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In two breeding experiments, straightbred and crossbred rabbits were evaluated for performance characters relating to reproduction, disease resistance, growth and carcass quality. In the first experiment, New Zealand White (NN) and Flemish Giant (FG) straightbreds and FG sire x (Florida White-New Zealand White dam) terminal-crossbreds (TX) were involved. Reproductive performance was generally lower for small crossbred compared to straightbred doe groups, which were similar. However, doe group comparisons based on total production per unit of building area were not made. For NN straightbreds compared to FG straightbred and TX groups, litter size was larger and litter weight was heavier at 56 d and feed intake was increased. Average daily gain and 56 d weight per rabbit were larger but mortality from respiratory diseases was higher for FG straightbreds, while performance was similar between NN and TX groups. Total mortality was lowest in TX compared to straightbred litters. From carcass

appraisal investigations, FG-sired progeny had more favorable body composition than NN progeny. Comparisons of terminal-crosses to straightbred groups revealed crossbred advantages for body measurement and lean yield traits.

In the second experiment, three sire breeds: Californian (CC), NN and FG and four dam genetic groups: CC and NN straightbreds and Californian x New Zealand White (CN) and New Zealand White xCalifornian (NC) reciprocal crossbred does were involved. In addition, two diets were fed to does and litters, either a commercial control diet or a 74% alfalfa diet. Preweaning and postweaning traits involving reproduction, disease resistance and litter growth were significantly influenced by straightbred doe, maternal heterosis, maternal breed and dietary effects, while sire breed effects on litter performance were more important during the postweaning phase. Important breed additive effects were found for carcass quality and lean yield traits. Maternal breed and heterotic and direct heterotic effects on carcass traits were generally of negligible importance. Carcass weights were heaviest in progeny of FG paternity and of crossbred dam maternity. Total meat percentage of carcasses was similar for all genetic groups evaluated.

In conclusion, both experiments suggest the potential utilization of a large sire breed with straightbred or crossbred does of NN maternity to increase litter growth, disease resistance and slaughter weights of terminal-cross rabbits.

EVALUATION OF RABBIT BREEDS AND CROSSES FOR OVERALL COMMERCIAL PRODUCTIVITY

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Contributions of Junior Authors to Thesis Manuscripts

William D. Hohenboken was Mr. Lukefahr's major professor and thesis advisor. He aided Mr. Lukefahr in developing the original experimental plan and design and in analyzing the data statistically. He edited each of the manuscripts.

Peter R. Cheeke and Nephi M. Patton are administrators of the Oregon State University Rabbit Research Facility, where Mr. Lukefahr's research was conducted. They worked with him in planning the management and care of the experimental animals. They both edited each of the manuscripts.

Walter H. Kennick is administrator of the Oregon State University Clark Meat Science Laboratory. He aided Mr. Lukefahr in techniques and procedures for the carcass and meat quality experiments and edited the manuscript of which he is junior author.

EVALUATION OF RABBIT BREEDS AND CROSSES FOR OVERALL COMMERCIAL PRODUCTIVITY

CHAPTER 1

INTRODUCTION

Genetic exploitation of existing breed resources is a practical breeding approach to attempt to increase economic returns to the commercial meat rabbit enterprise. To ensure optimal success from this genetic approach, it is imperative that breeds under commercial consideration be characterized for economically important traits. In the United States, rabbit producers, perhaps by tradition, maintain purebred New Zealand White stock as the meat breed of choice in commercial operations. Hence, the roles of breed selection and crossbreeding to maximize breed and heterotic contributions to performance characters have not been thoroughly investigated in rabbits. In other countries, however, economic benefits have been realized in commercial rabbit farms through the use of large sire breeds and hybrid doe stock. These benefits are the result of breed complementation and heterosis as related to increased growth potential and disease resistance in terminal-crossbred rabbits. Secondly, estimation of doe repeatability and phenotypic correlations for and among performance characters are of basic interest with respect to doe culling strategies and among trait relationships.

In two breeding experiments, evaluation of several potentially suitable breeds and crossbreds, estimation of the repeatability and computation of phenotypic correlations for and among economic production traits will be made and reported.

CHAPTER 2

GENETIC EFFECTS ON MATERNAL PERFORMANCE AND PREWEANING LITTER TRAITS IN RABBITS[1]

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Summary

Maternal performance and preweaning litter traits were evaluated during a 10-mo period for 101 litters of three divergent genetic groups: purebred Flemish Giant (FG), purebred New Zealand White (NZW) and a three-breed terminal-cross of Flemish Giant sires x Florida White-New Zealand White dams (TX). A general tendency was observed ($P < .10$) for the effects of genetic group and/or does within genetic group to influence all characters examined. For the doe traits studied, teat number was greatest while body weight at breeding age (154 d), litter interval, 21-d litter weight and 1 to 21-d feed intake were lowest ($P < .05$) for crossbred does. These traits were similar, with the exception of body weight for which FG does were heavier, between the purebred doe groups. For the preweaning litter traits studied, litter size at birth was lowest in the TX group (the purebred groups being similar) and was greatest at weaning for NZW ($P < .05$). Percentage of kits born alive was lowest ($P < .05$) in the FG group, while the NZW and TX groups were similar. Litter and average birth and weaning weights, litter daily gain and doe and litter feed intake (1 to 28 d) were all highest in FG litters and lowest in TX litters. Repeatability estimates were low (less than .05) for litter size traits and moderate to high (ranging from .18 to .58) for litter interval, litter weight at 21 d, doe feed intake and efficiency, litter growth rate and survival and doe and litter feed intake and efficiency. Litter size traits were positively asso-

ciated with litter weight traits and litter daily gain, but were negatively associated with average birth and weaning weights. Litter weaning weight was highly correlated with doe and litter feed intake and efficiency (gain/feed intake) during the preweaning period.

(Key Words: Rabbit, Maternal Performance, Repeatability, Crossbreeding.)

Introduction

The importance of maternal performance of the doe to efficiency of rabbit production is recognized by commercial producers but is not well substantiated in the scientific literature. The preparturient act of nest-building and subsequent maternal behavior (Sawin and Crary, 1953; Verga et al., 1978; Delaveau, 1979), level of fertility and litter size (Gregory, 1932; Venge, 1950; Hulot and Matheron, 1979; Partridge et al., 1981) and milk production as related to preweaning litter growth rate (Lebas, 1969; Niehaus and Kocak, 1973; Lukefahr et al., 1981) are major components that influence overall maternal performance. Reports on repeatability of maternal traits in rabbits are limited (Donal, 1973; Rouvier et al., 1973; Lampo and Van Den Broeck, 1975; Suh et al., 1978). Furthermore, the potential role of breed differences and crossbreeding systems towards improving maternal performance has not been thoroughly investigated in the United States (Gregory, 1932; Rollins and Casady, 1964). The objectives of this experiment were: (1) to examine the effects of genetic group, age of dam and month of service on doe and litter preweaning traits, (2) to compute estimates of the within genetic group repeatability of doe performance and (3) to examine residual correlations between doe and litter preweaning traits.

Materials and Methods

General. The data set consisted of 101 preweaning litter records from three genetic groups: purebred Flemish Giant (FG), purebred New Zealand White (NZW) and a three-breed terminal cross of Flemish Giant sires x Florida White-New Zealand White dams. This small crossbred dam was included to determine whether a reduction of cage space and feed intake requirements and an increase in the doe herd size would result in improved production efficiency. Crossbred does were housed in 76.2 x 61.0 x 45.7 cm cages, while NZW and FG does were housed in 76.2 x 91.4 x 45.7 cm cages. The FG (a breed raised primarily for exhibition as opposed to commercial meat production purposes) served as the terminal sire breed to produce three-breed cross (TX) offspring of comparable 56-d market weight to purebred NZW, the most popular commercial breed in the United States.

Twenty-four FG, 35 NZW and 42 TX litters were produced by 11 FG, 12 NZW and 12 crossbred does in the 10-mo period from October, 1979 to July, 1980. All rabbits were housed in an enclosed facility with exhaust fans and a continuous light source and were fed a commercial pelleted diet[4] ad libitum over the main course of the experiment. Due to manufacturer discontinuation of the first diet, a second diet[5] was used in the last 2 mo of the experiment.

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[4]Ralston Purina Co., St. Louis, MO (Purina Rabbit Checkers).

[5]Carnation Albers' Milling Co., Portland, OR (Commercial Family Ration).

Does were considered of breeding age at 154 d (standard breeding age in commercial operations) and were first exposed to bucks at that time. They were diagnosed for pregnancy by abdominal palpation 10 d following service and were provided with a nestbox containing sanitized wood shavings 18 d later if pregnancy was confirmed. A doe was immediately returned to the buck for a second service if pregnancy was not detected on d 10, and she was returned to the buck every other day thereafter until a service was observed. Following the birth of the first and all subsequent litters, does were exposed to a buck for mating 14 d post-partum, a breeding schedule more intensive than ordinarily used in commercial practice. Litters were sired by seven FG and 12 NZW bucks. To allow assessment of rearing ability of dams, fostering of rabbits between litters was not practiced. Litters were weaned at 28 d of age. Young doe replacements were added to the herd as needed throughout the course of the study.

Doe traits included weight at first breeding (154 d), teat number, litter interval, 21-d litter weight and 1 to 21-d feed intake and feed efficiency (21-d litter weight/feed intake). Litter interval was computed as the number of days between successive kindlings of the same doe. Weight of the litter at 21 d of age is considered an excellent criterion of the lactational performance of the doe due to its high association with actual 1 to 21 d milk yield (Lebas, 1969; Niehaus and Kocak, 1973; Lukefahr et al., 1981).

Preweaning litter traits included total litter size born and percentage of kits born alive, litter and average birthweight, litter and average weaning weight (adjusted for litter size), litter daily gain (weaning weight-birth weight/28 d), litter size at weaning, percentage of surviving kits and doe plus litter feed intake and feed efficiency (weaning weight-birthweight/feed intake) from birth to weaning.

Statistical Analyses. Doe weight at breeding age and teat number were subjected to least-squares analysis of variance (Harvey, 1975) using the following mathematical model and assuming that month effects were not important.

$$Y_{ij} = \mu + G_i + e_{ij}, \qquad (1)$$

where Y_{ij} = weight or teat number of the j^{th} doe of the i^{th} genetic group.

