

Indirect Estimates of Ewe Milk Production Based on Lamb Growth

Since it is rather difficult to obtain milk production records by the method used in this study, it would be desirable to have a simpler and more rapid method of estimating the milk production of the ewe. This would involve choosing a trait which is closely related to the milk production of ewe. Based on the results of the analyses of variance in tables 15 through 18 it would appear that the net weight gain or body weight of the lamb would be a good choice, a trait that is easy to measure and at the same time closely related with the milk production of the ewe. The simple correlations between lamb net weight gain and the cumulative milk production of the ewe per lamb reared for the 1960-61 season are presented in table 21. The corresponding correlations for the 1961-62 season using lamb body weight instead of lamb gain are presented in table 22.

A general comparison of the results in these two tables would indicate that lamb net weight gain is slightly more highly correlated with

TABLE 21

CORRELATIONS[a] BETWEEN TOTAL LAMB GAIN AND CUMULATIVE MILK PRODUCTION TO DIFFERENT WEEKS 1960-61 DATA

Lamb Gain	Cumulative Milk Production									
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Week 1	0.734	0.649	0.690	0.679	0.662	0.644	0.644	0.647	0.650	0.646
" 2		0.822	0.848	0.840	0.830	0.813	0.810	0.809	0.808	0.803
" 3			0.868	0.862	0.853	0.836	0.832	0.828	0.825	0.819
" 4				0.861	0.853	0.836	0.833	0.827	0.822	0.815
" 5					0.852	0.838	0.835	0.830	0.825	0.818
" 6						0.817	0.813	0.808	0.801	0.794
" 7							0.802	0.796	0.788	0.781
" 8								0.776	0.768	0.760
" 9									0.754	0.746
" 10										0.759

[a] Level of Significance

$P < .01$

$r = 0.282$; 86 d.f.

TABLE 22

CORRELATIONS[a] BETWEEN LAMB BODY WEIGHT AND
CUMULATIVE MILK PRODUCTION AT DIFFERENT WEEKS 1961-62 DATA

Lamb Body Weight	Cumulative Milk Production									
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Week 1	0.647	0.674	0.667	0.683	0.697	0.700	0.699	0.712	0.707	0.699
" 2		0.751	0.758	0.763	0.770	0.771	0.766	0.776	0.768	0.758
" 3			0.800	0.801	0.802	0.804	0.795	0.803	0.792	0.781
" 4				0.810	0.811	0.810	0.801	0.805	0.793	0.781
" 5					0.812	0.814	0.805	0.806	0.794	0.784
" 6						0.819	0.810	0.813	0.803	0.795
" 7							0.797	0.802	0.793	0.786
" 8								0.792	0.783	0.778
" 9									0.768	0.762
" 10										0.752

[a] Level of Significance

$P < .01$

$r = 0.250$; 104 d.f.

the total milk production of the ewe per lamb reared than lamb body weight and total milk production per lamb reared. However, it should be kept in mind that the differences in the corresponding correlations between seasons are also confounded with seasons which may account for part of the differences in these correlations. The correlations between lamb net weight gain after the first week with cumulative milk production at 10 weeks ranged from 0.746 to 0.819 which would indicate that from 55 to 67 percent of the variation in cumulative milk production at 10 weeks could be accounted for by the variation in lamb net weight gain at some earlier week. The corresponding correlations for the 1961-62 season using lamb body weight instead of lamb net weight gain ranged from 0.752 to 0.795 which would indicate that from 56 to 63 percent of the variation in cumulative milk production per lamb reared at 10 weeks could be accounted for by the variation in lamb body weight at some earlier week. Other workers have also correlated lamb gain and total milk production over varying periods of time. Bonsma (1939) reported a correlation of 0.812 between lamb gain and total milk production at 11 weeks. Shrewsbury et al. (1943) reported a correlation of 0.89 between lamb gain and total milk production at eight weeks. Wallace (1948) reported a correlation of 0.83 between lamb gain and total milk production at eight weeks. Similar correlations have also been reported by Guyer and Dyer (1954), Barnicoat et al. (1949, 1956), Burris and Baugus (1955) and Owen (1957). Although these workers have calculated their correlations on a within lamb rearing type basis, they are in general agreement with the results of this study.

Regression Equations to Predict Milk Production

In order to use lamb growth as a predictor of the milk production of the ewe simple linear regression equations were calculated which are presented in tables 23 and 24. The comparison of the results in these tables with the results in tables 15 through 18 indicate that during the early weeks of the lactation the standard errors of estimate are very similar. However, as the lambs grow older and other factors such as age of ewe, breed of sire of the lamb, and lamb rearing type become more important factors in the milk production of the ewe, the accuracy of simple regression equations decreases. Nevertheless the accuracy of net weight gain or lamb body weight alone compare very favorably with the more complex analyses up to about seven weeks. In general the correlations between lamb growth and total milk production at 10 weeks were the highest (see tables 21 and 22) when the lambs were about three to seven weeks of age. It has also been shown (see tables 19 and 20) that the part-whole correlations of total milk production at previous weeks with total milk production at 10 weeks are rather high. Thus it would appear that this single trait either net weight gain or body weight of the lamb at three to seven weeks would be a reliable indicator of the total milk production of the ewe per lamb reared. To utilize these equations in table 24 it is only necessary to multiply the weight of the lamb by the regression coefficient of the equation which is closest to the lamb's age. However, the lambs should be about the same age and somewhere between three and seven weeks of age in order to achieve the best results. In the case of twin lambs the resulting estimates for each lamb would be added together to obtain an estimate of the milk production of their dam.

TABLE 23

PREDICTION EQUATIONS FOR ESTIMATING CUMULATIVE EWE MILK PRODUCTION PER LAMB REARED AT DIFFERENT WEEKS BASED ON LAMB NET WEIGHT GAIN 1960-61 DATA

Week	Intercept	Net Weight Gain Reg. Coef.	Net Weight Gain Std. Error	r^2	Standard Error of Estimate
1	5.792	2.886**	0.287	0.539**	3.205
2	6.879	3.504**	0.262	0.676**	5.530
3	4.441	3.896**	0.240	0.753**	7.092
4	-0.537	4.126**	0.265	0.741**	9.583
5	-6.763	4.255**	0.282	0.726**	12.017
6	-17.593	4.429**	0.338	0.667**	15.533
7	-33.058	4.611**	0.371	0.643**	18.333
8	-42.721	4.565**	0.401	0.602**	21.562
9	-56.922	4.594**	0.433	0.569**	24.856
10	-59.246	4.344**	0.402	0.576**	26.613

**$P < .01$

TABLE 24

PREDICTION EQUATIONS FOR ESTIMATING CUMULATIVE EWE MILK PRODUCTION PER LAMB REARED AT DIFFERENT WEEKS BASED ON LAMB BODY WEIGHT 1961-62 DATA

Week	Intercept	Lamb Body Wt. Reg. Coef.	Lamb Body Wt. Std. Error	r^2	Standard Error of Estimate
1	3.297	1.180**	0.145	0.419**	3.758
2	5.438	1.910**	0.164	0.564**	5.832
3	4.478	2.479**	0.182	0.640**	8.237
4	3.123	2.819**	0.200	0.656**	10.824
5	-1.274	3.104**	0.219	0.659**	13.318
6	-8.393	3.367**	0.231	0.671**	15.508
7	-12.239	3.426**	0.254	0.635**	18.401
8	-17.088	3.442**	0.262	0.627**	20.489
9	-17.215	3.326**	0.272	0.590**	23.143
10	-20.023	3.260**	0.280	0.566**	25.336

** $P < .01$

Wallace (1948) calculated simple regression equations for estimating milk production at 28 days based on the 28 day weight of the lamb. His regression coefficients were about 3.3 and the corresponding correlation coefficients were about 0.91. Barnicoat et al. (1956) used the weight of the lamb at six weeks to estimate the average daily milk production of the ewe over the third to ninth week of her lactation. They concluded that this method was a fairly reliable index of the milk production of the ewe during this period. Owen (1957), working with the ewes rearing single lambs only, calculated a simple ratio of the milk consumed to the live weight of the lamb at four weeks. To estimate the milk production of the ewe he merely multiplied the weight of the lamb at four weeks of age by this ratio which was about five to one.

In order to compare the standard errors of estimate of these various equations with the standard deviations of the unadjusted data the means and standard deviations of cumulative milk production of the ewes per lamb reared are presented in table 25. The average total milk production per lamb reared of the ewes in the second season were somewhat higher than in the first season which is due to a combination of season to season variation and the increased age of the ewes in the second season. It is not possible to compare the means at the various weeks in this study with those of other workers because of the method of measurement. However the total milk production of the ewes in this study on a within age of ewe and rearing type basis are similar to those of other workers.

Although the simple regression equations, presented in tables 23 and 24, indicated that a fairly reliable estimate of the milk production of the ewe may be obtained by their use, it was observed in the analyses of

TABLE 25

MEANS AND STANDARD DEVIATIONS FOR CUMULATIVE MILK PRODUCTION PER LAMB REARED

1960-61 Season: 88 Lambs

Week	1	2	3	4	5	6	7	8	9	10
Mean	15.98	33.79	50.19	64.86	78.85	90.08	99.33	107.57	114.66	119.59
Std. Dev.	4.77	9.64	14.13	18.46	22.69	26.60	30.32	33.77	37.32	40.38

1961-62 Season: 106 Lambs

Week	1	2	3	4	5	6	7	8	9	10
Mean	18.73	38.71	58.00	75.91	92.25	107.23	119.97	130.78	140.67	148.78
Std. Dev.	4.60	8.80	13.67	18.35	22.71	26.90	30.32	33.23	35.94	38.25

variance of the 1961-62 milk production data that age of dam and birth weight were also important factors during the early weeks of the ewe's lactation. Likewise rearing type and breed of sire of the lamb were also important sources of variation in the latter stages of the lactation period. Thus a new set of prediction equations were calculated on a within age of ewe basis for the 1961-62 seasons data. These equations took the birth weight, body weight and the rearing type of the lamb into consideration and are presented in tables 26 and 27. The breed of sire of the lamb was ignored because all sire breeds were not represented in each age of ewe group. These equations suffer from the lack of numbers since they are based on 22, 25, 28, and 31 lambs in the two, three, four, and five year old ewe groups respectively.

The differences due to lamb rearing type were significant ($P < .05$) in the five year old ewe group during the seventh through tenth week of lactation. Although the partial regression coefficients for rearing were equally as large or larger than in the five year old ewe group the corresponding standard errors in the other age of ewe groups were relatively larger. These higher standard errors are probably due in part to the smaller number of twins in these age groups. In a few instances early in the lactation period the partial regression coefficients for rearing were negative which would indicate that the individual twin lambs actually received more milk than the singles.