Analyses of the remaining doe and litter traits included the random effect of does within genetic group, age of dam of the litter at kindling (days) and month as additional sources of variation in the following model:

$$Y_{ijk} = \mu + G_i + D_{ij} + b_{1i}(A-\bar{A}_i)+b_{2i}(A-\bar{A}_i)^2 + b_{3i}(M-\bar{M}_i)+b_{4i}(M-\bar{M})^2 + e_{ijk}, \qquad (2)$$

where Y_{ijk} = observation of the k^{th} litter of the j^{th} doe in the i^{th} genetic group,

μ = overall least-squares mean,

G_i = effect due to the i^{th} genetic group (i=1,2,3),

D_{ij} = effect due to the j^{th} doe within the i^{th} genetic group,

A = age of dam in days at kindling,

b_{1i} and b_{2i} = partial linear and quadratic regression coefficients of Y_{ijk} on A within the i^{th} genetic group,

M = month of service of the litter,

b_{3i} and b_{4i} = partial linear and quadratic regression coefficients of Y_{ijk} on M within the i^{th} genetic group and

e_{ijk} = the random error.

Residual correlations among the performance traits were obtained from these analyses.

Genetic group comparisons were made by the Student-Newman-Keul's method following a significant overall F-test. Repeatabilities were estimated as intraclass correlations of repeated records on the same doe. Approximate standard errors of the repeatability estimates were calculated by the procedure of Swiger et al. (1964).

Results and Discussion

Analysis of Variance. Genetic group effect was an important source of variation for doe weight at breeding age and for teat number ($P < .05$). Levels of significance, coefficients of variation, residual mean squares and degrees of freedom from (model 2) analyses of variance for the remaining doe and litter characters are presented in table 1. The quadratic regression of month of service and the breed x month interaction were not significant sources of variation for any doe or preweaning litter trait, so those factors are not presented in the table. Litter interval, doe feed efficiency, litter daily gain, percentage survival rate and doe and litter feed efficiency from birth to weaning did not differ ($P > .05$) among genetic groups. Doe variation within genetic groups was not important ($P > .05$) for litter size born and weaned and litter and average birth weight.

Age of the dam was positively associated ($P < .05$) with all doe and litter characters with the exception of litter interval, percentage of kits born alive and percentage survival rate. The presence of age of dam or parity effects for litter size, weight and survival traits has previously been reported (Rouvier et al., 1973; Van Den Broeck and Lampo, 1975; Suh et al., 1978; Delaveau, 1979). A quadratic age of dam x breed interaction was observed ($P < .05$) for litter weight at 21 d, doe feed efficiency, litter weaning weight and daily gain, percentage survival rate and doe and litter feed efficiency. In general, as age increased for FG and crossbred does, performance improved, although at a declining rate for FG, but at an increasing rate for crossbred does. For NZW does, performance tended to decrease linearly as age increased. Whether these relationships are real, are a result of the limited nature of the data set or are due to some other unexplained cause cannot be ascertained. The linear month effect influenced ($P < .05$) all litter weight and efficiency traits. From autumn through to summer, litter weight and efficiency tended to decrease. Sittmann et al. (1964) reported a similar monthly trend (a decline from spring to autumn) for doe conception rate and litter size traits in rabbits also maintained in the western United States.

Genetic Group Comparisons. Overall least-squares means, genetic group means and accompanying standard errors are provided in table 2. Differences between groups are to be considered as composite genetic effects since heterotic and breed effects are partially confounded in purebred vs crossbred comparisons. Large differences were detected ($P < .05$) among genetic groups for doe weight at breeding age; FG were heaviest, NZW were intermediate and crossbred does were lightest, as expected. Crossbred does had a larger ($P < .05$) teat number than purebred does, possibly due to heterosis, while purebred doe groups did not differ significantly.

Litter interval in days was shorter (approaching significance at P=.10) in the crossbred doe group. Increased percentages of fertile matings and/or an increased probability that a doe would accept a buck at the first scheduled breeding are factors that could explain a shortened litter interval in the crossbred group. Dividing 365 d in a year by the genetic group means for litter interval, an annual rate of 6.6, 7.1 and 7.6 litters per FG, NZW and crossbred doe respectively, could be realized. This represents a 10% crossbred advantage.

Litter weight at 21 d was comparable for purebred doe groups but was lighter in the crossbred doe group ($P < .05$). Decreased milk yield and(or) litter size of the smaller crossbred does may have caused this difference. Venge (1963) found that does of small breeds (Himalayan and Polish) produced less milk per day than the medium weight breed (Blue Vienna) used in their experiment; litter size was lower in the small breeds as well. Furthermore, Cowie (1969) observed that Dutch does (a small breed) produced less milk in the first 6 wk of the lactational period than NZW does (3,820 vs 6,940 g).

Decreased feed intake was revealed ($P < .05$) for crossbred does, while no differences were found between FG and NZW does. The latter breeds were quite divergent in body weight. One reason for lack of a significant difference between FG and NZW does in feed intake may be the differences in litter size reared to weaning (7.56 vs 9.24 for FG and NZW groups, respectively). Interestingly, no genetic group differences were detected for doe feed efficiency, possibly due to feed wastage, the counterbalancing effect of increasing litter size on decreasing average individual kit weights and/or significant variation among does.

For the preweaning litter traits, litter size at birth was smallest ($P < .05$) for TX litters, while purebred groups did not differ. A positive association between ovulation rate and weight of the breed may have accounted for the above observation (Gregory, 1932; Venge, 1950; Hulot and Matheron, 1979). However, by weaning age (28 d), litter size was similar in TX and FG litters (due to a lower percentage of purebred FG kits born alive) and greatest for NZW litters. Poorer maternal ability of FG does at kindling was chiefly responsible for the lowered percentage ($P < .05$) of kits born alive to that group compared with NZW and TX litters. Litter birthweight was heaviest ($P < .05$) in FG and NZW litters and lightest in TX litters. Average birthweight/kit was heaviest ($P < .05$) for FG and similar for TX and NZW litters. Heavier average birthweights in giant breeds of rabbits have been reported previously (Venge, 1950; Carregal, 1980).

Litter weaning weights were similar for FG and NZW breeds and lightest for TX litters. The FG had heavier average weaning weights, while NZW and TX litters did not differ. Superiority in average weight at weaning for giant breeds of rabbits has also been reported by Ouhayoun and Poujardieu (1979) and Carregal (1980). No differences among genetic groups were observed ($P > .05$) for litter daily gain nor for percentage survival rate of the litter to weaning. Breed differences in survival rate during the growing period have been reported previously by Heckmann et al. (1971) and Whitney et al. (1976).

Decreased average weight gains in larger litters may have been partly responsible for failure to detect significant genetic group differences for litter daily gain. Lower feed intake of the doe and litter from birth to weaning was detected ($P < .05$) in TX litters as expected, while no differences were found between FG and NZW litters. Doe and litter feed efficiency (1 to 28 d) were similar for all three groups.

A partial advantage of the three-breed terminal-cross mating system involving the smaller crossbred does (which is not assessed in this article) is that less cage space and, therefore, higher stocking densities per unit of floor space might contribute to improved overall efficiency of rabbit production.

Repeatability Estimates. Estimates of repeatabilities for doe and preweaning litter characters are presented in table 3. Repeatability of litter interval, a summation of the gestation length (about 31 d in rabbits) and the number of days required for a fertile mating, a function of libido and conception rate, was .27. Other reports on repeatability of litter interval in rabbits are not available.

Repeatability of litter weight at 21 d, a criterion of lactational performance, was .25. Rouvier et al. (1973) reported repeatabilities for this trait of .13 and .24 in populations of NZW and Fauve de Bourgogne does, respectively.

Repeatabilities of doe feed intake and feed efficiency were .58 and .27, respectively. Other repeatability estimates on these two characters are not available for comparison.

Repeatabilities of litter size born and weaned were .05 and .02, respectively. For litter size born, the estimate is similar to the value of .06 from Suh et al. (1978), but is lower than .16 from Rouvier et al. (1973), both estimates being derived from NZW populations. Donal (1973) and Suh et al. (1978) reported repeatabilities of .20 and .09 for litter size weaned.

Repeatabilities of percentage of kits born alive and survival rate of the litter to weaning were .33 and .18, respectively. Rouvier et al. (1973) reported a repeatability of .05 for percentage of kits born dead. Lampo and Van Den Broeck (1975) reported a repeatability of .12 for percentage of kits weaned.

Repeatabilities of litter and average birth weight were .09 and .04, respectively. Because these traits were highly influenced by litter size (table 4) and since litter size is lowly repeatable, low repeatability estimates for litter and average birth weight were to be expected. Lampo and Van Den Broeck (1975) estimated the repeatability of litter birth weight to be .12.

Repeatabilities of litter weaning weight, average adjusted weaning weight and litter daily gain were .22, .41 and .25, respectively. Lampo and Van Den Broeck (1975) reported a repeatability of .18 for individual weaning weight, unadjusted for litter size.

Repeatabilities of doe and litter feed intake and efficiency (1 to 28 d) were .28 and .36, respectively. Lampo and Van Den Broeck (1975) estimated repeatability of doe and litter efficiency during the same period to be .15. This is lower than our estimate, possibly due to smaller litters reared to weaning (4.1 vs 8.0 in the present study) in the breed, the Witte van Dendermonde.

In general, doe traits were moderately to highly repeatable, litter size and birth weight traits were lowly repeatable and survival, litter growth and efficiency traits were moderately repeatable. It is recommended to commercial rabbit producers that culling could be practiced on litter interval to increase productivity, on litter weight at 21 d to improve milking ability and on average adjusted weaning weight to attain high growth potential of the progeny. Our data does not suggest that direct selection for litter size traits, as commonly is practiced in commercial rabbit herds, would be efficient from a genetic standpoint.

Residual Correlations. The residual correlations between doe weight at breeding age and teat number (8, 9 or 10) and the correlation between teat number and survival rate of the litter were low at -.02 and .14, respectively. Partridge et al. (1981) similarly found no evidence of a relationship between teat number and survival rate; although litters in that experiment apparently did not exceed eight kits, allowing at least one teat/kit. However, Kawinska et al. (1979) reported, from a population in which the number of functional teats ranged from 6 to 8, a correlation of .62 between teat number and litter size at weaning.

Residual correlations among remaining doe and preweaning litter traits, with the exception of litter interval, are presented in table 4. Litter weight at 21 d was highly related to feed intake and feed efficiency of the doe (.62 and .86) and also was moderately to highly related to litter size and other weight traits.

As number of kits born in the litter increased, percentage survival of the litter tended to decrease (r = -.40). Litter size and litter weight traits were highly positively correlated, while a large negative association existed between litter size and average weight traits ($P < .01$), as reported by Venge (1950), Rouvier et al. (1973) and Van Den Broeck and Lampo (1975). As litter size increased, feed intake and efficiency of the doe and litter also increased, which is in agreement with the findings of Van Den Broeck and Lampo (1975). A large negative association existed between percentage of kits born alive and average weaning weight; probably a result of the relationship of a decreased litter size with increased average milk intake per kit. Litter and average birth and weaning weight traits were strongly related in the expected directions.

CHAPTER 3

POSTWEANING LITTER GROWTH AND INCIDENCE OF MORTALITY OF PUREBRED FLEMISH GIANT AND NEW ZEALAND WHITE AND THREE BREED TERMINAL-CROSS RABBITS[1]

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SUMMARY

A total of 690 weanling rabbits from 86 litters and representing three genetic groups; purebred Flemish Giant, purebred New Zealand White and Flemish Giant sire x (Florida White - New Zealand White dam) terminal-cross, were evaluated for postweaning litter growth and incidence of mortality. New Zealand White litters were larger ($P < .05$) than Flemish Giant purebred and terminal-cross litters and as a consequence, had a heavier litter weight at market age. However, slightly lower average weaning and market weights were observed in New Zealand Whites compared to Flemish Giant sired groups. Flemish Giant purebreds had heavier average market weights, tended ($P < .06$) to gain weight more rapidly and incurred higher death losses due to respiratory disease ($P < .05$). Terminal-cross litters gained weight at a similar rate to New Zealand White litters ($P > .05$) and had the lowest total percentage of deaths compared to both purebred groups. Age of dam influenced litter weaning weight ($P < .05$). Month of birth influenced average market weight, average daily gain and feed efficiency ($P < .05$). Residual correlations among postweaning litter growth traits indicated a strong positive association ($P < .01$) between litter size and litter weight traits, between litter size and litter feed intake, between average daily gain and average market weight and between average daily gain and litter feed efficiency.
(Key Words: Rabbits, Postweaning Growth, Mortality, Crossbreeding.)

Introduction

Studies on postweaning litter growth and mortality rate of rabbits (Heckmann et al., 1971; Ouhayoun and Poujardieu, 1979; Carregal, 1980; Partridge et al., 1981) have demonstrated significant differences among breeds. There is, however, no documentation of studies conducted in North America involving two or more breeds and comparing postweaning litter growth and mortality rate of rabbits. The effects of utilizing and combining dam and sire breeds of varying mature body sizes on postweaning litter growth rate have also been reported (Castle, 1929; Venge, 1953; Ouhayoun and Poujardieu, 1979; Ouhayoun, 1980).

The purpose of this study was to examine genetic group effects for several postweaning litter growth and mortality traits. In addition, residual correlations among postweaning litter characters, litter size and growth traits were computed to determine the direction and magnitude of associations.

Materials and Methods

A total of 690 weanling rabbits were evaluated in litter groups for postweaning litter growth and mortality rate. In the experiment, 18 purebred Flemish Giant (FG),30 purebred New Zealand White (NZW) and 38 three-breed terminal-cross (Flemish Giant sire x Florida White - New Zealand White crossbred dam) litters were involved. The small crossbred doe was evaluated to determine whether reduced feed and cage space requirements were feasible and would allow improved production efficiency. Crossbred does were mated to FG bucks in an attempt to produce a three-breed terminal-cross (TX) rabbit of comparable weight to purebred NZW at market age.

Litters were born during a 10-mo period (November, 1979 through August, 1980) in a closed building supplied with exhaust fans and a continuous 24 h light source. Rabbits were weaned at 28 d of age and moved to growing pens (cage dimension of 91x61x46 cm) as litter groups where they remained until marketing age (56 d of age). A commercial pelleted diet[4] was fed ad libitum in standard commercial feeders to all litters; however, in the final 2 mo of the experiment, the diet was changed[5] due to the manufacturer's discontinuation of the first diet. Month-of-birth effects on postweaning litter performance in the final 2 mo of the experiment are therefore confounded with diet. No successful attempt was made to quantify feed wasted by the rabbits. Age of the dam at kindling ranged from 6 to 14 mo.

Postweaning litter traits included litter size at weaning and at marketing, litter and average weaning and market weights, the within-litter coefficient of variation for market weight (based on individual weight records), litter and average daily feed intake and gain and litter feed efficiency (gain/feed intake) from 28 to 56 d of age.

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[4]Ralston Purina Co., St. Louis, MO (Purina Rabbit Checkers).

[5]Carnation Albers' Milling Co., Portland, OR (Commercial Family Ration.

Mortality traits recorded during the postweaning period included percentages of death within a litter due to respiratory (pneumonia) and enteric diseases and total mortality percentage. The etiological factors responsible for each mortality case were not pathologically confirmed.

The data were analyzed by least-squares analysis of variance (Harvey, 1975) to partition variation in postweaning litter growth and mortality traits to differences attributable to genetic groups, age-of-dam and month-of-birth of the litter. Interactions among these main effects were assumed not to be important. Differences among means of genetic groups were tested for significance by the Student-Newman-Keul's procedure following an overall significant F-test.

Results and Discussion

Analysis of Variance. Overall least-squares means and coefficients of variation for postweaning litter growth and mortality traits are shown in table 5. The coefficients of variation for the mortality traits were high due to low means overall and to high mortality levels in some litters and no mortality in most others. The percentage levels of mortality during the postweaning period are comparable to previous reports (Rollins and Casady, 1967; Chen et al., 1978). Percentage of total deaths due to respiratory and(or) enteric disease was 66 percent. Hinton (1979) reported that these two conditions caused 49 percent of total deaths in rabbits within the first six months of life.

The effect of genetic group was significant for many characters. Litter market weight, the within-litter coefficient of variation for market weight, average feed intake, average daily gain, litter feed efficiency and percentages of enteric and total death loss were not, however, significantly affected by this source. For both litter market weight and average daily gain, differences among genetic groups approached significance ($P < .06$). Failure to detect significant genetic group differences for average feed intake and litter feed efficiency may have been caused by feed wastage.

Age of dam affected litter weaning weight ($P < .05$). Age or parity of the dam effects on litter weight traits have been reported previously (Casady et al., 1962; Rollins et al., 1963; Rouvier et al., 1973). Does that kindled at 6 mo of age generally reared the lightest weight litters to weaning age. Because age of dam effects were not important for litter size at weaning, decreased litter weaning weights in our study were probably due at least partly to lowered milk production of first parity does as previously demonstrated (Kalinowski and Rudolph, 1975; Lukefahr et al., 1981).

Month of birth affected average market weight, average daily gain and litter feed efficiency (all $P < .05$). Studies on month-of-birth or year effects on litter growth traits in rabbits are limited and inconsistent in conclusions (Casady et al., 1962; Rouvier et al., 1973; Van Den Broeck and Lampo, 1975). In the present experiment, there was no seasonal trend in incidence of respiratory deaths. Rollins and Casady (1967) observed no season-within-year, litter size, parity of the doe or fostering effects on respiratory death rate, but the year effect was significant. Furthermore, month of birth affected the level of enteric outbreaks, a higher incidence occurring during colder months (Rollins and Casady, 1967).

Comparisons among Genetic Groups. Least-squares means and standard errors for postweaning litter growth and mortality traits for the genetic groups are presented in table 6. Litter size at weaning and marketing (56 d) was largest ($P < .05$) for NZW litters, while FG and TX breed groups differed significantly at weaning but not at marketing. Frequency distributions of litter size at weaning for the three genetic groups are presented in figure 1. Litter weaning weight was greatest ($P < .05$) in NZW litters due to their larger litter size. Genetic group differences for litter market weight were observed ($P < .06$). The effects of heavier individual weights for FG sired groups counterbalanced the effect of a smaller litter size, as observed in studies involving a single breed (Van Den Broeck and Lampo, 1975; Rao et al., 1977). Average weaning and market weights were heaviest ($P < .05$) for FG purebred rabbits, with no differences between NZW and TX individuals. This is in agreement with previous reports involving comparisons of giant, medium and small breeds or crossbreds (Ouhayoun and Poujardieu, 1979; Jensen, 1980; Ouhayoun, 1980). NZW purebred litters consumed more feed than FG purebred and TX litters, although the differences were not significant. A lack of significance was observed for differences among genetic groups in average daily feed intake and litter feed efficiency. Differences in feed efficiency in favor of FG over NZW sired progeny have been reported previously (Ouhayoun and Poujardieu, 1979). Litter feed efficiency values in this study are lower (perhaps due to feed wastage) than previously reported values during the same growth period (Reddy et al., 1977; Chen et al., 1978). FG individuals tended to gain at a faster rate than NZW and TX rabbits ($P < .06$).

Respiratory death percentage was greatest ($P < .05$) in FG purebreds and was estimated to be zero in NZW and TX. In the present study, the low percentages of deaths due to respiratory and enteric deaths are comparable to an earlier report (Rollins and Casady, 1967) of 1.3 and 3.7% deaths from 15 to 56 d of age. Total death percentage tended to be lower in the TX group than in either purebred group, possibly due to heterosis.

Correlations. Residual correlations involving the postweaning litter size and growth traits are presented in table 7. Mortality traits were not included because of low overall incidence and a preponderance of litters with no mortality. Other studies, however, have reported that no significant relationship exists between litter size and mortality (Rollins and Casady, 1967; Rouvier et al., 1973; Rao et al., 1977).