Because of the inter-relationship of birth weight and body weight the partial regression coefficient for birth weight was generally negative when both variables were included in the equation even though the simple correlations between birth weight and total milk production were always

TABLE 26

PREDICTION EQUATIONS AND STANDARD ERRORS FOR ESTIMATING CUMULATIVE EWE MILK PRODUCTION PER LAMB REARED AT DIFFERENT WEEKS BASED ON THE REARING TYPE, BIRTH WEIGHT AND BODY WEIGHT OF THE LAMB 1961-62 DATA

Age of Ewe	Week	Inter-cept	Rearing Reg. Coef.	Rearing Std. Error	Birth Wt. Reg. Coef.	Birth Wt. Std. Error	Body Wt. Reg. Coef.	Body Wt. Std. Error	R^2	Standard Error of Estimate
2	1	2.874	-1.107	0.832	-2.240**	0.712	2.713**	0.478	0.688**	2.800
3	1	-2.078	-0.653	1.035	-0.567	1.227	2.103	0.859	0.695**	3.094
4	1	5.847	0.847	0.877	-2.032*	0.876	2.242**	0.668	0.544**	3.247
5	1	12.147	0.938	0.919	0.263	0.896	0.357	0.721	0.376**	3.000
2	2	3.986	-1.970	1.616	-2.654*	1.124	3.392**	0.541	0.726**	5.466
3	2	3.199	0.773	1.355	0.666	1.298	1.943**	0.663	0.836**	4.194
4	2	17.683	1.875	1.315	-2.616*	0.996	2.403**	0.585	0.668**	4.696
5	2	16.940	0.677	1.471	-0.414	1.130	1.407	0.703	0.554**	4.976
2	3	5.978	-1.401	1.870	-3.710**	1.224	3.972**	0.444	0.842**	6.436
3	3	5.960	0.843	2.016	1.136	1.741	2.264**	0.734	0.850**	5.889
4	3	23.496	2.535	2.020	-4.312**	1.407	3.155**	0.694	0.697**	7.082
5	3	16.394	-0.951	1.713	-2.429	1.242	2.829**	0.603	0.734**	6.027
2	4	6.272	0.214	3.216	-4.832*	2.053	4.504**	0.628	0.779**	11.145
3	4	-1.247	0.754	2.554	1.947	2.114	2.584**	0.745	0.870**	7.501
4	4	26.327	2.982	2.815	-4.883*	1.872	3.353**	0.798	0.681**	9.446
5	4	23.856	0.776	2.069	-2.066	1.456	2.652**	0.600	0.772**	7.367
2	5	-1.394	2.795	3.911	-4.551	2.481	4.599**	0.652	0.784**	13.938
3	5	-4.662	3.038	3.654	3.436	3.102	2.452*	0.952	0.835**	11.012
4	5	23.557	2.821	3.474	-5.748*	2.364	3.714**	0.937	0.650**	11.476
5	5	31.205	3.124	2.614	-2.123	1.926	2.621**	0.684	0.773**	9.313

* $P < .05$

** $P < .01$

TABLE 27

PREDICTION EQUATIONS AND STANDARD ERRORS FOR ESTIMATING CUMULATIVE EWE MILK PRODUCTION PER LAMB REARED AT DIFFERENT WEEKS BASED ON THE REARING TYPE, BIRTH WEIGHT AND BODY WEIGHT OF THE LAMB 1961-62 DATA

Age of Ewe	Week	Inter-cept	Rearing Reg. Coef.	Rearing Std. Error	Birth Wt. Reg. Coef.	Birth Wt. Std. Error	Body Wt. Reg. Coef.	Body Wt. Std. Error	R^2	Standard Error of Estimate
2	6	-17.162	4.674	4.302	-4.565	2.665	4.973**	0.646	0.816**	15.118
3	6	-5.612	5.541	4.067	3.654	3.334	2.581**	0.913	0.860**	12.290
4	6	25.476	2.936	3.780	-5.950*	2.532	3.656**	0.899	0.641**	12.908
5	6	36.480	5.625	3.213	-1.497	2.350	2.440**	0.758	0.750**	11.788
2	7	-24.602	6.586	5.440	-4.178	3.279	4.915**	0.737	0.779**	18.937
3	7	-7.569	6.415	4.578	4.136	3.567	2.594**	0.907	0.862**	13.572
4	7	37.590	5.035	4.481	-5.566	3.119	3.155**	1.001	0.571**	15.404
5	7	39.587	7.603*	3.700	-0.015	2.754	2.095*	0.830	0.711**	14.307
2	8	-25.894	10.308	5.844	-5.273	3.597	4.905**	0.742	0.787**	20.525
3	8	-6.897	9.569	4.780	5.521	3.855	2.309*	0.889	0.861**	15.063
4	8	39.700	6.412	4.389	-5.620	3.205	3.043**	0.920	0.584**	16.098
5	8	42.192	9.233*	3.844	-0.838	2.947	2.249**	0.589	0.732**	15.250
2	9	-29.492	12.935	6.878	-4.213	4.195	4.536**	0.792	0.754**	24.083
3	9	-21.672	9.423	5.137	4.957	3.976	2.695**	0.894	0.866**	16.047
4	9	59.292	8.419	5.017	-4.836	3.520	2.413*	0.903	0.538**	18.237
5	9	51.432	10.841*	4.349	-0.129	3.332	1.922*	0.803	0.698**	17.471
2	10	-23.126	15.181	7.478	-4.476	4.570	4.244**	0.788	0.741**	26.201
3	10	-19.523	10.876	5.648	5.776	4.167	2.451**	0.823	0.847**	18.355
4	1C	21.123	11.688	5.898	-3.375	4.142	1.819	1.078	0.460**	21.123
5	10	53.527	12.088*	4.620	0.166	3.835	1.822*	0.864	0.682**	18.994

* $P < .05$

** $P < .01$

positive. The partial regression coefficient for birth weight was significant ($P < .05$ to $P < .01$) in the two year old ewe group during the first four weeks and in the four year old ewe group during the first six weeks. Birth weight was non-significant in the other age groups.

Lamb body weight was the most important factor in these prediction equations. In the equations for the two year old ewes, lamb body weight was highly significant ($P < .01$) at all weeks. In the three year old ewe group lamb body weight was generally highly significant ($P < .01$) after the first week. Lamb body weight was highly significant ($P < .01$) in the equations for the four year old ewes up to the ninth week. In the five year old ewe group lamb body weight was significant after the second week.

In general, the within age of ewe group equations had standard errors of estimate which were smaller than the standard errors of estimate for the corresponding weeks for the simple linear regression equations presented in tables 24 and 25. This would be expected since these within age of ewe prediction equations take more sources of variation into consideration. The within age of ewe group means and standard deviations for total milk production of the ewe per lamb reared at different weeks are presented in table 28. It should be remembered that since milk production was estimated on a per lamb reared basis, the differences in the number of twins within an age group will tend to bias any comparisons of the means among these age groups. A better comparison of age of ewe differences would be figures 3 and 4. However, the means and standard deviations are presented in order to compare the standard errors of estimate of the prediction equations with the corresponding standard deviations of the raw data.

TABLE 28

MEANS AND STANDARD DEVIATIONS OF CUMULATIVE MILK PRODUCTION PER LAMB REARED ON WITHIN AGE OF EWE BASIS 1961-62 DATA

				Two Year Old Ewes: 22 Lambs[a]						
Week	1	2	3	4	5	6	7	8	9	10
Mean	18.20	37.38	55.29	74.55	91.31	106.46	120.16	131.57	142.77	152.11
Std. Dev.	4.64	9.66	14.98	21.95	27.37	32.59	37.30	41.18	44.99	47.66
				Three Year Old Ewes: 25 Lambs[b]						
Week	1	2	3	4	5	6	7	8	9	10
Mean	20.82	43.64	66.42	85.25	102.27	118.99	133.52	145.06	155.01	163.64
Std. Dev.	5.24	9.70	14.21	19.46	25.35	30.69	34.23	37.79	41.00	43.90
				Four Year Old Ewes: 28 Lambs[c]						
Week	1	2	3	4	5	6	7	8	9	10
Mean	17.27	36.53	54.29	71.09	86.45	100.72	112.07	122.47	131.94	139.34
Std. Dev.	4.54	7.68	12.13	15.76	18.30	20.30	22.16	23.54	25.28	27.11
				Five Year Old Ewes: 31 Lambs[d]						
Week	1	2	3	4	5	6	7	8	9	10
Mean	18.74	37.66	56.49	73.69	90.09	104.18	116.05	126.20	135.51	143.06
Std. Dev.	3.60	7.07	11.08	14.63	18.55	22.36	25.24	27.95	30.17	31.94

[a] 16 lambs reared as singles, 6 reared as twins

[b] 13 lambs reared as singles, 12 reared as twins

[c] 8 lambs reared as singles, 20 reared as twins

[d] 9 lambs reared as singles, 22 reared as twins

Conclusions

The results of the analyses of variance of net lamb gain and lamb body weight at different weeks throughout the lactation period indicated that several factors contribute to the variation in lamb growth rate. Although the sex of the lamb was non-significant at most weeks in this portion of the study, the partial regression coefficients for the differences in favor of the males increased as the lambs grew older. This would indicate that the age or weight of the lamb should be considered when appraising the magnitude of the differences between the sexes. The rearing type of the lamb (singles reared as singles and twins reared as twins) was highly significant ($P < .01$) at all weeks in both seasons. The differences between the rearing types during the lactation period tended to increase as the lamb grew older. Age of dam differences were also a highly significant ($P < .01$) influence on lamb growth rate. Lambs reared by yearling and two year old ewes tended to be considerably lighter than lambs reared by ewes which were three years old and older, which would indicate that the age of dam influence on lamb growth in curvilinear.

The first order interactions, sex by rearing, sex by age of dam and rearing by age of dam were less conclusive. Based on the analyses of variance these interactions were non-significant, however, in some instances the constants for these interactions were rather large. This was particularly evident in the case of the rearing by age of dam interaction. In general the differences between rearing types were less in the younger age of ewe groups than in the older ewe groups.

In the analyses of lamb growth rate during the lactation period several covariables were taken into consideration. Although the simple correlations of many of the covariables with net lamb gain or lamb body weight were significant, when all of them were considered simultaneously in the analyses of lamb growth most of them were non-significant. The outstanding exception was lamb birth weight which exhibited a highly significant ($P < .01$) influence on lamb growth throughout the lactation period.

In the milk production study lamb net weight gain and lamb body weight were highly correlated with the cumulative milk production of the ewe per lamb reared. The average level of milk production of the ewe at 10 weeks was rather small which indicated that the milk production of the ewe after 10 weeks is a minor source of nutrients for the lamb. The ewes rearing twins produced about 30 percent more total milk during the 10 week lactation period than ewes rearing single lambs.

In the analyses of sources of variation in the cumulative milk production of the ewe per lamb reared during the first 10 weeks of her lactation several factors were important. Female lambs consumed more milk than male lambs but this difference was not generally statistically significant. As noted earlier, the male lambs were heavier than the females during the lactation period but since all lambs had access to creep feed it was not possible to determine any difference in the relative efficiency of the two sexes in converting milk to gain. The rearing type of the lamb was not a significant source of variation in the cumulative milk production of the ewe until the latter half of the lactation. Age of ewe differences were important, however, the relative differences in cumulative milk production per lamb reared among the age of ewe groups were not conclusive. The breed of sire of the lamb appeared to be an important factor in the cumulative milk production of the ewe. The relationship between milk production and lamb growth within breed of sire groups was conflicting and inconsistent. Since no estimate of creep feed consumption by sire groups was available it was not possible to determine whether or not these inconsistencies among the sire groups were due to differences in the feed efficiency of their lambs. Further investigations will have to be made before any definite conclusions may be drawn in regard to any possible differences in feed efficiency among the progeny of these sire breeds. Within season time trends were unimportant as estimated by lamb birth date and lamb birth date squared in the second season. The simple correlations of ewe body weight and condition score with milk production per lamb reared were significant in the second season but the partial correlations were small and non-significant.

The results of the various prediction equations which were calculated to estimate the milk production of the ewe indirectly based on the growth of her lamb indicated that the lamb must be at least three weeks old before these equations were very reliable. A comparison of the prediction equations for estimating the cumulative milk production of the ewe per lamb reared at various weeks indicated that lamb net gain or lamb body weight was the most important factor in these equations. The simple linear regression equations using lamb net gain or lamb body weight to predict the milk production of the ewe at three to six weeks compared favorably with the multiple regression equations for the same period. As the lactation progressed other factors also contributed to the variation in the milk production of the ewe. Thus when the rearing type and birth weight of the lamb were included in conjunction with lamb body weight within the various ewe groups, greater accuracy was achieved. The results of these prediction equations indicate that it is possible to obtain a fairly reliable estimate of the milk production of the ewe based on the growth of her lamb.

SUMMARY

This study was composed of two parts. The data used in both parts were obtained from the experimental sheep flock at the Fort Reno Livestock Research Station. Part I was concerned with the estimation of the repeatability of the birth weight, 70 day weight and rate of gain from 70 to 140 days of the lamb as a characteristic of its dam. Part II was concerned with the estimation of the milk production of the ewe and its relationship to the growth of the lamb.

In part I data were collected on 829 lambs over a six year period, which represented the progeny of 176 grade Rambouillet and Rambouillet x Panama-Rambouillet ewes. The data were adjusted for several known sources of variation. The sex of lamb was highly significant ($P < .01$) in the analyses of birth weight, 70 day weight and rate of gain from 70 to 140 days. The birth and rearing type of the lamb had a highly significant ($P < .01$) influence on birth weight and 70 day weight. The influence of birth and rearing type on rate of gain from 70 to 140 days was significant in some instances but was dependent upon what other sources of variation were also included in the analyses. The year the lamb was born had a highly significant ($P < .01$) influence on all the traits. The sex by rearing and sex by year interactions appeared to be unimportant. However the rearing by year interaction was significant ($P < .05$) in the analyses of birth weight and 70 day weight. Within season time trends, as estimated by lamb birth date and birth date

squared, were unimportant in the analyses of birth weight and 70 day weight. In the case of rate of gain from 70 to 140 days birth date and birth date squared were major sources of variation ($P < .01$) in the rate of gain of the lambs during this period. Lamb birth weight, when considered as a covariable, had a highly significant ($P < .01$) linear relationship with 70 day weight but the non-linear (quadratic) relationship was unimportant. However, birth weight squared was a significant ($P < .05$) source of variation in the analyses of rate of gain from 70 to 140 days, whereas the linear influence of birth weight was non-significant.