As expected, a positive relationship between litter size and litter weight and a negative relationship between litter size and average individual weight at weaning and at marketing age were observed ($P < .05$). Heavier litter and average weights at weaning were associated ($P < .05$) with heavier litter and average market weights. In larger litters, total feed intake was increased; but average individual feed intake was decreased and feed efficiency was improved. No association was found between individual average daily gain and litter size. Compensatory gain in larger litters (within which individual rabbits had lower weaning weights, $r = -.34$) may have contributed to the low correlation estimate. It is concluded, therefore, that in larger litters, improved feed efficiency ($r = .33$) may be a compensatory effect. Average market weight (lighter in larger litters) is positively correlated to average feed intake, thus, indirectly influencing rate of gain.

Although fostering (equalizing litter sizes at birth) was not practiced in our experimental herd, the depressing effect of being reared in a large litter might partially have been alleviated through fostering, a common commercial practice, thereby increasing average weights, feed intake and gains while decreasing marketing age. In support of this speculation, a heavier market weight was preceded by a heavier weaning weight, increased average feed intake and increased rate of gain (all correlations $\geq .44$ and significant at $P < .05$); while no direct relationship of average market weight to feed efficiency was found. Furthermore, heavier average market weights were moderately related ($r = -.35$) to within litter variation in market weight, although this association may not be due entirely to size of the litter. A strong relationship existed between average feed intake and feed efficiency (r = -.75), while total litter feed intake and average daily gain were not related, possibly due to feed wastage and(or) lowered feed efficiency due to overconsumption. Average daily gain and litter feed efficiency were highly correlated in a desirable direction (r = .70).

Conclusions. With the genetic groups involved in this experiment, the data suggest the utilization of NZW purebred does as the maternal source and FG bucks as the terminal sire breed for improved levels of prolificacy, growth and survival. A potential advantage of mating systems involving the smaller crossbred does (which was not assessed in this study) is that less cage space and, therefore, higher stocking densities/unit of floor space might be possible. The undesirable direction of the residual correlations between litter size and average weaning and market weights warrants further investigation to devise breeding and managerial systems to increase litter uniformity, feed intake, rate of gain and average market weight and thereby to decrease marketing age.

CHAPTER 4

CARCASS AND MEAT CHARACTERISTICS OF FLEMISH GIANT AND NEW ZEALAND WHITE PUREBRED AND TERMINAL-CROSS RABBITS[1]

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Summary

Twenty Flemish Giant, 22 New Zealand White and 23 Flemish Giant x Florida White-New Zealand White, terminal-cross market rabbits were evaluated for carcass quantity and quality traits. Analyses of variance identified significant differences among genetic groups in all body measurement and carcass traits studied ($P < .05$), except carcass loin width and percentage giblets. The effects of litter size at weaning and age at slaughter likewise were significant for several carcass traits. Overall, Flemish Giant-sired progeny had more favorable body composition than New Zealand White progeny ($P < .01$). Comparison of terminal-crosses to purebred groups revealed crossbred advantages for body measurement and lean yield traits ($P < .05$). However, terminal-crosses deposited slightly more fat and were less tender than purebreds ($P < .05$). Residual correlations indicated a strong positive relationship between preslaughter weight and carcass weight and lean yield traits. Moderate to high positive correlations between body measurement and carcass weight traits also were observed. The multiple regression of cooked meat weight on body weight and body loin width at slaughter was calculated. The coefficient of determination corresponding to this linear model was .74. This study demonstrates the potential of the Flemish Giant as a terminal sire breed and the potential role of crossbred meat rabbits in the commercial sector of the rabbit industry.

(Key Words: Rabbit, Breeds, Meat Yield, Carcass Composition.)

Introduction

Commercial production of meat rabbits is a significant agricultural enterprise in the United States and in many countries throughout the world. Because of traditional meat consumption patterns, marginal economic feasibility of rabbit meat production, minimal attention by the scientific community, limited supply of rabbit meat and other factors, rabbit meat consumption per annum in the United States (13,200 metric t) is substantially lower than in other countries (Dubbell, 1975).

In the literature, there is evidence of differences in carcass characteristics among rabbit breeds and crossbreds (Rouvier, 1970; Haubold, 1974; Holdas, 1977; Ouhayoun and Poujardieu, 1979; Jensen, 1980). In addition, reports indicate that postweaning growth and carcass characteristics are moderately to highly heritable (Bogdan, 1970; Mostageer et al., 1971; Ouhayoun et al., 1973; Poujardieu et al., 1974; Valderrama de Diaz and Varela-Alvarez, 1975). Between and within-breed selection for carcass quality should therefore be an effective means to achieve improvement in the rabbit meat industry. The objectives of this experiment were: (1) to investigate the effects of breed type, litter size at weaning and age at slaughter on carcass traits of market rabbits; (2) to quantify differences in carcass traits between sire breed groups and between crossbred and purebred groups; (3) to compute residual correlations between body measurement and carcass characters, and (4) to construct an equation for predicting carcass quality from body measurement traits.

Materials and Methods

Twenty Flemish Giant (FG), 22 New Zealand White (NZW) and 23 market rabbits of a three-breed terminal-cross of Flemish Giant sires x Florida White-New Zealand White crossbred females, of both sexes and ranging in age from 57 to 64 d, were chosen at random from within six, five and eight litters for carcass appraisal. Three FG and four NZW sires were represented. FG bucks were mated to these small hybrid does to produce a three-breed terminal-cross rabbit comparable in weight to purebred NZW at market age.

All litters were fed a commercial pelleted diet[4] ad libitum, weaned at 28 d of age and moved to a growing facility as a litter group. Rabbits to be used in the carcass evaluation study were fasted for approximately 24 h before slaughter. Slaughter was conducted on 3 d within a 19-d period, with 18, 22 and 25 fryers processed on the first, second and third days. In preliminary management of the data, individual records from the first and third day were adjusted by a multiplicative factor to the appropriate breed mean on the second slaughter day, the day in which all the breed groups were present, to remove possible day effects.

Body and carcass length were measured from the first thoracic vertebra to the tuber ischiadicum (pin bones). Body and carcass loin width were measured as the lateral distance (cm) from the right to

[4] Carnation Albers' Milling Co., Portland, OR (Commercial Family Ration).

the left transverse processes of the lumbar vertebral column over the top of the mid-loin. Abdominal fat or leaf fat was removed from the abdominal cavity and kidneys. Dressing percentage was computed as total weight of the hot carcass, abdominal fat and giblets (heart, liver and kidneys), divided by the preslaughter weight, times 100.

After preslaughter and carcass weights and measurement data were collected, carcasses were split into halves with a band-saw. One side was hung at 0 C for 24 h, and the amount of shrinkage during the period was recorded as the weight difference expressed as a percentage of the prehanging weight. The other side of the carcass was steam-cooked in a plastic bag for 90 min at 66 to 68 C, and lean tissue yield was determined. Cooked meat weight and lean meat yield expressed as a percentage of preslaughter weight were multiplied by two to adjust to a whole-carcass basis. Muscle tenderness was assessed by Warner-Bratzler shear tests on 16-mm^2 samples from the mid longissimus dorsi muscle of each carcass. The amount of shear force required to cut through the muscle sample was recorded in kg/cm^2. After the 24-h chilling period, the forearm and shoulder were removed at the scapula, the uncooked meat was removed, and the chemical composition (percentages of moisture, ash, protein and ether extract) for the muscle tissue was determined by AOAC (1970) methods. Percentages of ash, protein and ether extract were expressed on a dry matter basis.

The data were analyzed by least-squares analysis of variance (Harvey, 1975) with the mathematical model:

$$Y_{ij} = \mu + \beta_i + b_{1i} (L-\overline{L}_i) + b_2(A-\overline{A}) + E_{ij}, \quad (3)$$

Y_{ij} = the observed value of a given dependent variable,

μ = the overall mean,

β_i = the fixed effect of the i^{th} breed type,

b_{1i} = the regression of Y on litter size within the i^{th} breed type,

L = the size of the litter at weaning (i.e., the number weaned),

b_2 = the regression of Y on age at slaughter,

A = the age at slaughter and

E_{ij} = the random error.

Sex was not included as an independent variable because sex records unfortunately were lost on seven individuals. For the remaining 58 rabbits, sexes were fairly equally balanced among breed type groups, so the effect of the exclusion on results should be minimal. Linear contrast comparisons were used to examine differences between sire breed groups and between crossbred and purebred groups. Breed comparisons were made by Least Significant Difference. A prediction equation was fitted by multiple regression to assess cooked meat weight from live measurement data.

Results and Discussion

The effects of breed type and of litter size at weaning (computed on both a between and a within-breed basis) were important sources of variation in carcass traits. Important breed type differences ($P < .05$) were found on all traits except carcass loin width and percentage giblets.

An increase in size of the litter at weaning (pooled regression across breed type) was associated ($P < .05$) with decreased body length, hot carcass weight and carcass measurement characters, as expected. In addition, decreased percentages of abdominal fat and cooking loss and decreased dressing percentage were observed, along with increased percentages of chill shrinkage, lean meat in the carcass and moisture, ash and protein content of the muscle ($P < .05$). The negative association between size of the litter and weight of the rabbit at 56 d of age has been reported previously (Rao et al., 1977). Fostering newborn kits to an average litter size might therefore increase average milk consumption and(or) reduce competition for feeder space. This could reduce within-litter variance and increase market and hot carcass weights and dressing percentage of the market rabbits.

The within breed type regressions on litter size at weaning were not equal for carcass length, percentage of abdominal fat, lean meat in the carcass, cooking loss and lean meat yield expressed as a percentage of preslaughter weight and muscle tenderness. Compensatory growth in larger litters from the more prolific maternal breeds involved, breed differences in maturity rate and(or) sampling error may have affected the slopes of the within-breed type regression coefficients.

Although the range in age at slaughter was small (only 7 d), this variable was positively associated ($P < .05$) with carcass loin width and cooking loss. Differences in slaughter age have been reported to affect live, dressed and organ weights, meat to bone ratio and chemical composition of meat from rabbits slaughtered at 8, 12 and 16 wk of age (Rao et al., 1977, 1978; Chen et al., 1978).