The repeatability estimates calculated from the adjusted data in part I varied considerably depending upon what factors were considered in the adjustment of the data. When the data were adjusted for differences due to the sex and rearing type of the lamb and the year the record was made, the repeatability estimates for birth weight, 70 day weight and rate of gain from 70 to 140 days were 0.369, 0.234 and 0.137 respectively. These repeatability estimates were rather low consequently it would be desirable to have more than one record available in evaluating the ewe's performance.

In part II the data were collected over a two year period on 141 Dorset x Western crossbred ewes. The cumulative milk production of the ewe per lamb reared was estimated at weekly intervals from one to 10 weeks following the birth of the lamb(s). In the analyses of these data on a within year basis, several sources of variation in the milk production of the ewe were considered. The sex of the lamb may be an important factor in the milk production of the ewe during the lactation period but the results of this study were not conclusive on this point. The rearing type of the lamb was not a significant factor in the cumulative milk production of the ewe per lamb reared until the latter half of the lactation period. The ewes rearing twin lambs produced about 30 percent more total milk during the 10 week lactation period than the ewes rearing single lambs. Age of ewe differences were important. However, the relative differences in the cumulative milk production per lamb reared among the age of ewe groups were not conclusive. The breed of sire of the lamb appeared to be an important source of variation in the cumulative milk production of the ewe during the latter stages of the lactation period. The sex by rearing, sex by age of ewe and rearing by age of ewe interactions were non-significant. Within season time trends as estimated by lamb birth date and birth date squared during the second season were unimportant. Lamb net gain and lamb body weight were highly correlated with the cumulative milk production of the ewe per lamb reared. In general the average level of milk production of the ewe per lamb reared at 10 weeks was rather small which indicated that the milk production of these ewes after 10 weeks would be a minor source of nutrients to the lamb.

The results of the various prediction equations which were calculated to estimate the milk production of the ewe indirectly based on the growth of her lamb indicated that the lamb must be at least three weeks old before these equations were very reliable. A comparison of the prediction equations for estimating the cumulative milk production of the ewe per lamb reared at various weeks indicated that lamb net gain or lamb body weight was the most important factor in these equations. The simple linear regression equations using lamb net gain or lamb body weight to predict the cumulative milk production of the ewe at three to six weeks compared favorably with the multiple regression equations. As the lactation progressed other factors also contributed to the variation in the milk production of the ewe. The results of these prediction equations indicate that it is possible to obtain a fairly reliable estimate of the milk production of the ewe based on the growth of her lamb(s).

LITERATURE CITED

Alexander, G. and H. L. Davis. 1959. Relationship of milk production to the number of lambs born or suckled. Aust. J. Agr. Res. 10:720.

Anderson, R. L. and T. A. Bancroft. 1952. Statistical Theory in Research. McGraw-Hill Book Co., New York.

Anonymous, 1953. Estimates of the heritability of seasonal data of lambing for Southdown and Hampshire ewes. Kent. Agr. Exp. Sta. 66th Annual Rept. p 38.

Barnicoat, C. R., A. G. Logan and A. I. Grant. 1949. Milk-secretion studies with New Zealand Romney ewes. J. Agr. Sci. 39:237.

Barnicoat, C. R., P. F. Murray, E. M. Roberts and G. S. Wilson, 1956. Milk-secretion studies with New Zealand Romney Ewes. J. Agr. Sci. 48:9.

Bettini, T. M. 1952. Some causes of the variation in length of lactation and milk production in the Sardinian ewe. An. Breed. Abstr. 20-241. (Abstr.).

Blackwell, R. L. and C. R. Henderson. 1955. Variation in fleece weight, weaning weight and birth weight of sheep under farm conditions. J. Animal Sci. 14:831.

Bogart, R., R. C. deBaca, L. D. Calvin and O. M. Nelson. 1957. Factors affecting birth weights of crossbred lambs. J. Animal Sci. 16:130.

Bonsma, F. N. 1939. Factors influencing the growth and development of lambs with special references to cross-breeding of Merino sheep in fat lamb production in South Africa. Univ. Pretoria Pub. Ser. 1 Agr. No. 48.

Brothers, Don G. 1961. Selection of lambs that yield the greatest experimental efficiency in growth studies from approximately fifty to ninety pounds. Ph.D. Thesis, Okla. State Univ.

Brothers, Don G. and J. V. Whiteman. 1961. Influence of early weaning on creep-fed milk lambs when weaned on weight or age. J. Animal Sci. 20:420.

Burris, M. J. and C. A. Baugus. 1955. Milk consumption and growth of suckling lambs. J. Animal Sci. 14:186.

Cameron, C. D. T. and L. S. Hamilton. 1961. Effects of age at weaning of Shropshire lambs on weight gains and carcass score. Can. J. Animal Sci. 4:180.

Cartwright, T. C. and J. A. Carpenter, Jr. 1961. Effects of nursing habits on calf weights. J. Animal Sci. 20:904. (Abstr.).

Cassard, D. W. and W. C. Weir. 1956. Heriditary and environmental variation in the weights and growth rates of Suffolk lambs under farm conditions. J. Animal Sci. 15:1221. (Abstr.).

Chapman, A. B. and J. L. Lush. 1932. Twinning, sex ratios, and genetic variability in birth weight in sheep. J. Heridity. 23:473.

deBaca, R. C., R. Bogart, L. D. Calvin and O. M. Nelson. 1956. Factors affecting weaning weights of crossbred spring lambs. J. Animal Sci. 15:667.

Doney, J. M. and Munro, Joan. 1962. The effect of suckling, management and season on sheep milk production as estimated by lamb growth. Animal Prod. 4:215.

Fuller, J. G. and F. Kleinheinz. 1904. On the daily yield and composition of milk from ewes of various breeds. Wis. Agr. Exp. Sta. 21st Annual Rpt. p 48.

Guyer, P. Q. and A. J. Dyer. 1954. Study of factors affecting sheep production. Mo. Agr. Exp. Sta. Res. Bul. 558.

Harrington, R. B., Don G. Brothers and J. V. Whiteman. 1962. Heritability of gain of lambs measured at different times and by different methods. J. Animal Sci. 21:78.

Harrington, R. B., J. V. Whiteman and R. D. Morrison. 1958. Estimates of some sources of variation in body weight of crossbred lambs at different ages. J. Animal Sci. 17:743.

Harvey, W. R. 1960. Least-squares analysis of data with unequal subclass numbers. ARS-20-8. U. S. D. A.

Hazel, L. N. and C. E. Terrill. 1945a. Effects of some environmental factors on weanling traits of range Rambouillet lambs. J. Animal Sci. 4:331.

Hazel, L. N. and C. E. Terrill. 1945b. Heritability of weaning weight and staple length in range Rambouillet lambs. J. Animal Sci. 4:347.

Hazel, L. N. and C. E. Terrill. 1946a. Effects of some environmental factors on weanling traits in range Columbia, Corriedale and Targhee lambs. J. Animal Sci. 5:318.

Hazel, L. N. and C. E. Terrill. 1946b. Heritability of weanling traits in range Columbia, Corriedale and Targhee lambs. J. Animal Sci. 5:371.

Hazel, L. N. and C. E. Terrill. 1946c. Effects of some environmental factors on fleece and body characteristics of range Rambouillet yearling ewes. J. Animal Sci. 5:382.

Henderson, C. R. 1953. Estimation of variance and covariance components. Biometrics 9:226.

Hundley, W. S. and R. C. Carter. 1956. Heritability of growth rate and market grade in mutton lambs. J. Animal Sci. 15:1226. (Abstr.)

Hunter, G. L. 1956. The maternal influence on size in sheep. J. Agr. Sci. 48:36.

Karam, H. A., A. B. Chapman and A. L. Pope. 1953. Selecting lambs under farm flock conditions. J. Animal Sci. 12:148.

Kean, G. R. and W. L. Henning. 1949. Birth weight and average daily gain in hothouse lamb production. J. Animal Sci. 8:362.

MacNaughton, W. N. 1957. Repeatability and heritability of birth, weaning and shearling weights among range sheep in Canada. J. Sci. Iowa State Coll. 31:465. (Abstr.).

Mason, I. L. and P. Dassatt. 1954. Milk, meat and wool production in the Langhe sheep of Italy. An Breed. Abstr. 22:223. (Abstr.).

McCance, I. 1959. The determination of milk yield in the Merino ewe. Aust. J. Agr. Res. 10:839.

McCance, I. and G. Alexander. 1959. The onset of lactation in the Merino ewe and its modification by nutritional factors. Aust. J. Agr. Res. 10:699.

Munro, Joan. 1955. Studies on the milk yields of Scottish Blackface ewes. J. Agr. Sci. 46:131.

Neidig, R. E. and E. S. Iddings. 1919. Quantity and composition of ewe's milk: its relation to the growth of lambs. J. Agr. Res. 17:19.

Nelson, R. H. and G. Venkatchalam. 1949. Estimates of the heritability of birth weight and weaning weight of lambs. J. Animal Sci. 8:607. (Abstr.).

Owen, J. B. 1957. A study of the lactation and growth of Hill sheep in their native environment and under lowland conditions. J. Agr. Sci. 48:387.

Phillips, R. W. and W. M. Dawson. 1940. Some factors affecting survival, growth and selection of lambs. U. S. D. A. Circ. No. 538.

Ragab, M. T., A. A. Asker and M. R. Kadi. 1953. Genetic factors affecting weights of Ossimi lambs. Empire J. Exp. Agr. 21:304.

Ritzman, E. G. 1917. Ewe's milk, its fat content and relation to growth of lambs. J. Agr. Res. 8:29.

Shelton, M. and F. Campbell. 1962. Influence of environmental adjustments on heritability of weaning weight of range Rambouillet lambs. J. Animal Sci. 21:91.

Shrewsberry, C. L., F. N. Andrews, Claude Harper and M. R. Zelle. 1943. The value of alfalfa and certain of its fractions in the nutrition of breeding ewes. J. Animal Sci. 2:209.

Sidwell, G. M. 1956. Some aspects of twin versus single lambs of Navajo and Navajo crossbred ewes. J. Animal Sci. 15:202.

Sidwell, G. M., and J. O. Grandstaff. 1949. Size of lambs at weaning as a permanent characteristic of Navajo ewes. J. Animal Sci. 8:373.

Snedecor, G. M. 1956. Statistical Methods. (5th ed.). Iowa State College Press, Ames, Iowa.

Spencer, D. A., R. G. Schott, R. W. Phillips and B. Aune. 1942. Performance of ewes bred first as lambs compared with ewes bred first as yearlings. J. Animal Sci. 1:27.

Taylor, J. M. and L. N. Hazel. 1955. The growth curve of pigs between 134 and 174 days of age. J. Animal Sci. 14:1133.

Terrill, C. E., G. M. Sidwell and L. N. Hazel. 1947. Effects of some environmental factors on yearling traits of Columbia and Targhee ewes. J. Animal Sci. 6:115.

Thompson, W. and A. M. Thomson. 1953. Effect of diet on milk yield of the ewe and growth of her lamb. British J. Nutr. 7:263.

Venkatachalam, G., R. H. Nelson, F. Thorp, Jr., R. W. Luecke and M. L. Gray. 1949. Causes and certain factors affecting lamb mortality. J. Animal Sci. 8:392.

Vesely, J. A. and S. B. Slen. 1961. Heritabilities of weaning weight, yearling weight, and clean fleece weight in range Romnelet sheep. Can. J. An. Sci. 41:109.

Wallace, L. R. 1948. The growth of lambs before and after birth in relation to level of nutrition. J. Agr. Sci. 38:93.

Whiting, F., S. B. Slen and L. M. Bezeau. 1952. The quantity and quality of mature ewe's milk as influenced by the level of protein in the ration. Sci. Agr. 32:365.

Yao, T. S., V. L. Simmons and R. G. Schott. 1953. Heritability of fur characters and birth weight in Karakul lambs. J. Animal Sci. 12:431.

A P P E N D I X

TABLE 29

PARTIAL REGRESSION COEFFICIENTS

AND STANDARD ERRORS FOR BIRTH WEIGHT IN PART I

	Equation 2		Equation 4		Equation 6		Equation 8	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Intercept	-31.194		7.689		-33.504		7.664	
Sex (Male)	0.346**	0.084	0.353**	0.093	0.374**	0.051	0.365**	0.052
Rear. (SS)	1.256**	0.106	1.235**	0.107	1.265**	0.097	1.261**	0.308
Rear. (TS)	-0.793**	0.175	-0.786**	0.180	-0.805**	0.161	-0.787**	0.163
Year (55)	-1.791**	0.203	-1.636**	0.203	-1.898**	0.162	-1.742**	0.161
Year (56)	-1.210**	0.200	-1.233**	0.203	-1.101**	0.110	-1.153**	0.110
Year (57)	0.358	0.240	0.519*	0.241	0.341**	0.126	0.513**	0.123
Year (58)	0.687**	0.186	0.462*	0.184	0.807**	0.111	0.619**	0.106
Year (59)	1.179**	0.170	1.111**	0.172	1.140**	0.105	1.067**	0.105
Male x SS	0.072	0.099	0.065	0.100	---	---	---	---
Male x TS	-0.133	0.168	-0.068	0.170	---	---	---	---
Male x 55	0.095	0.160	0.080	0.162	---	---	---	---
Male x 56	-0.067	0.109	-0.071	0.111	---	---	---	---
Male x 57	0.095	0.123	0.118	0.125	---	---	---	---
Male x 58	-0.120	0.105	-0.098	0.106	---	---	---	---
Male x 59	-0.007	0.104	0.026	0.106	---	---	---	---
SS x 55	-0.326	0.232	-0.338	0.236	---	---	---	---
SS x 56	-0.209	0.218	-0.205	0.221	---	---	---	---
SS x 57	-0.101	0.253	-0.115	0.256	---	---	---	---
SS x 58	0.164	0.201	0.268	0.203	---	---	---	---
SS x 59	0.289	0.193	0.275	0.196	---	---	---	---
TS x 55	0.287	0.343	0.168	0.345	---	---	---	---
TS x 56	-0.324	0.379	-0.224	0.384	---	---	---	---
TS x 57	0.115	0.448	0.056	0.455	---	---	---	---
TS x 58	-0.233	0.340	-0.265	0.345	---	---	---	---
TS x 59	-0.014	0.314	0.034	0.319	---	---	---	---
Birth Date	0.226	0.216	---	---	0.243	0.213	---	---
Bth. Date Sq.	-0.003	0.004	---	---	-0.004	0.004	---	---

* $P < .05$

** $P < .01$

TABLE 30

PARTIAL REGRESSION COEFFICIENTS AND STANDARD ERRORS FOR 70 DAY WEIGHT. EQUATIONS 1 THROUGH 4 IN PART I (CONTINUED IN TABLE 31)

	Equation 1		Equation 2		Equation 3		Equation 4	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Intercept	-35.470		-107.348		29.359		48.900	
Sex (Male)	1.836**	0.336	2.666**	0.364	1.902**	0.352	2.679**	0.418
Rear. (SS)	3.308**	0.420	6.257**	0.462	3.772**	0.436	6.431**	0.474
Rear. (TS)	0.818	0.658	-1.099	0.773	0.601	0.689	-1.147	0.815
Year (55)	-2.122**	0.783	-6.463**	0.882	-3.441**	0.805	-7.103**	0.920
Year (56)	-0.607	0.749	-3.511**	0.871	-0.691	0.785	-3.412**	0.919
Year (57)	0.580	0.877	1.431	1.044	-0.452	0.911	0.674	1.090
Year (58)	4.018**	0.688	5.693**	0.811	5.538**	0.698	6.596**	0.832
Year (59)	-1.010	0.645	1.840*	0.742	-0.258	0.669	2.219**	0.778
Male x SS	-0.701	0.363	-0.580	0.429	-0.657	0.380	-0.565	0.453
Male x TS	1.810**	0.613	1.536*	0.730	1.408*	0.641	1.301	0.768
Male x 55	-0.786	0.584	-0.532	0.695	-0.638	0.612	-0.433	0.733
Male x 56	-0.144	0.401	-0.247	0.474	-0.155	0.421	-0.253	0.501
Male x 57	-0.677	0.450	-0.491	0.535	-0.767	0.472	-0.564	0.565
Male x 58	0.000	0.383	-0.289	0.456	-0.184	0.401	-0.402	0.481
Male x 59	0.478	0.381	0.438	0.454	0.264	0.399	0.299	0.478
SS x 55	0.495	0.850	-0.219	1.010	0.463	0.891	-0.212	1.066
SS x 56	-0.274	0.803	-0.633	0.947	-0.337	0.842	-0.643	1.000
SS x 57	-1.131	0.925	-1.352	1.103	-0.868	0.966	-1.099	1.160
SS x 58	-0.907	0.733	-0.554	0.873	-1.571*	0.764	-1.028	0.916
SS x 59	-0.326	0.714	0.225	0.840	-0.263	0.748	1.993	0.886
TS x 55	-1.139	1.252	-0.481	1.492	-0.073	1.302	0.279	1.563
TS x 56	-0.475	1.389	-1.337	1.651	-1.330	1.451	-1.917	1.738
TS x 57	1.393	1.640	1.575	1.952	1.588	1.717	1.615	2.058
TS x 58	2.414	1.243	1.914	1.480	2.673	1.302	2.152	1.557
TS x 59	-1.074	1.153	-0.984	1.368	-1.328	1.208	-1.128	1.445
Bth. Date	0.589	0.789	1.130	0.940	---	---	---	---
Bth. Date Sq.[a]	-0.124	0.129	-0.302	0.153	---	---	---	---
Bth. Wt.	3.109**	0.068	---	---	0.293**	0.071	---	---
Bth. Wt. Sq.[a]	-0.046	0.040	---	---	-0.047	0.043	---	---

* $P < .05$ [a]Shift two decimal places to the left

** $P < .01$

TABLE 31

PARTIAL REGRESSION COEFFICIENTS AND STANDARD ERRORS

FOR 70 DAY WEIGHT. EQUATION 5 THROUGH 8 IN PART I (CONTINUED FROM TABLE 30)

	Equation 5		Equation 6		Equation 7		Equation 8	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Intercept	-40.093		-116.661		29.613		48.965	
Sex (Male)	1.094**	0.197	1.966**	0.226	1.245**	0.205	2.028**	0.229
Rear. (SS)	3.009**	0.390	5.945**	0.419	3.331**	0.406	6.022**	1.342
Rear. (TS)	1.038	0.603	-0.876	0.702	0.786	0.630	-0.936	0.712
Year (55)	-1.766**	0.654	-6.317**	0.708	-3.226**	0.661	-7.083**	0.701
Year (56)	-0.368	0.428	-2.950**	0.478	-0.178	0.446	-2.665**	0.481
Year (57)	-0.161	0.468	0.665	0.551	-1.210**	0.473	-0.080	0.537
Year (58)	3.099**	0.422	5.016**	0.483	4.389**	0.411	5.749**	0.461
Year (59)	-0.316	0.415	2.383**	0.458	0.450	0.424	2.777**	0.458
Bth. Date	0.616	0.787	1.192	0.931	---	---	---	---
Bth. Date Sq.[a]	-0.129	0.128	-0.212	0.152	---	---	---	---
Bth. Wt.	0.311**	0.066	---	---	0.290**	0.069	---	---
Bth. Wt. Sq.[a]	-0.047	0.039	---	---	-0.046	0.041	---	---

** $P < .01$ [a]Shift two decimal places to the left.

TABLE 32

PARTIAL REGRESSION COEFFICIENTS AND STANDARD ERRORS FOR RATE OF GAIN FROM 70 TO 140 DAYS. EQUATIONS 1 THROUGH 4 IN PART I (CONTINUED IN TABLE 33)

	Equation 1		Equation 2		Equation 3		Equation 4	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Intercept	5.868		5.401		0.471		0.516	
Sex (Male)	0.026**	0.005	0.030**	0.005	0.024**	0.005	0.029**	0.005
Rear. (SS)	-0.011	0.006	0.006	0.006	-0.017**	0.006	0.002	0.006
Rear. (TS)	0.014	0.010	0.005	0.010	0.017	0.010	0.006	0.010
Year (55)	-0.026*	0.012	-0.048**	0.011	-0.012	0.012	-0.034**	0.012
Year (56)	0.017	0.011	0.002	0.011	0.018	0.011	0.000	0.012
Year (57)	-0.014	0.013	-0.009	0.013	-0.001	0.013	0.007	0.014
Year (58)	0.027**	0.010	0.035**	0.010	0.010	0.010	0.016	0.010
Year (59)	-0.017	0.010	-0.002	0.009	-0.026**	0.010	-0.011	0.010
Male x SS	-0.002	0.005	0.000	0.005	-0.003	0.006	-0.000	0.006
Male x TS	-0.001	0.009	-0.001	0.009	0.005	0.009	0.003	0.010
Male x 55	0.000	0.009	0.001	0.009	-0.000	0.009	-0.002	0.009
Male x 56	-0.005	0.006	-0.008	0.006	-0.005	0.006	-0.007	0.006
Male x 57	-0.004	0.007	-0.002	0.007	-0.003	0.007	-0.000	0.007
Male x 58	0.003	0.006	0.001	0.006	0.005	0.006	0.004	0.006
Male x 59	0.001	0.006	0.001	0.006	0.003	0.006	0.004	0.006
SS x 55	0.003	0.013	-0.003	0.013	0.004	0.013	-0.003	0.013
SS x 56	-0.002	0.012	-0.001	0.012	-0.002	0.012	-0.008	0.013
SS x 57	-0.012	0.014	-0.014	0.014	-0.018	0.014	-0.020	0.015
SS x 58	0.006	0.011	0.010	0.011	0.015	0.011	0.020	0.012
SS x 59	-0.005	0.011	0.002	0.011	-0.005	0.011	0.003	0.011
TS x 55	0.001	0.019	0.005	0.019	-0.015	0.019	-0.012	0.020
TS x 56	-0.018	0.021	0.020	0.021	-0.007	0.021	-0.007	0.022
TS x 57	0.003	0.024	0.007	0.025	0.004	0.025	0.007	0.026
TS x 58	0.008	0.018	0.004	0.019	0.003	0.019	-0.002	0.020
TS x 59	0.007	0.017	0.004	0.017	0.009	0.018	0.006	0.018
Bth. Date[a]	-3.705**	1.168	-3.418**	1.198	---	---	---	---
Bth. Date Sq.[b]	0.635**	0.190	0.594**	0.195	---	---	---	---
Bth. Wt.[a]	-0.058	0.100	---	---	-0.043	0.103	---	---
Bth. Wt. Sq.[b]	0.119*	0.060	---	---	0.122	0.061	---	---

* P < .05 [a]Shift two decimal places to the left

** P < .01 [b]Shift four decimal places to the left

TABLE 33

PARTIAL REGRESSION COEFFICIENTS AND STANDARD ERRORS FOR RATE OF GAIN FROM 70 TO 140 DAYS. EQUATIONS 5 THROUGH 8 IN PART I (CONTINUED FROM TABLE 32)

	Equation 5		Equation 6		Equation 7		Equation 8	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Intercept	5.776		5.255		0.469		0.514	
Sex (Male)	0.024*	0.003	0.030**	0.003	0.022**	0.003	0.028**	0.003
Rear. (SS)	-0.013*	0.006	0.006	0.005	-0.017**	0.006	0.004	0.017
Rear. (TS)	0.015	0.009	0.005	0.009	0.018*	0.009	0.006	0.009
Year (55)	-0.024*	0.010	-0.048**	0.009	-0.007	0.010	-0.032**	0.009
Year (56)	0.025**	0.006	0.010	0.006	0.022**	0.006	0.009	0.006
Year (57)	-0.019**	0.007	-0.014*	0.007	-0.007	0.007	0.001	0.007
Year (58)	0.024**	0.006	0.034**	0.006	0.010	0.006	0.019**	0.006
Year (59)	-0.019**	0.006	-0.004	0.006	-0.029**	0.006	-0.012*	0.006
Bth. Date[a]	-3.645**	1.148	-3.322**	1.189	---	---	---	---
Bth. Date Sq.[a]	0.625**	0.187	0.579**	0.194	---	---	---	---
Bth. Wt.[a]	-0.064	0.096	---	---	-0.044	0.099	---	---
Bth. Wt. Sq.[b]	0.125*	0.057	---	---	0.125*	0.059	---	---