Breed type least-squares means and standard errors are presented in table 8. FG purebreds had higher ($P < .05$) preslaughter and hot carcass weights than NZW purebreds and TX, while latter groups did not differ significantly. Higher slaughter weights for market fryers of giant rabbit breeds, similar in age to fryers of medium and small breeds or breed crosses, have been reported by Dudley and Wilson (1943), Ouhayoun and Poujardieu (1979), Jensen (1980) and Ouhayoun (1980). Longer bodies and carcasses for FG purebreds also were detected ($P < .05$). This observation may be due to the large number of presacral vertebrae characteristic of the giant rabbit breeds, as reported in the literature (Stohl, 1978). NZW purebreds had shorter bodies ($P < .05$) than fryers in both FG-sired groups. TX had significantly wider loins ($P < .05$) as measured on the live rabbit (while FG and NZW purebreds did not differ), but no breed type differences were observed in carcass loin width.

Percentage abdominal fat was lower for FG purebreds and higher for TX. This may have been due to differences in maturation rate. Ouhayoun and Poujardieu (1979) and Ouhayoun (1980) reported that progeny sired by giant-sized breeds deposited less carcass and intramuscular fat than progeny sired by small-sized breeds. The Florida White, a small, early maturing breed, contributes 25% of the TX inheritance. In our study, dressing percentage was lowest ($P < .05$) for NZW purebreds. Percentage chill shrinkage (an indicator of free moisture content) was greater ($P < .05$) for TX than for the purebred groups, which did not differ.

NZW purebreds yielded less ($P < .05$) cooked meat weight and a lower percentage of lean meat, based on both carcass and preslaughter weights, and had a substantially higher ($P < .05$) cooking loss than FG-sired groups. FG-sired groups did not differ significantly from each other in any of these traits except percentage lean meat of the carcass. Percentage bone in the carcass was lowest for TX, intermediate for NZW purebreds and highest for FG purebreds ($P < .05$). This observation was particularly interesting in that the extreme breed types were both of FG paternity. A maternal genetic effect of the breed of dam for the two breed types may have influenced this trait. The meat to bone ratio was highest ($P < .05$) in the TX group. This probably was due primarily to reduced percentage of bone. Rao et al. (1978) reported similar meat to bone ratios for NZW purebreds of similar age. Muscle tenderness differed ($P < .05$) only between FG purebreds and TX, with values lower for the latter group. Muscle tissue from FG purebreds consistently yielded higher percentages of moisture, ash and protein and a lower percentage of ether extract ($P < .05$) than muscle from NZW purebreds and TX, while the latter two groups did not differ significantly. Percentages of moisture, protein and ether extract (wet-weight basis) calculated for NZW purebreds were similar to values from other reports involving the same breed (Reddy et al., 1977; Rao et al., 1978).

Comparisons of FG vs NZW sire progeny groups and of TX vs the average of FG and NZW purebreds are presented in table 9. Body and carcass length, dressing percentage, percentage chill shrinkage, cooked meat weight, percentage lean meat in carcass, meat to bone ratio, lean meat yield expressed as a percentage of preslaughter weight and percentages of moisture, ash and protein in the muscle were greater and percentages of cooking loss and ether extract in the muscle were lower, for FG-sired purebred and terminal-cross progeny ($P < .05$) than for NZW purebreds. Therefore, utilization of the FG as a terminal-sire breed in crossbreeding schemes may increase total lean carcass yield. In comparisons of TX and the average of FG and NZW purebreds, an advantage for crossbreds was found for dressing percentage and lean meat yield after cooking ($P < .05$). In addition, TX had a more compact body frame (wider loin and shorter carcass), incurred slightly greater shrinkage losses, deposited slightly more abdominal fat and had lower cooked meat tenderness ($P < .05$). Overall, these results point out the potential of combining breed strengths via crossbreeding to develop high quality rabbit carcasses.

Residual correlations between selected body measurement and carcass characters are given in table 10. Strong associations between preslaughter weight and lean meat yield and hot carcass weight and moderate to high positive relationships between body and carcass measurement characters with lean meat yield and hot carcass weight were observed. The correlations between preslaughter weight and hot carcass weight and between hot carcass weight and meat to bone ratio were .97 and .33, and were similar in magnitude to the values of .98 and .54, reported by Rouvier (1970).

An equation for predicting cooked meat weight from body weight and loin width at approximately 60 d of age was derived.

Curvilinear effects were not important, and the "best-fit" equation was:

$$\hat{Y} = -109.5 + .3180\ (X_1) + 10.14\ (X_2); \text{ and} \qquad (4)$$

$$R^2 = .74,$$

where

$\hat{Y}$ is the predicted cooked meat weight,

X_1 is body weight (g) at approximately 60 d of age and

X_2 is loin width (cm) at approximately 60 d of age.

Results of this study indicate the potential contributions of the FG as a terminal sire breed and of the development of hybrid meat rabbits to improve carcass quality and consumer acceptance.

CHAPTER 5

DOE REPRODUCTION AND PREWEANING LITTER PERFORMANCE OF STRAIGHTBRED AND CROSSBRED RABBITS[1]

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Summary

Reproductive characters (N=430 matings) of four doe genetic groups and preweaning performance of litters (N=280) were evaluated in a 15 month study. Doe genetic groups were New Zealand White (NN) and Californian (CC) straightbreds and Californian x New Zealand White (CN) and New Zealand White x Californian (NC) crossbreds. Diets provided to does and litters were either a commercial control or a 74% alfalfa ration. Sires of litters included NN, CC, and Flemish Giant (FG) straightbred bucks. The linear and quadratic regression on age of dam affected ($P < .01$) litter birth weight. The NN were superior to CC does ($P < .01$) for weight at first breeding at 154 d, litter birth and weaning weights, percentage survival of kits from birth to weaning and doe and preweaning litter feed intake and efficiency. Numbers born and reared per litter to weaning at 28 d were likewise greater for NN vs CC straightbred does. Maternal heterosis was significant for number born, litter birth and weaning weights and doe and preweaning litter feed intake. Reciprocal crossbred differences were observed ($P < .05$) for doe breeding weight, number born and weaned per litter, litter birth and weaning weights and doe and preweaning litter feed intake, favoring CN does reared by NN straightbred dams over NC does. Diet significantly affected all traits studied with the exception of doe longevity, doe fertility percentage, and doe and litter feed efficiency, in consistent favor of the 74% alfalfa ration. Percentage survival at birth was 15%

lower in litters sired by NN compared to CC bucks ($P < .05$). Fertility was higher ($P < .05$) for does mated to FG vs CC or NN bucks. Also, litters sired by FG bucks vs the average of NN and CC bucks had a higher survival percentage at birth and heavier litter birth weights ($P < .05$) and tended to have heavier weaning weights. Repeatabilities (t) of doe production were moderate ($.10 < t < .35$) for number born and weaned, litter birth weight, percentages of kit survival at birth and to weaning and doe and preweaning litter feed intake.
(Key Words: Rabbits, Breeds, Heterosis, Diet, Reproduction, Litter Growth.)

Introduction

There currently are over forty recognized breeds of rabbits in the United States (American Rabbit Breeders Association, 1981). These breeds differ markedly in pelage coloration and structure, in body size and conformation, in growth rate, in fecundity, in disease resistance and in other characteristics. Despite this available breed variation, one breed, the New Zealand White, is traditionally used as a straightbred in commercial meat rabbit production.

Studies on breed evaluation for economic traits in North America are limited (Gregory, 1932; Rollins and Casady, 1964; Lukefahr et al., 1982). Other research (Rouvier et al., 1973; Hulot and Matheron, 1979; Campos et al., 1980; Carregal, 1980; Partridge et al., 1981) on breed differences for maternal and preweaning litter traits has demonstrated the potential role of utilizing existing breed resources to maximize bioeconomic returns to the commercial rabbit enterprise.

The objectives of our study were: (1) to examine the effects of doe genetic group, diet, variation among does within groups, sire breed of litter, month of experiment and age of dam on doe and preweaning litter performance, (2) to quantify differences in performance traits among straightbred and reciprocal crossbred does, differences due to heterosis and differences due to sire breed of litter, and (3) to estimate repeatabilities for doe production traits.

Materials and Methods

Population and Management. Four doe genetic groups and two diets were cross-classified in a factorial arrangement of treatments in a 15 month study (November, 1980 to February, 1982). Three sire breeds of litters were represented in each doe genetic group x diet cell (table 11). A total of 117 does: 35 New Zealand White (NN) and 40 Californian (CC) straightbreds and 22 Californian x New Zealand White (CN) and 20 New Zealand White x Californian (NC) reciprocal crossbreds were involved. The Californian breed, raised primarily for exhibition, was included in the study because of its meat-type conformation, its limited usage in commercial rabbit production in this country and its popularity in Europe.

Does of each breed group were randomly alloted at standard breeding age (154 d) to one of two diets. The first was a commercial pelleted ration[4] that served as the control. The second diet had higher fiber and lower energy content than the control diet. It contained 74% alfalfa (IRN No. 1-00-111) and no cereal grains. The hypothesis that a lower fiber level and(or) a higher energy concentration of the diet relates to excessive microbial fermentation in the hindgut and subsequently, to diarrhea, toxicosis and death, particularly in the weanling rabbit, has been advanced (Cheeke and Patton, 1980). Protein content was appreciably lower in the commercial control diet (approx. 18.8%) than in the 74% alfalfa ration

[4]Carnation Albers' Milling Co., Portland, OR (Commercial Family Ration.)

(approx. 22.1%). Ingredient and chemical composition for both diets were presented by Harris (1982).

Three sire breeds -- NN, CC, and Flemish Giant (FG) straightbreds -- produced a total of 280 litters. Fifteen NZW, 16 CC, and 11 FG bucks were involved. Bucks of the NN and CC breeds generally weigh between 3.6 and 5.0 kg at maturity (approx. 8 mo), while FG bucks may exceed 9.1 kg at maturity (American Rabbit Breeders Association, 1981). The influences of sire breed on postweaning growth and mortality and on carcass merit were of major interest in the overall experiment. Those results will be reported elsewhere. All bucks received the commercial control diet.

The experimental population was maintained in an enclosed, environmentally-controlled building. Air intake plenums and exhaust fans were thermostatically regulated[5] at 15.6 C. Broad spectrum fluorescent bulbs were used throughout the study on a 16h:8h light-dark cycle to facilitate year-round breeding. Quonset-hut style commercial cages (dimensions of 76.2 x 76.2 x 45.7 cm) fitted with a 25.4 cm screened metal feeder housed all rabbits. The water supply was automated. Walkways were concrete and the manure pits were surfaced with a fine to coarse underlying gradient of gravel and with a drain pipe at the bottom layer. Manure was removed twice per annum.