* $P < .05$ [a]Shift two decimal places to the left

** $P < .01$ [b]Shift four decimal places to the left

TABLE 34
ANALYSES OF VARIANCE FOR REPEATABILITY ESTIMATES OF 70 DAY WEIGHT AND RATE OF GAIN FROM 70 DAYS TO 140 DAYS WHEN DATA ADJUSTED FOR SEX OF LAMB, LAMB BIRTH AND REARING TYPE, YEAR RECORD WAS MADE, SEX BY REARING, SEX BY YEAR AND REARING BY YEAR INTERACTIONS, LAMB BIRTH DATE, LAMB BIRTH DATE SQUARED, LAMB BIRTH WEIGHT AND LAMB BIRTH WEIGHT SQUARED. (EQUATION 1)

70 Day Weight

Source of Variation	d.f.	Mean Square
Total	652	26.25
Among Ewes	175	36.31
Lambs within Ewes	449	24.07

Repeatability = 0.121 Standard Error = 0.031

Gain 70 Days to 140 Days

Source of Variation	d.f.	Mean Square
Total	652	0.00614
Among Ewes	175	0.00771
Lambs within Ewes	447	0.00594

Repeatability = 0.074 Standard Error = 0.032

TABLE 35
ANALYSES OF VARIANCE FOR REPEATABILITY ESTIMATES OF BIRTH WEIGHT, 70 DAY WEIGHT, AND RATE OF GAIN FROM 70 TO 140 DAYS WHEN DATA ADJUSTED FOR SEX OF LAMB, LAMB BIRTH AND REARING TYPE, YEAR RECORD WAS MADE, SEX BY REARING, SEX BY YEAR AND REARING BY YEAR INTERACTIONS, LAMB BIRTH DATE, AND LAMB BIRTH DATE SQUARED.
(EQUATION 2)

Birth Weight

Source of Variation	d.f.	Mean Square
Total	652	2.18
Among Ewes	175	4.38
Lambs within Ewes	449	1.46

Repeatability = 0.351   Standard Error = 0.025

70 Day Weight

Source of Variation	d.f.	Mean Square
Total	652	39.36
Among Ewes	175	64.96
Lambs within Ewes	449	31.84

Repeatability = 0.221   Standard Error = 0.028

Gain 70 to 140 Days

Source of Variation	d.f.	Mean Square
Total	652	0.00661
Among Ewes	175	0.00888
Lambs within Ewes	449	0.00614

Repeatability = 0.109   Standard Error = 0.031

TABLE 36

ANALYSES OF VARIANCE FOR REPEATABILITY ESTIMATES OF 70 DAY WEIGHT AND RATE OF GAIN FROM 70 TO 140 DAYS WHEN DATA ADJUSTED FOR SEX OF LAMB, LAMB BIRTH TYPE AND REARING, YEAR RECORD WAS MADE, SEX BY REARING, SEX BY YEAR AND REARING BY YEAR INTERACTIONS, AND LAMB BIRTH WEIGHT AND LAMB BIRTH WEIGHT SQUARED. (EQUATION 3).

70 Day Weight

Source of Variation	d.f.	Mean Square
Total	652	29.47
Among Ewes	175	40.64
Lambs within Ewes	449	26.95

Repeatability = 0.120   Standard Error = 0.031

Gain 70 to 140 Days

Source of Variation	d.f.	Mean Square
Total	652	0.00667
Among Ewes	175	0.00888
Lambs within Ewes	449	0.00623

Repeatability = 0.103   Standard Error = 0.031

TABLE 37

ANALYSES OF VARIANCE FOR REPEATABILITY ESTIMATES OF BIRTH WEIGHT, 70 DAY WEIGHT AND RATE OF GAIN FROM 70 TO 140 DAYS WHEN DATA ADJUSTED FOR SEX OF LAMB, LAMB BIRTH AND REARING TYPE, YEAR RECORD WAS MADE, SEX BY REARING, SEX BY YEAR AND REARING BY YEAR INTERACTIONS. (EQUATION 4).

Birth Weight

Source of Variation	d.f.	Mean Square
Total	652	2.24
Among Ewes	175	4.56
Lambs within Ewes	451	1.47

Repeatability = 0.362 Standard Error = 0.024

70 Day Weight

Source of Variation	d.f.	Mean Square
Total	652	40.84
Among Ewes	175	66.19
Lambs within Ewes	451	33.36

Repeatability = 0.210 Standard Error = 0.029

Gain 70 to 140 Days

Source of Variation	d.f.	Mean Square
Total	652	0.00729
Among Ewes	175	0.01034
Lambs within Ewes	451	0.00652

Repeatability = 0.136 Standard Error = 0.031

TABLE 38

ANALYSES OF VARIANCE FOR REPEATABILITY ESTIMATES OF 70 DAY WEIGHT AND RATE OF GAIN FROM 70 DAYS TO 140 DAYS WHEN DATA ADJUSTED FOR SEX OF LAMB, LAMB BIRTH AND REARING TYPE, YEAR RECORD WAS MADE, LAMB BIRTH DATE, LAMB BIRTH DATE SQUARED,LAMB BIRTH WEIGHT AND LAMB BIRTH WEIGHT SQUARED. (EQUATION 5)

70 Day Weight

Source of Variation	d.f.	Mean Square
Total	652	27.76
Among Ewes	175	40.01
Lambs within Ewes	464	23.91

Repeatability = 0.154 Standard Error = 0.030

Gain from 70 to 140 Days

Source of Variation	d.f.	Mean Square
Total	652	0.00626
Among Ewes	175	0.00772
Lambs within Ewes	464	0.00589

Repeatability = Standard Error = 0.032

TABLE 39
ANALYSES OF VARIANCE FOR REPEATABILITY ESTIMATES OF BIRTH WEIGHT, 70 DAY WEIGHT AND RATE OF GAIN FROM 70 TO 140 DAYS WHEN DATA ADJUSTED FOR SEX OF LAMB, LAMB BIRTH AND REARING TYPE, YEAR RECORD WAS MADE, LAMB BIRTH DATA AND LAMB BIRTH DATE SQUARED (EQUATION 6)

Birth Weight

Source of Variation	d.f.	Mean Square
Total	652	2.26
Among Ewes	175	4.47
Lambs within Ewes	466	1.48

Repeatability = 0.352 Standard Error = 0.025

70 Day Weight

Source of Variation	d.f.	Mean Square
Total	652	41.49
Among Ewes	175	68.81
Lambs within Ewes	466	32.21

Repeatability = 0.235 Standard Error = 0.028

Source of Variation	d.f.	Mean Square
Total	652	0.00705
Among Ewes	175	0.00919
Lambs within Ewes	466	0.00642

Repeatability = 0.104 Standard Error = 0.031

TABLE 40

ANALYSES OF VARIANCE FOR REPEATABILITY ESTIMATES OF 70 DAY WEIGHT AND RATE OF GAIN FROM 70 TO 140 DAYS, WHEN DATA ADJUSTED FOR SEX OF LAMB, LAMB BIRTH AND REARING TYPE, YEAR RECORD WAS MADE, LAMB BIRTH WEIGHT AND LAMB BIRTH WEIGHT SQUARED. (EQUATION 7)

70 Day Weight

Source of Variation	d.f.	Mean Square
Total	652	31.09
Among Ewes	175	44.31
Lambs within Ewes	466	26.85

Repeatability = 0.149   Standard Error = 0.030

Gain from 70 to 140 Days

Source of Variation	d.f.	Mean Square
Total	652	0.00680
Among Ewes	175	0.00893
Lambs within Ewes	466	0.00616

Repeatability = 0.108   Standard Error = 0.031

TABLE 41
ANALYSES OF VARIANCE FOR REPEATABILITY ESTIMATES OF BIRTH WEIGHT, 70 DAY WEIGHT AND RATE OF GAIN 70 TO 140 DAYS, WHEN DATA ADJUSTED FOR SEX OF LAMB, LAMB BIRTH AND REARING TYPE AND YEAR RECORD WAS MADE (EQUATION 8).

Birth Weight

Source of Variation	d.f.	Mean Square
Total	652	2.31
Among Ewes	175	4.66
Lambs within Ewes	468	1.47

Repeatability = 0.369 Standard Error = 0.024

70 Day Weight

Source of Variation	d.f.	Mean Square
Total	652	42.65
Among Ewes	175	70.55
Lambs within Ewes	468	33.04

Repeatability = 0.234 Standard Error = 0.028

Gain from 70 to 140 Days

Source of Variation	d.f.	Mean Square
Total	652	0.00748
Among Ewes	175	0.01039
Lambs within Ewes	468	0.00654

Repeatability = 0.137 Standard Error = 0.031

TABLE 42
ANALYSES OF VARIANCE FOR REPEATABILITY ESTIMATES OF BIRTH WEIGHT, 70 DAY WEIGHT AND RATE OF GAIN FROM 70 TO 140 DAYS WHEN DATA WERE IN ITS UNADJUSTED FORM (EQUATION 9).

Birth Weight

Source of Variation	d.f.	Mean Square
Total	652	4.25
Among Ewes	175	6.50
Lambs within Ewes	477	3.42

Repeatability = 0.195   Standard Error = 0.029

70 Day Weight

Source of Variation	d.f.	Mean Square
Total	652	84.99
Among Ewes	175	123.27
Lambs within Ewes	477	70.95

Repeatability = 0.166   Standard Error = 0.030

Gain 70 to 140 Days

Source of Variation	d.f.	Mean Square
Total	652	0.00866
Among Ewes	175	0.01128
Lambs within Ewes	477	0.00770

Repeatability = 0.111   Standard Error = 0.031

TABLE 43

PARTIAL REGRESSION COEFFICIENTS AND STANDARD

ERRORS FOR TOTAL LAMB GAIN 1960-61 DATA IN PART II

	Week 1		Week 2		Week 3		Week 4		Week 5	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Mean	-3.073		-4.990		-4.071		-3.512		-2.603	
Sex (Male)	0.052	0.115	0.090	0.174	0.127	0.229	0.185	0.279	0.261	0.326
Rear. (SS)	0.906**	0.329	2.385**	0.525	3.268**	0.692	4.171**	0.844	4.944**	0.986
A. of Dam (1)	-1.477**	0.434	-3.519**	0.670	-4.784**	0.878	-5.456**	1.071	-6.451**	1.251
A. of Dam (2)	0.283	0.315	0.590	0.477	0.866	0.630	1.025	0.768	0.922	0.898
A. of Dam (3)	0.756*	0.291	1.653**	0.444	2.189**	0.585	2.603**	0.713	3.093**	0.833
B. of Sire (D)	-0.267	0.274	-0.800	0.368	-1.157*	0.487	-1.602**	0.594	-2.226**	0.694
Suffolk	0.001	0.336	0.185	0.509	3.329	0.672	0.853	0.820	1.499	0.958
Hampshire	-0.310	0.314	-0.735	0.475	-0.848	0.627	-1.036	0.765	-1.672	0.894
Sex x Rear.	0.154	0.121	0.150	0.184	0.098	0.242	-0.125	0.295	-0.164	0.344
Male x 1	-0.524	0.256	-0.676	0.392	-0.695	0.517	-0.397	0.630	-0.354	0.736
Male x 2	-0.261	0.191	-0.262	0.289	-0.264	0.383	-0.306	0.466	-0.358	0.545
Male x 3	0.355	0.186	0.400	0.281	0.387	0.371	0.385	0.452	0.404	0.529
Rear. x 2	0.190	0.262	0.680	0.409	0.964	0.541	1.446*	0.659	1.644*	0.770
Rear. x 4	0.102	0.282	0.442	0.443	0.555	0.586	0.758	0.714	1.054	0.834
Dam Bdy Wt.	0.010	0.012	0.013	0.018	0.019	0.024	0.038	0.029	0.041	0.034
Dam Cond. Sc.	-0.063	0.115	-0.107	0.174	-2.209	0.230	-0.202	0.280	-0.217	0.328
Lamb Bth. Wt.	1.267*	0.542*	2.539**	0.818	3.063**	1.086	3.058*	1.324	3.675*	1.548
L. Bth. Wt. Sq.	-0.071*	0.033*	-0.135**	0.050	-0.154	0.066	-0.142	0.081	-0.169	0.094

* $P < .05$

** $P < .01$

TABLE 44

PARTIAL REGRESSION COEFFICIENTS AND STANDARD ERRORS FOR TOTAL LAMB GAIN 1960-61 DATA IN PART II

	Week 6		Week 7		Week 8		Week 9		Week 10	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Mean	-1.184		0.009		0.081		-0.211		0.548	
Sex (Male)	0.493	0.356	0.711	0.394	0.946*	0.428	1.164*	0.450	1.129*	0.531
Rear. (SS)	5.299**	1.076	5.652**	1.192	6.197**	1.295	6.902**	1.359	7.818**	1.605
A. of Dam (1)	-6.385**	1.366	-6.652**	1.511	-6.892**	1.644	-7.336**	1.725	-8.772**	2.037
A. of Dam (2)	0.655	0.980	0.754	1.085	1.375	1.179	1.919	1.237	2.185	1.461
A. of Dam (3)	3.184**	0.909	3.210**	1.007	3.048**	1.094	3.123**	1.148	3.630**	1.356
B. of Sire (D)	-2.644**	0.758	-2.966**	0.840	-3.114**	0.912	-3.184**	0.957	-3.169**	1.130
Hampshire	1.832	1.045	1.984	1.158	1.669	1.258	1.836	1.321	2.085	1.559
Suffolk	-1.861	0.975	-1.699	1.081	-1.363	1.174	-1.054	1.232	-0.912	1.455
Sex x Rear.	-0.171	0.376	-0.395	0.416	-0.436	0.452	-0.468	0.474	-0.540	0.560
Male x 1	-0.382	0.803	-0.337	0.890	-0.358	0.967	-0.233	1.015	-0.460	1.198
Male x 2	-0.318	0.595	-0.416	0.659	-0.304	0.716	-0.518	0.751	-0.674	0.887
Male x 3	0.357	0.577	0.269	0.639	0.270	0.694	0.250	0.729	0.613	0.860
Rear. x 2	1.744*	0.840	1.941*	0.931	2.133*	1.016	2.472*	1.062	2.769*	1.253
Rear. x 4	1.362	0.911	1.358	1.009	1.777	1.096	2.241	1.150	2.621	1.358
Dam Bdy. Wt.	0.047	0.037	0.050	0.041	0.066	0.044	0.074	0.046	0.078	0.055
D. Cond. Sc.	-0.096	0.357	-0.096	0.396	-0.085	0.430	0.017	0.452	-0.081	0.533
Lamb Bth. Wt.	3.801*	1.689	4.452*	1.871	4.735*	2.033	5.209*	2.133	5.640*	2.519
L. Bth. Wt. Sq.	-0.167	0.104	-0.205	0.114	-0.210	0.124	-0.230	0.131	-0.241	0.154

* $P < .05$

** $P < .01$

TABLE 45

PARTIAL REGRESSION COEFFICIENTS AND STANDARD

ERRORS FOR LAMB BODY WEIGHT 1961-62 DATA IN PART II

	Week 1		Week 2		Week 3		Week 4		Week 5	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Intercept	3.607		16.924		15.868		15.067		35.495	
Sex (Male)	0.120	0.100	0.234	0.175	0.367	0.243	0.415	0.286	0.410	0.354
Rear. (SS)	0.745**	0.132	1.324**	0.235	2.147**	0.332	2.838**	0.381	2.501**	0.522
A. of Dam (2)	-0.222	0.230	0.644	0.415	-1.386*	0.560	-1.784**	0.630	-2.084*	0.797
A. of Dam (3)	-0.258	0.220	-0.169	0.363	0.612	0.505	1.100	0.581	0.923	0.713
A. of Dam (4)	0.256	0.192	0.629	0.326	0.898	0.460	0.769	0.566	1.260	0.658
B. of Sire (D)	-0.336	0.184	-0.447	0.320	-0.373	0.462	-0.284	0.556	-0.517	0.659
Hampshire	-0.338	0.200	-0.423	0.342	-0.454	0.486	-0.391	0.567	-0.039	0.708
Suffolk	0.144	0.323	0.065	0.555	0.089	0.816	0.590	0.956	0.560	1.131
Sex x Rear.	0.084	0.109	0.205	0.191	0.244	0.267	0.287	0.314	0.263	0.383
Male x 2	-0.104	0.182	-0.244	0.318	-0.544	0.441	-0.792	0.521	-0.995	0.636
Male x 3	0.093	0.190	0.169	0.328	0.316	0.458	0.544	0.543	0.600	0.676
Male x 4	-0.020	0.179	-0.015	0.306	0.044	0.426	0.099	0.500	0.537	0.620
SS x 2	-0.046	0.196	-0.263	0.338	-0.575	0.479	-1.086	0.573	-1.238	0.692
SS x 3	0.171	0.191	0.243	0.326	0.226	0.459	0.212	0.580	0.372	0.685
SS x 4	-0.118	0.193	0.149	0.331	0.275	0.496	0.948	0.601	0.769	0.686
Dam Bdy Wt.	-0.129	0.090	-0.136	0.145	-0.117	0.227	-0.020	0.325	-0.026	0.299
D. B. Wt. Sq.[a]	0.046	0.030	0.053	0.048	0.056	0.081	0.016	0.113	0.019	0.101
D. Cond. Sc.	0.627	0.662	0.118	1.037	0.430	1.093	0.645	1.401	-0.469	1.258
D. C. S. Sq.	-0.041	0.060	-0.004	0.094	-0.081	0.104	-0.031	0.128	0.027	0.124
Lamb Bth Dte.	0.054	0.040	0.012	0.069	0.032	0.101	0.045	0.116	-0.056	0.139
L. Bth. D. Sq.[a]	-0.010	0.007	-0.007	0.013	-0.012	0.018	-0.020	0.021	0.004	0.026
Lamb Bth. Wt.	1.137**	0.080	1.351**	0.139	1.544**	0.203	1.732**	0.231	2.061**	0.281
L. Bth. Wt. Sq.	-0.008	0.015	-0.013	0.026	-0.012	0.037	-0.003	0.043	0.016	0.053

[a]Shift decimal two places to left

* P < .05

** P < .01

TABLE 46

PARTIAL REGRESSION COEFFICIENTS AND STANDARD ERROR FOR LAMB BODY WEIGHT 1961-62 DATA IN PART II

	Week 6		Week 7		Week 8		Week 9		Week 10	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Intercept	65.928		66.775		62.160		27.214		71.291	
Sex (Male)	0.367	0.360	0.464	0.442	0.817	0.488	0.960	0.521	0.853	0.582
Rear. (SS)	3.430**	0.472	3.204**	0.645	3.743**	0.710	4.213**	0.710	3.507**	0.741
A. of Dam (2)	-2.679**	0.820	-3.259**	0.998	-3.589**	1.057	-4.680**	1.128	-4.469**	1.251
A. of Dam (3)	2.473**	0.790	1.511	0.870	2.083*	0.938	-2.344*	1.033	2.215	1.163
A. of Dam (4)	0.816	0.703	1.817*	0.841	2.231*	0.951	2.540*	1.000	2.368*	1.116
B. of Sire (D)	0.060	0.707	-0.751	0.828	-0.674	0.878	-0.841	0.976	-0.676	1.097
Hampshire	0.288	0.718	0.372	0.884	0.730	1.000	1.255	1.010	1.769	1.223
Suffolk	0.533	1.167	0.153	1.450	-0.001	1.567	-0.102	1.665	-0.587	1.928
Sex x Rear	0.094	0.399	0.245	0.483	0.516	0.528	0.479	0.577	0.410	0.633
Male x 2	-1.212	0.661	-0.922	0.806	-1.064	0.861	-1.309	0.941	-1.299	1.056
Male x 3	0.828	0.687	0.401	0.841	0.356	0.909	0.252	0.977	0.055	1.098
Male x 4	-0.064	0.633	-0.071	0.778	-0.051	0.858	-0.126	0.910	0.121	1.023
SS x 2	-1.561*	0.709	-1.400	0.878	-1.406	0.919	-1.609	1.012	-1.253	1.129
SS x 3	0.252	0.700	1.286	0.853	0.887	0.913	0.707	0.998	0.944	1.140
SS x 4	1.118	0.714	0.514	0.868	1.262	0.990	1.206	1.059	1.219	1.178
Dam Bdy. Wt.	-0.281	0.369	-0.271	0.452	-0.035	0.528	0.236	0.474	0.013	0.667
D. B. Wt. Sq.[a]	0.134	0.125	0.094	0.150	0.026	0.174	-0.058	0.160	-0.000	0.224
D. Cond. Sc.	0.589	1.294	1.221	1.743	0.538	2.220	-0.492	2.110	-1.133	2.690
D. C. Sc. Sq.	-0.196	0.122	-0.144	0.151	-0.150	0.200	-0.072	0.188	0.065	0.242
Lamb Bth Dte.	-0.131	0.143	-0.116	0.174	-0.155	0.187	-0.097	0.205	-0.252	0.231
L. Bth. D. Sq.[a]	0.006	0.027	0.006	0.032	0.001	0.035	0.013	0.038	0.039	0.043
Lamb Bth. Wt.	2.023**	0.302	2.212**	0.361	2.334**	0.394	2.430**	0.416	2.793**	0.470
L. Bth. Wt. Sq.[a]	0.023	0.055	0.067	0.086	0.018	0.072	0.009	0.079	0.015	0.087

[a]Shift decimal two places to left

* $P < .05$

** $P < .01$

TABLE 47

SIMPLE CORRELATIONS BETWEEN THE COVARIABLES

AND NET LAMB GAIN AT ONE THROUGH TEN WEEKS 1960-61 DATA PART II

Week	1	2	3	4	5	6	7	8	9	10
Dam Body Wt.[a]	0.258	0.240	0.234	0.250	0.254	0.261	0.256	0.261	0.260	0.263
Dam Cond. Score[a]	-0.002	-0.015	-0.029	-0.009	-0.011	0.006	-0.012	-0.005	0.008	-0.006
Lamb Bth. Wt.	0.403	0.497	0.533	0.552	0.555	0.583	0.568	0.575	0.576	0.578
Lamb Bth. Wt. Sq.	0.407	0.502	0.541	0.562	0.562	0.590	0.571	0.576	0.577	0.588

[a]The ewes were weighed and scored about three weeks prior to lambing.

Level of Significance $r = 0.216$ $P < .05$; $r = 0.282$ $P < .01$ 86 d.f.

TABLE 48

SIMPLE AND PARTIAL CORRELATIONS BETWEEN COVARIABLES

AND LAMB BODY WEIGHT AT ONE THROUGH TEN WEEKS 1961-62 PART II

Week	1	2	3	4	5	6	7	8	9	10
Dam Body Wt.[a]	0.196	0.213	0.194	0.271	0.297	0.287	0.219	0.223	0.205	0.209
	-0.157	-0.103	-0.057	0.007	-0.010	-0.084	-0.066	-0.007	0.055	0.002
Dam B. Wt. Sq.[a]	0.214	0.231	0.213	0.291	0.315	0.307	0.236	0.236	0.225	0.226
	0.168	0.121	0.078	0.016	0.020	0.117	0.069	0.017	-0.040	0.000
Dam Cond. Score[a]	0.219	0.302	0.223	0.118	0.343	0.181	0.258	0.170	0.158	0.215
	0.104	0.016	0.043	-0.051	-0.040	0.050	0.077	0.027	-0.026	-0.046
Dam C. Sc. Sq.[a]	0.222	0.311	0.234	0.133	0.385	0.171	0.266	0.171	0.183	0.235
	-0.075	-0.005	-0.086	-0.026	0.024	-0.173	-0.105	-0.082	-0.042	0.030
Lamb Bth. Date	0.172	0.099	0.079	0.076	0.070	0.060	0.057	0.056	0.087	0.079
	0.148	0.019	0.036	0.043	-0.045	0.101	-0.073	-0.091	-0.052	-0.119
Lamb Bth. D. Sq.	0.196	0.131	0.111	0.111	0.112	0.103	0.101	0.103	0.131	0.133
	-0.154	-0.058	-0.074	-0.106	-0.019	0.027	0.022	0.032	0.039	0.100
Lamb Bth. Wt.	0.888	0.817	0.780	0.763	0.763	0.743	0.728	0.736	0.726	0.726
	0.884	0.732	0.643	0.638	0.630	0.595	0.559	0.547	0.542	0.549
Lamb Bth. Wt. Sq.	0.331	0.299	0.298	0.299	0.306	0.301	0.290	0.293	0.280	0.292
	-0.057	-0.053	-0.037	-0.008	0.032	0.045	0.009	0.027	0.012	0.019

[a]Based on weights and scores closest to the adjusted age of the lamb

Level of Significance Simple cor. r = 0.194 P < .05 r = 0.250 P < .01 104 d.f.