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[5]Ventilation system and equipment were designed by Choretime Equipment, Inc., Milford, IN.

Mating first occurred at 154 d, and diagnosis of pregnancy through abdominal palpation followed 10 d later. Does diagnosed not pregnant were immediately returned to a buck for remating. The breed of each doe's first mate was chosen at random, with bucks for her second and third matings coming from the remaining two sire breeds. A doe's fourth exposure, regardless of whether a conception occurred, was again to a buck whose breed was chosen at random. Several bucks were maintained at all times for each breed. The specific buck used for mating was always the one of the appropriate breed with the greatest elapsed time since a previous mating. At 28 d of gestation, pregnant does were provided with a front-loading subterranean nest box containing sanitized wood shavings. Fostering of kits between litters was not practiced.

Doe management utilized a 14-d intensive breeding schedule following the first and subsequent parturitions, allowing for a maximum of eight litters per annum (31 d gestational length + 14 d postpartum until service x 8 matings). Approximately one-half of all does within each breed group had the opportunity to produce for one full year. Culling criteria included respiratory disease, mastitis, pododermititis (sore hocks), reproductive disorders (e.g., failure to conceive or rear a live litter to weaning in three consecutive mating exposures), intestinal and metabolic diseases and death. All marginal cases for culling were examined by a veterinarian. Young doe replacements were introduced as needed, throughout the course of the experiment, to replace does dying or culled for one of the above reasons. When a replacement was needed for a particular doe genetic group x diet subclass, she was chosen at random from young does of the appropriate genetic group available at that time. Upon weaning of the litter at 28 d of age, the dam was moved to a different cage, the rationale being that does appear to adapt better to a new cage environment than do weanling rabbits.

Litter management included a controlled, daily nursing period of approximately 4 min, although dams remained with the litter until nursing was complete, for the first 21 d of life. At 21 d, the litter was transferred from the nest box to the cage with the dam, and free access to feed and water was allowed until weaning one week later.

Performance traits collected from does were weight at first mating (154 d), longevity of production (measured only in does with a full year breeding potential) and fertility, recorded as the success (1) or failure (0) of a full-term pregnancy. Litter traits included number born (alive and dead), early survival (percentage born alive of total number born), litter birth weight, number weaned (28 d), late survival (percentage of live-born kits surviving to weaning age), litter weaning weight and doe and litter feed intake and efficiency (litter gain/feed intake) during the preweaning period. All these characteristics are of economic importance. Milk production and associative traits are discussed elsewhere (Lukefahr et al., 1983a).

Statistical Procedures. To accomplish the first objective, data were analyzed by least-squares procedures through analysis of variance (Harvey, 1975). The mathematical model for doe breeding weight included genetic group and season at first mating as potential sources of variation. Diet and genetic group x diet interaction were added sources of variation for longevity of production. The remaining doe and preweaning litter traits were subjected to the following model:

$$Y_{ijklm} = \mu + T_i + D_{ij} + S_k + (TS)_{ik} + M_l + b_1(A-\bar{A}) + b_2(A-\bar{A})^2 + E_{ijklm} \quad (5)$$

where

Y_{ijklm} = observed value of a given dependent variable,

μ = overall mean,

T_i = fixed effect of the i^{th} treatment (with seven degrees of freedom: three for doe genetic group, one for diet, and three for the interaction),

D_{ij} = random effect of the j^{th} doe within the i^{th} treatment,

S_k = fixed effect of the k^{th} sire breed,

$(TS)_{ik}$ = fixed effect due to the interaction of treatment and sire breed,

M_l = fixed effect of the l^{th} month of the experiment,

A = age of dam at kindling in days,

b_1 and b_2 = partial linear and quadratic regression coefficients of Y_{ijklm} on A and

E_{ijklm} = the random error.

Only litters in which one or more kits survived to weaning age (N=225) were included in the analysis of number weaned, litter weaning weight and doe and preweaning litter feed intake and efficiency.

To meet the second objective of the experiment, a set of orthogonal contrasts was made to quantify straightbred dam genetic group, heterosis, reciprocal crossbred, diet and sire breed effects. Each single degree of freedom contrast was tested for significance by the Student's t-test.

To meet the third objective, estimates of repeatability for doe production traits were computed as intraclass correlations of repeated records of the same doe, using variance components describing variation among and within does. Approximate standard errors of the repeatability estimates were computed according to the method of Swiger et al., (1964).

Results and Discussion

Analysis of Variance. The doe genetic group effect was significant for breeding weight at 154 d but not for longevity of production. Season of year did not influence ($P > .05$) either character. For the additional sources of variation of diet and doe genetic group x diet interaction on longevity of production, only the diet effect was important ($P < .05$).

Analyses of variance results, degrees of freedom, residual mean squares and tests of significance for the remaining doe and preweaning litter traits are presented in table 12. The source of variation for treatments, consisting of doe genetic groups, diet and the genetic group x diet interaction, significantly affected all traits with the exception of fertility percentage. Variation among does within treatments was likewise important ($P < .05$) for all performance traits, except for litter weaning weight and doe and litter feed efficiency. Percentage early survival and litter birth weight were strongly influenced ($P < .01$) and fertility percentage tended ($P < .08$) to be influenced by sire breed, the other traits not being affected to a statistically significant extent. Important sire breed effects for preweaning litter survival (Rouvier, 1973) and for individual weight traits (Carregal, 1980) have been demonstrated. Also, a treatment x sire breed interaction was detected ($P < .05$) for percentage early survival. Examination of the subclass means revealed that the interaction was primarily due to a very low average survival value of 7.6% in litters sired by NN bucks and reared by CC dams fed the commercial control diet. This group contained eight observations.

Month of the experiment influenced ($P < .05$) litter birth and weaning weights and doe and litter feed intake and efficiency through the preweaning period (table 12). However, no consistent trends were observed from plotting mean monthly values for each character. The population was maintained in an enclosed building with thermoregulated fans and a constant lighting regime (16h:8h light-dark cycle per day). This may have reduced the impact of some potential natural environmental effects.

The linear and quadratic regression effects of age of dam at kindling significantly influenced litter birth weight. The curve increased but at a decreasing rate as age of dam increased. Since the linear regression on age of dam did not affect the remaining traits, this source was deleted from the model. Some studies (Sittmann et al., 1964; Rouvier et al., 1973; Lukefahr, 1983) have reported an influence of doe age on preweaning litter traits.

Doe Genetic Group Comparisons. For doe breeding weight at 154 d, the difference of .42 kg between NN and CC does (table 13) was significant. Registration weight standards, as set by the American Rabbit Breeders Association (1981), require NN does to weigh between 4.5-5.4 kg and CC does to weigh between 3.9-4.8 kg by 8 months of age. Doe longevity was comparable for both straightbred groups during the first year of production. Heterosis for doe breeding weight and longevity was positive but small. The reciprocal difference between crossbred groups for doe breeding weight revealed a .21 kg advantage of CN does reared by NN dams (P <.05). Longevity was 93 d longer (P <.06), on average, in CN compared to NC does. Actual percentages of does completing an entire 12 months of production for the four genetic groups were 10% (NN), 9.5% (CC), 25% (CN), and 10% (NC). Reciprocal crossbred differences for both traits suggest the existence of maternal breed effects in favor of the NN group, possibly due to increased milk production of NN over CC does (Lukefahr et al., 1983a)

Doe genetic group means and selected contrasts for the remaining performance traits are provided in table 14. The difference in fertility between NN and CC does of -6.4% was not significant. Partridge et al. (1981) reported lower fertility levels of 56 and 60% for NN and CC straightbred does, although the breed ranking and difference were consistent with present results. Rouvier (1973) observed fertility levels of 63.5 and 62.9% for NN and CC does, involving a total of 550 matings.

The straightbred doe contrast for the remaining characters showed NN does to maintain an overall superiority to CC does. Large ($P<.01$) breed differences were detected for litter birth and weaning weights, percentage late survival and doe and preweaning litter feed intake and efficiency. Although not statistically significant, large breed differences were observed for number born and weaned per litter; NN does had a .86 and a 1.06 kit advantage compared to CC does. Campos et al. (1980) reported a difference of .46 kits at birth, also in favor of NN over CC does. Breed superiority of NN compared to CC does for number born and reared per litter has been demonstrated in European studies (Rouvier, 1973; Partridge et al., 1981).

Breed ranking for percentage early survival of litters (NN does had a 9.2% advantage over CC does) agrees with other reports (Campos et al., 1980; Partridge et al., 1981). Litter birth and weaning weights were heavier ($P<.01$) in litters reared by NN dams. This resulted partly from a larger litter size and partly from increased milk production (Lukefahr et al., 1983a) in the NN does. Percentage late survival was improved by 15.1% in litters of NN vs CC maternity, which confirms the results of Rouvier (1973). Straightbred NN dams plus litters consumed 2.0 kg more feed but were more efficient in converting feed to litter gain than straightbred CC dams plus litters ($P < .01$).

Maternal heterosis effects for production traits (table 14) were all positive, being significant for number born, litter birth and weaning weights and doe and preweaning litter feed intake. As a combined group, crossbred does kindled and reared larger and heavier litters to weaning (28 d) than the mean performance of straightbred doe groups, suggesting the existence of important non-additive genetic effects for these production traits. Rouvier (1973) reported maternal heterosis for litter weaning weight of 10.4%, which is similar to our estimate of 10.3%. Hulot and Matheron (1979) reported 10% heterosis for corpora lutea number involving the same maternal breeds. Their value is comparable to our estimate of 10.5% and to the estimate of 14% reported by Rollins and Casady (1964) for number of kits born per litter. Of interest, percentage fertility levels in CN and NC crossbred does were above levels found in NN and CC straightbreds as also reported by Partridge et al. (1981).