Partial cor. r = 0.217 P < .05 r = 0.283 P < .01 80 d.f.

TABLE 49

WITHIN AGE OF EWE AND LAMB REARING TYPE MEANS AT DIFFERENT WEEKS FOR LAMB BODY WEIGHT AND EWE MILK PRODUCTION (LBS. PER WEEK) PER EWE. 1960-61 DATA

Age of Ewe	Lamb Rear. Type	No.of Lambs		Week									
				1	2	3	4	5	6	7	8	9	10
1	SS	11	L. Bdy.Wt.	10.0	13.0	16.6	20.0	23.4	28.0	32.1	35.9	40.0	42.9
1	SS	11	Milk Prod.	12.5	15.0	12.9	10.0	9.8	8.4	6.8	5.4	4.1	2.4
2	SS	10	L. Bdy.Wt.	11.5	16.5	21.0	25.4	30.1	34.2	38.7	43.3	48.2	52.1
2	SS	10	Milk Prod.	16.4	21.2	19.0	18.4	18.3	13.9	11.6	11.0	9.8	7.1
3	SS	10	L. Bdy.Wt.	15.1	20.9	26.4	31.8	36.8	41.4	46.0	50.7	55.6	60.7
3	SS	10	Milk Prod.	21.8	23.9	23.7	21.5	19.2	16.2	14.1	12.6	10.7	8.2
4	SS	10	L. Bdy.Wt.	14.2	19.6	24.6	29.2	34.1	38.5	43.0	47.1	51.3	56.0
4	SS	10	Milk Prod.	20.7	23.2	21.3	19.4	20.4	17.1	14.5	12.3	12.3	8.9
2	TT	10	L. Bdy.Wt.	9.5	12.7	16.0	19.7	23.5	27.1	31.3	35.0	39.0	41.8
2	TT	10	Milk Prod.	24.3	27.3	23.5	24.4	21.7	18.9	16.4	15.3	12.3	8.4
3	TT	17	L. Bdy.Wt.	12.0	15.6	19.3	23.2	27.2	31.5	35.7	40.0	44.5	48.1
3	TT	17	Milk Prod.	29.1	28.2	26.8	22.6	21.2	15.1	10.6	8.8	7.9	5.1
4	TT	20	L. Bdy.Wt.	11.3	15.2	19.0	22.9	27.1	31.4	36.0	40.2	44.6	48.5
4	TT	20	Milk Prod.	30.2	33.8	31.4	26.9	25.4	19.9	16.5	15.4	12.1	7.9
Within Age of Ewe Group Milk Production Ratios: Twins to Singles													
2				148	129	123	132	118	136	141	139	126	119
3				133	117	113	105	110	93	75	70	74	62
4				146	146	148	139	125	116	114	125	82	88

TABLE 50

WITHIN AGE OF EWE AND LAMB REARING TYPE MEANS AT DIFFERENT WEEKS FOR BODY WEIGHT AND EWE MILK PRODUCTION (LBS. PER WEEK) PER EWE. 1961-62 DATA

Age of Ewe	Lamb Rear. Type	No. of Lambs		Week 1	2	3	4	5	6	7	8	9	10
2	SS	16	L. Bdy.Wt.	13.8	18.0	21.9	25.8	29.9	33.9	37.9	42.2	46.7	50.8
2	SS	16	Milk Prod.	19.0	20.1	19.3	21.1	18.8	17.0	15.7	13.4	13.3	10.2
3	SS	13	L. Bdy.Wt.	15.1	20.6	26.0	31.3	36.3	41.4	46.5	51.2	56.0	61.2
3	SS	13	Milk Prod.	23.7	26.5	26.0	22.5	21.2	21.5	17.4	14.5	12.4	10.4
4	SS	8	L. Bdy.Wt.	14.4	19.9	24.9	30.0	34.7	39.4	44.3	48.8	54.4	58.5
4	SS	8	Milk Prod.	21.2	23.1	22.4	20.7	17.4	15.6	13.1	11.7	11.4	9.1
5	SS	9	L. Bdy.Wt.	16.1	21.5	26.6	31.8	36.9	41.4	45.4	50.2	55.3	59.8
5	SS	9	Milk Prod.	21.5	22.4	22.4	21.8	21.6	18.5	14.2	13.6	11.4	9.0
2	TT	6	L. Bdy.Wt.	10.6	13.7	16.9	20.3	24.1	27.9	31.3	35.3	39.1	42.6
2	TT	6	Milk Prod.	32.2	33.3	28.4	28.9	22.9	20.6	17.0	12.0	11.5	11.7
3	TT	12	L. Bdy.Wt.	11.1	14.9	18.6	22.4	26.4	30.2	34.0	38.5	42.7	46.8
3	TT	12	Milk Prod.	35.3	37.7	38.5	29.8	25.0	23.1	22.9	16.8	14.6	13.1
4	TT	20	L. Bdy.Wt.	12.4	16.5	20.5	24.5	28.7	32.9	37.3	41.8	46.3	50.4
4	TT	20	Milk Prod.	31.4	35.4	31.8	30.5	29.1	27.5	21.3	19.7	17.4	13.5
5	TT	22	L. Bdy.Wt.	12.0	15.8	19.4	23.2	27.2	31.0	35.1	39.1	43.2	47.6
5	TT	22	Milk Prod.	35.2	35.1	34.8	30.6	28.6	24.6	21.8	17.5	17.0	13.9

Within Age of Ewe Group Milk Production Ratios: Twins to Singles

Age of Ewe	1	2	3	4	5	6	7	8	9	10
2	170	166	147	137	122	121	108	90	86	115
3	149	142	148	132	118	107	132	116	118	126
4	147	153	142	148	167	177	163	168	152	148
5	164	157	155	140	133	133	153	128	148	153

TABLE 51

PARTIAL REGRESSION COEFFICIENTS AND STANDARD ERRORS

FOR CUMULATIVE MILK PRODUCTION PER LAMB REARED AT ONE TO FIVE WEEKS 1960-61 DATA

	Week 1		Week 2		Week 3		Week 4		Week 5	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Mean	1.433		12.033		20.526		29.397		23.937	
Sex (Male)	0.234	0.384	-0.189	0.695	-0.236	0.880	-0.588	1.137	-1.535	1.456
Rear. (SS)	0.880	1.156	2.284	2.389	4.398	3.030	7.274	3.988	10.499*	5.119
A. of Dam (1)	-1.284	1.562	-1.468	3.168	-3.074	4.007	-9.957	5.102	-15.796**	6.545
A. of Dam (2)	-1.110	1.055	-1.282	1.927	-2.692	2.449	-2.454	3.160	-1.158	4.020
A. of Dam (3)	1.031	1.017	0.297	1.943	1.755	2.453	4.772	3.162	6.708	4.055
B. of Sire (D)	-0.234	0.820	-0.642	1.520	-0.419	1.942	-0.276	2.537	1.171	3.308
Hampshire	0.360	1.120	0.668	2.036	0.508	2.584	-0.357	3.355	-1.531	4.332
Suffolk	-1.077	1.055	-1.633	1.931	-3.252	2.437	-6.010	3.148	-6.516	4.072
Sex x Rear.	-0.387	0.407	-0.868	0.737	-0.959	0.927	-0.964	1.198	-0.677	1.532
Male x 1	0.077	0.878	0.740	1.599	0.861	2.007	-0.161	2.566	-1.327	3.277
Male x 2	0.298	0.645	0.576	1.162	0.558	1.473	0.455	1.900	0.126	2.430
Male x 3	-0.300	0.634	-0.861	1.140	-0.664	1.434	0.194	1.847	1.566	2.360
Rear. x 2	0.612	0.876	1.491	1.668	2.792	2.119	3.843	2.768	4.701	3.534
Rear. x 4	-0.734	0.941	-0.158	1.784	0.659	2.261	0.804	2.923	0.714	3.751
Ewe Bdy Wt.	-0.027	0.040	-0.047	0.072	-0.007	0.091	-0.149	0.118	-0.167	0.151
Ewe Cond. Sc.	0.201	0.386	0.562	0.699	0.983	0.887	1.059	1.143	1.581	1.461
Lamb Bth. Wt.	1.611	1.877	-0.495	3.490	-2.596	4.392	-1.520	5.583	-0.109	7.153
L. Bth. Wt. Sq.	-0.060	0.114	0.090	0.209	0.191	0.264	0.102	0.336	-0.006	0.430
Lamb Gain	2.253**	0.401	2.908**	0.481	3.412**	0.453	3.387**	0.489	3.298**	0.532

* P < .05

** P < .01

TABLE 52

PARTIAL REGRESSION COEFFICIENTS AND STANDARD ERRORS FOR

CUMULATIVE MILK PRODUCTION PER LAMB REARED AT SIX TO TEN WEEKS 1960-61 DATA

	Week 6		Week 7		Week 8		Week 9		Week 10	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Mean	25.082		11.253		1.849		-11.816		-22.194	
Sex (Male)	-3.146	1.665	-4.284*	1.840	-5.137*	2.238	-6.343*	2.396	-6.617*	2.546
Rearing (SS)	12.676*	5.774	13.716*	6.258	15.718*	7.545	14.619	8.105	14.403	8.644
A. of Dam (1)	-22.978**	7.232	-26.926**	7.804	-33.762**	9.294	-37.379**	9.859	-39.387**	10.659
A. of Dam (2)	0.548	4.535	1.981	4.965	2.899	6.009	3.043	6.404	4.854	6.897
A. of Dam (3)	8.347	4.553	8.707	4.918	10.592	5.825	10.948	6.145	10.745	6.618
Br. of Sire (D)	2.245	3.793	3.688	4.160	4.435	4.978	5.725	5.246	6.151	5.542
Hampshire	-3.517	4.931	-6.281	5.392	-6.373	-6.432	-8.287	6.812	-10.054	7.337
Suffolk	-7.158	4.619	-7.860	5.014	-9.873	5.984	-11.272	6.302	-11.800	6.778
Sex x Rear.	-0.377	1.736	0.348	1.909	1.223	2.297	2.215	2.431	2.774	2.620
Male x 1	-0.824	3.714	-0.850	4.062	-2.106	4.885	-3.607	5.164	-3.335	5.572
Male x 2	-1.373	2.751	-2.480	3.013	-3.803	3.619	-3.916	3.836	-4.503	4.139
Male x 3	2.960	2.670	4.579	2.917	6.375	3.509	7.925*	3.710	8.163*	4.012
Rear. x 2	5.522	3.998	6.358	4.377	7.988	5.268	7.087	5.609	7.002	6.026
Rear. x 4	-0.882	4.270	-2.488	4.659	-4.069	5.636	-7.113	6.010	-8.818	6.477
Ewe Bdy Wt.	-0.249	0.171	-0.305	0.187	-0.403	0.226	-0.473	0.240	-0.515*	0.258
Ewe Cond. Sc.	1.460	1.651	1.849	1.806	2.113	2.172	1.700	2.297	1.842	2.477
Lamb Bth. Wt.	1.866	8.076	3.645	8.873	7.691	10.657	11.342	11.313	14.984	12.120
L. Bth. Wt.^{2}	-0.137	0.485	-0.242	0.533	-0.485	0.639	-0.728	0.678	-0.961	0.728
Lamb Gain$_Y$	3.323**	0.555	3.521**	0.549	3.445**	0.609	3.584**	0.613	3.416**	0.560

* P < .05

** P < .01

TABLE 53

PARTIAL REGRESSION COEFFICIENTS AND STANDARD ERRORS FOR CUMULATIVE MILK PRODUCTION PER LAMB REARED AT ONE TO FIVE WEEKS 1961-62 DATA

	Week 1		Week 2		Week 3		Week 4		Week 5	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Intercept	54.445		26.928		-0.144		-45.837		29.305	
Sex (Male)	-0.123	0.346	-0.589	0.560	-1.503*	0.716	-0.777	0.989	-0.420	1.319
Rear. (SS)	-0.427	0.532	-0.137	0.875	-0.661	1.186	0.983	1.682	1.591	2.185
A. of Ewe (2)	0.146	0.792	-0.651	1.329	0.251	1.687	3.216	2.252	3.501	3.070
A. of Ewe (3)	1.599*	0.759	4.439**	1.147	5.530**	1.481	6.073**	2.023	4.369	2.664
A. of Ewe (4)	-1.454*	0.665	-2.476*	1.054	-4.151**	1.367	-6.482**	1.951	-6.006*	2.488
B. of Sire (D)	-0.020	0.644	1.242	1.023	2.471	1.347	4.106	1.900	5.302	2.448
Hampshire	0.070	0.896	0.959	1.090	0.979	1.421	0.516	1.939	-1.565	2.621
Suffolk	-0.031	1.107	-1.365	1.753	-3.421	2.372	-3.292	3.268	-5.871	4.192
Sex x Rear.	-0.367	0.373	-0.605	0.607	-0.637	0.780	-0.939	1.078	-0.154	1.421
Male x 2	0.132	0.623	0.135	1.007	1.376	1.294	3.492	1.801	2.816	2.390
Male x 3	1.147	0.653	1.016	1.037	-0.498	1.336	-0.338	1.863	-1.907	2.512
Male x 4	-0.132	0.612	0.109	0.968	-0.402	1.239	-1.552	1.706	0.433	2.294
SS x 2	-0.438	0.671	-0.918	1.071	0.141	1.405	1.145	1.995	2.596	2.609
SS x 3	-0.096	0.658	0.346	1.034	0.305	1.337	-1.686	1.978	0.547	2.549
SS x 4	1.301	0.663	1.351	1.048	1.284	1.445	1.469	2.080	-0.765	2.559
Ewe Bdy. Wt.	-0.355	0.311	-0.521	0.462	-0.678	0.660	-0.282	1.107	-1.305	1.105
E. B. Wt. Sq.[a]	0.013	0.010	0.191	0.152	0.262	0.235	0.171	0.387	0.444	0.375
E. Cond. Sc.	-2.001	2.279	0.949	3.274	-1.046	3.180	-2.204	4.784	-0.418	4.660
E. C. S. Sq.	0.019	0.207	-0.144	0.298	0.040	0.302	0.002	0.435	0.009	0.459
Lamb Bth Dte.	-0.185	0.137	-0.035	0.219	0.109	0.292	0.275	0.395	0.205	0.513
L. Bth D. Sq.[a]	0.039	0.025	0.029	0.041	0.026	0.053	-0.010	0.073	0.011	0.096
Lamb Bth. Wt.	-1.640**	0.510	-2.389**	0.643	-3.567**	0.771	-3.892**	0.102	-4.571**	1.337
L. Bth. Wt. Sq.[a]	0.051	0.052	0.050	0.083	0.006	0.107	-0.016	0.147	0.023	0.197
Lamb Bdy. Wt.	2.111*	0.378	2.869**	0.349	3.665**	0.321	3.756**	0.376	4.095**	0.409

[a]Shift decimal two places to the left

* $P < .05$

** $P < .01$

TABLE 54

PARTIAL REGRESSION COEFFICIENTS AND STANDARD ERRORS FOR

CUMULATIVE MILK PRODUCTION PER LAMB REARED AT SIX TO TEN WEEKS 1961-62 DATA

	Week 6		Week 7		Week 8		Week 9		Week 10	
	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error	Reg. Coef.	Std. Error
Intercept	55.491		110.199		186.637		264.160		161.703	
Sex (Male)	-0.831	1.490	-0.749	1.800	-0.784	1.967	-2.089	2.152	-2.092	2.389
Rear. (SS)	1.935	2.486	6.676*	2.973	9.694**	3.256	10.884**	3.439	12.253**	3.384
A. of Ewe (2)	4.077	3.584	5.515	4.288	4.381	4.475	5.505	5.027	7.890	5.446
A. of Ewe (3)	3.182	3.435	4.063	3.582	6.095	3.829	5.956	4.316	6.593	4.814
A. of Ewe (4)	-6.190*	2.911	-7.830*	3.497	-6.938	3.894	-8.995*	4.207	-9.801*	4.643
B. of Sire	6.646	2.908	6.683	3.365	8.014	3.493	8.740	3.973	11.310*	4.454
Hampshire	-2.917	2.954	-4.625	3.578	-7.422	3.977	-9.045	4.129	-8.248	5.014
Suffolk	-7.756	4.801	-4.863	5.863	-3.582	6.214	-3.032	6.743	-7.713	7.813
Sex x Rear.	0.749	1.639	1.874	1.956	2.790	2.106	3.238	2.347	2.096	2.571
Male x 2	1.223	2.774	1.031	3.284	-6.635	3.444	-3.316	3.858	1.671	4.316
Male x 3	-2.959	2.848	-3.910	3.403	-3.398	3.608	-3.049	3.960	-4.311	4.447
Male x 4	2.422	2.602	3.324	3.147	4.444	3.403	4.004	3.687	4.332	4.142
SS x 2	3.912	2.999	2.948	3.604	3.412	3.694	3.606	4.161	3.116	4.605
SS x 3	2.027	2.878	2.699	3.497	3.242	3.641	5.482	4.056	2.339	4.635
SS x 4	-2.876	2.980	-3.328	3.517	-2.645	3.963	-5.098	4.322	-2.062	4.800
Ewe Bdy. Wt.	-1.869	1.522	-1.707	1.831	-2.120	2.092	-2.868	1.924	-0.171	2.701
E. B. Wt. Sq.[a]	0.628	0.521	0.622	0.607	0.749	0.690	1.015	0.650	0.074	0.907
E. Cond. Sc.	-1.520	5.324	3.210	7.069	5.746	8.806	6.918	8.552	-7.699	9.999
E. C. S. Sq.	0.217	0.511	-0.475	0.612	-0.790	0.796	-0.827	0.762	0.455	0.979
Lamb Bth Dte.	0.135	0.589	-0.214	0.706	-0.297	0.745	-0.439	0.833	-0.519	0.944
L. Bth D. Sq.[a]	0.045	0.109	0.078	0.131	0.055	0.138	0.066	0.153	0.024	0.173
Lamb Bth. Wt.	-4.860**	1.544	-4.067*	1.765	-4.143*	0.187	-3.407	2.006	-2.007	2.277
L. Bth. Wt. Sq.[a]	-0.008	0.226	0.024	0.270	-0.069	0.287	0.098	0.319	-0.065	0.354
Lamb Bdy. Wt.	4.259**	0.454	3.822**	0.446	3.672**	0.438	3.428**	0.447	3.304**	0.447

[a]Shift decimal two places to the left

* $P < .05$

** $P < .01$

TABLE 55

SIMPLE CORRELATIONS BETWEEN THE COVARIABLES AND CUMULATIVE MILK PRODUCTION OF THE EWE PER LAMB REARED AT ONE THROUGH TEN WEEKS 1960-61 DATA

Week	1	2	3	4	5	6	7	8	9	10
Ewe Body Wt.[a]	0.153	0.119	0.134	0.135	0.148	0.138	0.131	0.126	0.126	0.123
Ewe Cond. Sc.[a]	-0.024	-0.021	-0.022	-0.019	-0.096	0.011	0.008	0.003	0.000	0.005
Lamb Bth. Wt.	0.561	0.544	0.527	0.490	0.465	0.449	0.438	0.434	0.398	0.398
Lamb Bth. Wt. Sq.	0.561	0.552	0.542	0.510	0.485	0.471	0.459	0.456	0.441	0.441
Lamb Gain	0.748	0.822	0.868	0.861	0.852	0.817	0.802	0.776	0.754	0.759

[a]The ewes were weighed and scored about three weeks prior to lambing

Level of Significance $r = 0.216$ $P < .05$; $r = 0.282$ $P < .01$ 86 d.f.

TABLE 56

SIMPLE AND PARTIAL CORRELATIONS BETWEEN THE COVARIABLES AND CUMULATIVE MILK PRODUCTION OF THE EWE PER LAMB REARED AT ONE THROUGH TEN WEEKS 1961-62 DATA

Week	1	2	3	4	5	6	7	8	9	10
Ewe Body Wt.[a]	0.299	0.255	0.257	0.295	0.294	0.277	0.240	0.229	0.218	0.206
	-0.126	-0.124	-0.113	-0.028	-0.130	-0.135	-0.103	-0.112	-0.163	-0.007
Ewe Body Wt. Sq.[a]	0.313	0.270	0.268	0.310	0.309	0.294	0.251	0.240	0.235	0.215
	0.139	0.139	0.123	0.049	0.130	0.133	0.113	0.120	0.171	0.009
Ewe Cond. Score[a]	0.373	0.355	0.298	0.178	0.389	0.282	0.335	0.264	0.228	0.271
	-0.097	0.032	-0.037	-0.051	-0.010	-0.032	0.050	0.072	0.090	-0.078
Ewe C. Sc. Sq.[a]	0.383	0.359	0.307	0.181	0.422	0.276	0.325	0.249	0.229	0.285
	0.100	-0.053	0.037	0.000	0.002	0.047	-0.086	-0.110	-0.120	0.052
Lamb Birth Date	0.158	0.165	0.135	0.148	0.137	0.122	0.099	0.079	0.079	0.070
	-0.148	-0.018	0.041	0.077	0.044	0.025	-0.034	-0.044	-0.058	-0.061
Lamb Bth. D. Sq.	0.191	0.193	0.150	0.169	0.161	0.157	0.142	0.126	0.130	0.126
	0.167	0.079	0.045	-0.016	0.013	0.046	0.066	0.044	0.048	0.016
Lamb Bth. Wt.	0.448	0.474	0.456	0.474	0.499	0.499	0.499	0.507	0.505	0.502
	-0.336	-0.381	-0.457	-0.390	-0.355	-0.330	-0.248	-0.239	-0.185	0.097
Lamb Bth. Wt. Sq.	0.159	0.157	0.145	0.163	0.176	0.178	0.176	0.186	0.191	0.190
	0.110	0.067	0.005	-0.012	0.013	-0.004	0.010	0.025	0.034	0.020
Lamb Body Wt.	0.647	0.751	0.800	0.810	0.812	0.819	0.797	0.792	0.768	0.752
	0.527	0.675	0.785	0.742	0.744	0.722	0.689	0.682	0.648	0.634

[a]Based on weights and scores closest to the adjusted age of the lamb

Level of Significance Simple Cor. $r = 0.194$ $P < .05$ $r = 0.250$ $P < .01$ 104 d.f.

Partial Cor. $r = 0.217$ $P < .05$ $r = 0.283$ $P < .01$ 80 d.f.

VITA

Rodney B. Harrington

Candidate for the Degree of

Doctor of Philosophy

Thesis: A STUDY OF SOME OF THE RELATIONSHIPS BETWEEN EWES AND THE GROWTH OF THEIR LAMBS

Major Field: Animal Breeding

Biographical:

Personal Data: Born near Bethel, Maine, April 30, 1931, the son of Bernard and Maude Harrington; married Gwenyth M. Smith, July 4, 1959. The father of one son, Rodney Bernard II.

Education: Received the Bachelor of Science degree from the University of Maine, with a major in Animal Husbandry in June, 1954; received the Master of Science degree from Oklahoma State University, with a major in Animal Husbandry in August, 1957; received the Master of Science degree from the University of New South Wales, Kensington, N. S. W. Australia, with a major in Wool Technology in May, 1962.

Experience: Served in the United States Army from September, 1954 to August, 1956; Graduate Assistant in Animal Husbandry at Oklahoma State University, 1956-57, 1959-62; technical officer in the School of Wool Technology, University of New South Wales, Kensington, N. S. W. Australia, 1957-59; joined the staff at Purdue University as an Instructor in Mathematics and Animal Science, January, 1962.

Professional Organizations: Member of American Society of Animal Science, The Biometric Society, Alpha Zeta and Sigma Xi.

Date of Final Examination: December, 1962.