The existence of reciprocal differences between CN and NC crossbred doe groups would suggest differences in maternal characteristics between the NN and CC dams that reared the crossbred does. Reciprocal differences were significant for number born and weaned per litter, litter birth and weaning weights and doe preweaning litter feed intake, all in favor of CN does having been reared by NN straightbred dams. These results may have been a reflection of heavier body weights ($P < .05$) of CN compared to NC does (table 13). One important aspect of the maternal breed environment supplied by NN vs CC dams is the substantial difference in milking ability in favor of NN does, which is highly correlated with preweaning litter weight traits (Lukefahr et al., 1983a). Reciprocal effects for percentages of doe fertility and for early and late survival in litters and for doe and preweaning litter feed efficiency were negligible. Consistent with our results, Partridge et al. (1981) reported similar fertility levels for CN and NC crossbred does.

Diet and Doe Genetic Group x Diet Interaction Comparisons. The diet means for longevity of production in does are shown in table 13. Does fed the 74% alfalfa ration had a 50 d advantage (approaching significance at $P < .07$) in longevity during the first production year over does fed the commercial ration. Specific reasons for the difference in longevity cannot be determined, since the two diets differed in nutritive content for energy, protein, minerals and vitamins.

Diet comparisons for the remaining performance traits of does and litters are presented in table 14. Differences in favor of the 74% alfalfa diet were found for number born and weaned, percentages of early and late survival in litters, litter birth and weaning weights and doe and preweaning litter feed intake (all $P < .01$). Particularly for the litter size and growth traits, the higher protein content in the 74% alfalfa diet (22.1% vs 18.8% in the commercial diet) may have improved performance. Diet differences for percentage doe fertility and doe and preweaning litter feed efficiency were small and non-significant.

A doe genetic group x diet interaction (involved the straightbred contrast of NN-CC does) was observed for percentage late survival in litters ($P < .05$). No change occurred, however, in the ranking of breeds across diets (or vice versa).

Sire Breed and Treatment x Sire Breed Interaction Comparisons. Sire breed means and selected contrasts for performance characters are shown in table 15. Differences for all traits were small in the first sire breed contrast of NN-CC breeds, with the exception of percentage early survival in litters. Percentage early survival was 14.9% lower ($P < .05$) in litters sired by NN bucks. Rouvier (1973) reported similar breed means for preweaning survival rates per litter for NN and CC sires, mated across three doe breeds, of 80.3 and 82.5%, respectively. Previous results with respect to number weaned (Rouvier, 1973) and weaning weights (Carregal, 1980) agree with present findings in demonstrating minor differences attributable to NN vs CC sires. Based upon our results, maternal breed effects appear to be much more important than sire breed effects in influencing preweaning litter characters.

The second sire breed contrast of [FG-1/2(NN+CC)], quantifying the effect of a large vs the average of two medium weight sire breeds, showed an important ($P < .05$) influence on percentages of fertility and early survival in litters and in litter birth weight, favoring the FG breed. A larger semen volume and increased total sperm output per ejaculate of FG bucks compared to bucks of small and medium weight breeds (Frölich and Venge, 1948) may explain the 9.1% fertility advantage of FG bucks over the combined average of NN and CC bucks. However, higher fertility was not associated ($P > .05$) with a larger number of kits born per litter. Percentage early survival was greatest ($P < .05$) in FG sired litters compared to the average of NN and CC litter groups. All FG sired litters had the potential of exhibiting maximal heterosis levels for survival, being fully crossbred. Only one-quarter of litter groups sired by NN or CC bucks, however, were themselves fully crossbred. The sire breed advantage of FG bucks over the average of NN and CC bucks for percentage late survival (birth to weaning) was small at 3.5%. Rouvier (1973) reported survival rates for Géant blanc du Bouscat (a large breed), NN and CC sired litters, produced across three maternal breeds (NN, CC and Petite Russe), of 70.1, 77.9 and 75.4%, in contrast with our results for a large breed.

Litters sired by FG bucks were heavier ($P < .01$) at birth than the average of NN and CC sired litters, as expected. In a separate experiment, Lukefahr (1983) reported average individual birth weights of 66 vs 53 g for FG and NN straightbred litters. Weaning weights in litters of FG paternity were .31 kg heavier than averaged litters of NN and CC paternity, although significance was not obtained. Doe and preweaning litter feed intake and efficiency were not affected ($P > .05$) through the use of the FG sire breed. Of interest, observed differences in performance traits from the FG sire breed contrast were all positive, indicating a consistent desirable trend associated with using the FG as a terminal sire breed.

Sire breed x treatment interactions (where treatments represented doe genetic group x diet subgroups) were observed ($P < .05$) for percentage early survival, litter birth and weaning weights and number weaned per litter. However, of the 156 total possible interactions computed from the data set for all characters studied, only 7 (<5%) single degree of freedom interaction contrasts were detected as being significant. Thus, the biological and economic importance of these interactions is open to question.

Repeatability Estimates. Estimates of repeatability for doe production traits are presented in table 16. Repeatability of fertility, recorded as the success (1) or failure (0) of a mating to result in a full-term pregnancy, was .09. Other reports on repeatability of fertility in rabbits are not available.

Repeatability of total number born per litter was .26. Rouvier et al. (1973) and Suh et al. (1978) reported repeatabilities of .16 and .06, both from NN populations. Lukefahr (1983) reported a pooled estimate of repeatability for total number born of .05, obtained from FG and NN straightbred and Florida White x New Zealand White crossbred does. Rouvier et al. (1973) obtained a repeatability estimate of .32 for the same character from a Fauve de Bourgogne population.

Repeatabilities of early and late survival (percentage kits alive at birth and percentage weaned of live-born progeny) were .16 and .22. Lukefahr (1983) presented repeatabilities of .33 for percentage early survival and .18 for percentage late survival. Rouvier et al. (1973) estimated repeatabilities of percentage live-born kits at birth to be .05 and .21 from two distinct straightbred populations. Lampo and Van den Broeck (1975) reported repeatability for percentage kits weaned to be .12, as obtained from a Witte van Dendermonde population.

Repeatabilities of litter birth and weaning weights were .33 and .07. Lampo and Van den Broeck (1975) estimated repeatability of litter birth weight to be .12. Other estimates of repeatability for litter birth and weaning weights of .09 and .22 were reported by Lukefahr (1983).

Repeatability of number weaned per litter was estimated at .23. Donal (1973), Suh et al., (1978), and Lukefahr (1983) reported repeatabilities of .20, .09, and .02 for number weaned.

Repeatabilities of doe and litter feed intake and efficiency through the preweaning period were .19 and .05. For doe and litter feed intake during the same growth period, Lampo and Van den Broeck (1975) and Lukefahr (1983) reported repeatabilities of .15 and .28, respectively. A higher estimate of repeatability for doe and litter feed efficiency of .36 was obtained by Lukefahr (1983).

In general, low to moderate levels of repeatability for all characters investigated were observed. Therefore, culling of does based on a single production record would not be advised. Number of kits weaned per litter (at 28 d) should be a practical trait on which to base culling strategies of does of similar genetic background, to improve mean herd productivity.

CHAPTER 6

CHARACTERIZATION OF STRAIGHTBRED AND CROSSBRED RABBITS FOR MILK PRODUCTION AND ASSOCIATIVE TRAITS[1]

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Summary

Two-hundred-twenty-five lactation and litter performance records from eighty-two does representing four genetic groups and two diet regimes were analyzed to quantify breed, heterosis, reciprocal F1 cross and diet effects for milk production and associative traits. Doe genetic groups were New Zealand White (NN) and Californian (CC) straightbreds and Californian x New Zealand White (CN) and New Zealand White x Californian (NC) reciprocal crossbreds. Pelleted diets fed to does and litters were either a commercial control or a 74% alfalfa ration. Three sire breeds of litters included NN, CC and Flemish Giant (FG) straightbreds. Doe genetic group and diet were important sources of variation ($P < .05$) for all traits examined except for litter milk efficiency (litter gain/milk intake) and doe feed efficiency (milk yield/feed intake). The sire breed of litter effect did not influence ($P > .05$) lactational performance of does nor associative preweaning traits. Straightbred NN does were heavier at kindling, yielded more milk, reared a heavier litter by 21 d and were more efficient in converting feed into milk than were straightbred CC does ($P < .01$). Significant heterosis was detected for milk production and for litter size and weight at 21 d. Reciprocal differences between crossbred doe groups were observed ($P < .05$) for litter milk efficiency and doe feed intake. The 74% alfalfa ration was superior to the commercial control diet for effects on milk production and

litter size and weight at 21 d, although doe feed intake was increased. Significant estimates of doe repeatability were obtained for litter size at 21 d, doe feed intake and efficiency and doe weight at kindling. Separate breed group estimates of repeatability for milk production were -.04, .47, .55 and .46 for NN, CC, CN and NC does. Residual correlations revealed that both litter size and weight traits at birth and at 21 d were related (correlations ranging from .48 to .99) to milk production of the dam. Furthermore, litter weight at 21 d was an excellent predictor (r = .99) of the dams' milk production from kindling to 21 d of age of the litter. Doe weight at kindling was lowly related (r = .10) while doe feed intake and efficiency were highly related (correlations of .63 and .81) to milk production.

(Key Words: Rabbits, Breeds, Heterosis, Diet, Lactation, Litter Growth).

Introduction

In the rabbit, early litter growth and survival are dependent in part on the intrinsic ability of the dam to provide an adequate maternal environment. One major postnatal maternal trait is milk production. Studies demonstrating the strong influence of milk yield of the doe on preweaning growth rate of the litter have been reported (Lebas, 1969; de Blas and Galvez, 1973; Niehaus and Kocak, 1973).

Venge (1963) reported differences in milk production among dam breeds divergent in adult body weight. Breed differences have also been reported by Cowie (1969), who found New Zealand White does to surpass Dutch does in total milk production over a 6 wk period. Selection of existing dam breeds for milk production and for reproductive traits could be a feasible approach to increase production in the commercial meat rabbit industry. Another potential genetic approach would be to develop crossbred doe stock to utilize possible maternal heterosis for reproductive characters and for milk production.

The objectives of the present experiment were (1) to examine the effects of diet, month of experiment and age of dam on milk production and associative traits; (2) to quantify differences among straightbred and reciprocal crossbred does, differences due to heterosis and differences among sire breeds of litters in milk production and associative traits; (3) to estimate repeatabilities for milk production and associative traits and (4) to examine residual correlations among milk production and associative traits.

Materials and Methods

The 15 mo experiment (November, 1980 to February, 1982) involved litters representing four doe genetic groups, two diet regimes and three sire breeds. Doe genetic groups were New Zealand White (NN) and Californian (CC) straightbreds and Californian x New Zealand White (CN) and New Zealand White x Californian (NC) reciprocal crossbreds. The NN is the predominant meat breed used for commercial meat rabbit production in the United States, while the CC (a meat-type breed) is primarily raised for exhibition purposes. At a standard age at first breeding of 154 d, each doe was randomly assigned to one of the two diet regimes. Does were remated 14-d post-partum following the first and subsequent parturitions, allowing for a maximum of eight litters per annum. Pelleted diets compared in the study were a commercial control[4] and a 74% alfalfa ration. The rationale for the 74% alfalfa diet was discussed by Lukefahr et al. (1983b). These diets differed in most nutritive aspects, e.g. protein level and energy concentration. Ingredients and chemical composition for both diets were presented by Harris (1982). Sire breeds of litters were straightbred NN, CC and Flemish Giant (FG). The first two breeds are of medium mature weight, while the FG is a

[4] Carnation Albers' Milling Co., Portland, OR (Commercial Family Ration).

breed with large mature size (American Rabbit Breeders Association, 1981). In the preceding paper (Lukefahr et al., 1983b), population management and housing were discussed in detail.

The data set consisted of 225 doe records, collected from day of kindling (parturition) to 21 d of age of the litter, for the following characters: total milk production (1-21 d), litter 21 d weight, litter milk efficiency (to be defined), litter size at 21 d (number of young), doe weight at kindling and doe feed intake and efficiency (to be defined). A total of 1728 young surviving to day 21 were involved. Milk production was estimated daily from 1-21 days of age of the litter using the weigh-suckle-weigh method. Unlike other mammalian livestock species, the normal nursing behavior of the rabbit involves a single daily nursing period (Venge, 1963; Zarrow et al., 1965). Therefore, the experimental nursing method was consistent with the natural one in regards to suckling frequency. Access of the doe to the litter for nursing was controlled by opening a gate that otherwise separated the nest box from the doe cage. Nursing generally lasted only 3-4 min and ended abruptly when the doe vacated the nest box. Litters subsisted solely on milk until day 21 when they were removed from the nest box and placed in the doe cage.

Litter milk efficiency was calculated as the ratio of litter gain (litter 21 d weight-litter birth weight) to total milk intake from 1-21 d. Doe feed intake was recorded from 1-21 d, and doe feed efficiency was calculated as the ratio of total milk production to doe feed intake.

Data were analyzed by least-squares analysis of variance (Harvey, 1975) according to the following mathematical model:

$$Y_{ijklm} = \mu + T_i + D_{ij} + S_k + (TS)_{ik} + M_l + b_1(A-\bar{A}) + b_2(A-\bar{A})^2 + E_{ijklm} \quad (6)$$

where

Y_{ijklm} = observed value of a given dependent variable,

μ = overall mean,

T_i = fixed effect of the i^{th} treatment (with seven degrees of freedom: three for doe genetic group, one for diet and three for the interaction),

D_{ij} = random effect of the j^{th} doe within the i^{th} treatment,

S_k = fixed effect of the k^{th} sire breed,

$(TS)_{ik}$ = fixed effect due to the interaction of treatment and sire breed,

M_l = fixed effect of the l^{th} month of the experiment,

A = age of dam at kindling in days,

b_1 and b_2 = partial linear and quadratic regression coefficients of Y_{ijklm} on A and

E_{ijklm} = the random error.

A selected set of orthogonal linear contrasts was made to evaluate straightbred doe breed, heterosis, reciprocal crossbred, diet and sire breed of litter effects for milk production and associative traits. Tests of significance were made for each single degree of freedom contrast by the Student's t-test.

Repeatabilities for milk production and associative traits were estimated as the intraclass correlation between repeated records of the same doe, using among and within doe variance components obtained from analyses of variance, as described in equation 6. Approximate standard errors of the repeatability estimate were calculated according to the procedure of Swiger et al. (1964). Residual correlations were obtained from least-squares analyses of variance results.

Results and Discussion

Analysis of Variance. The analyses of variance results, degrees of freedom, residual mean squares and tests of significance for milk production and associative traits are presented in table 17. The treatment effect, consisting of doe genetic group, diet and the genetic group x diet interaction sources of variation, was important ($P < .01$) for milk production, litter size and weight at 21 d, doe weight at kindling and doe feed intake. Significant variation among does within genetic groups was detected for litter size at 21 d, doe weight at kindling and doe feed intake and efficiency. The sire breed and the treatment x sire breed interaction sources of variation did not influence any performance traits ($P > .05$), so these sources were deleted from table 17. The month of experiment effect was significant for litter size at 21 d, doe kindling weight and doe feed intake. However, upon examination of the monthly least-squares means, no pattern was observed. The interpretation of the month effect is therefore open to question. The age of dam linear regression effect was significant for doe feed efficiency (negative slope), while the linear and quadratic regression effects were significant for doe feed intake. For doe feed intake, the curve increased but at a decreasing rate as doe age advanced.

Doe Genetic Group and Diet Comparisons. Least-squares genetic group and diet means and selected contrasts for milk production and associative traits are shown in table 18. Straightbred NN does were superior ($P < .01$) to CC does for milk production (3.97 vs 3.06 kg). Bartelli and Altomonte (1968), using litter 21 d weight as a reflection of milk production, similarly reported NN does to exceed CC does in milking ability. In our experiment, NN does were heavier than CC does, a significant difference of .54 kg, which could have caused the greater milk production. Venge (1963) and Cowie (1969) reported that milk production level closely paralleled mature doe weights across breeds.

In the present study,21 d litter weights corresponded with the genetic group rankings for milk production. Litter milk efficiency (litter gain/milk intake) was slightly improved in litters reared by NN vs CC dams, although the difference was not significant. Cowie (1969) reported litter milk efficiency values of .45 and .38 for NN and Dutch (a small breed) straightbreds, from days 9 to 31 of lactation. Although moderate breed differences between NN and CC does were shown for litter size at 21 d and for doe feed intake (NN does having the larger means), significance was not detected. The NN doe breed was more efficient ($P < .01$) compared to the CC doe breed in converting feed into milk during the three week post-partum period.

Positive heterosis was observed ($P < .05$) for milk production and litter size and weight at 21 d of age. Although heterosis for milk production has been found in several laboratory and livestock species, studies involving rabbits are not available for comparison. Heterosis for litter milk efficiency, doe weight at kindling and doe feed intake and efficiency was small ($P > .05$).

Reciprocal differences existed for milk production, litter milk efficiency, litter size at 21 d (all $P < .08$) and doe feed intake ($P < .05$). Greater milk production, a larger litter size and an increase in feed consumption of CN does reared by NN dams were observed, compared to NC does reared by CC dams. Thus, important maternal breed effects may exist for the above characters. Litters from NC vs CN does were more efficient ($P < .05$) in converting milk to weight gain. Reciprocal differences were not significant for litter 21 d weight, doe weight at kindling or doe feed efficiency.

From a separate analysis, least-squares means, according to week of lactation, for milk production of straightbred and crossbred doe groups are presented in figure 2. The NN does produced more milk than CC does over the entire three week period. Also, milk yield increased between weeks 2 and 3 for NN does but decreased for the CC straightbreds. The figure also illustrates direct heterosis and maternal breed effects for milk production. Doe groups of NN maternity surpassed does of CC maternity and, within maternal breed group, were remarkably similar in slope of lactation through the three week post-partum period. In the study of Lebas (1969), involving 143 lactation records of does from the Fauve de Bourgogne breed, the lactation curve of the rabbit was shown to be fairly asymetric over a 1-42 d post-partum period. The peak of the lactation curve occurred at approximately 19 d (240 g), followed by a sharp decline to day 42.

Does receiving the 74% alfalfa ration produced more milk and reared larger and heavier litters by day 21. Doe feed intake, however, was increased ($P < .01$). The higher protein content in the 74% alfalfa ration (22.1 vs 18.8% in the control diet) may explain the above trend. However, since diets also differed in content of other nutrients (e.g. energy concentration and/or fiber level), specific dietary effects on performance cannot be explained. Conversion of feed to milk production was nearly identical for each diet, even though does fed the 74% alfalfa ration consumed more feed. A greater lactational demand due to rearing a larger litter and the lower caloric density (Harris, 1982) of the 74% alfalfa ration may have stimulated greater appetite of does on that diet. Litter milk efficiency and doe weight at kindling were not influenced ($P > .05$) by diet.

Single degree of freedom contrasts for doe genetic group x diet interactions, for sire breed of litter effects (involving the comparisons between litters sired by NN vs CC medium weight breeds and the comparison between litters sired by the large FG breed vs the combined average of NN and CC medium weight breeds) and for all possible remaining two and three factor interactions were never found to be significant. Sire breed of litter differences in fetal secretions of placental lactogen (a mammogenic hormone) and in suckling intensity as possibly related to milk production of the dam thus appear to play a small overall role in preweaning growth rate and survival, as compared to maternal genetic effects previously discussed.

Repeatabilities. Estimates of repeatability, pooled across doe genetic groups, for milk production and associative traits are presented in table 19. Repeatability of milk production was estimated to be -.02. This may reflect the presence of a negative environmental covariance between adjacent records of the same doe. However, separate genetic group estimates for repeatability of milk production of -.04, .47, .55 and .46 for NN, CC, CN and NC does indicated that the negative environmental component, if real, was breed specific. A possible explanation for the negative repeatability in NN does is an increased lactational stress associated with the intensive 14 d breeding schedule in does with an otherwise above-average lactational capacity.

Repeatabilities of litter 21 d weight and litter milk efficiency, traits closely related to milk production, were estimated to be -.03 and -.19. In a separate experiment involving FG and NN straightbreds and Florida White x NN crossbred does, Lukefahr (1983) reported a pooled repeatability estimate of .25 for litter 21 d weight. Rouvier et al. (1973) found repeatabilities for the same trait to be .13 and .24 in NN and Fauve de Bourgogne doe populations.

Repeatability of litter size at 21 d was estimated to be .23, consistent with repeatability estimates of .13 and .25 reported by Rouvier et al. (1973).

Repeatabilities for doe weight at kindling, doe feed intake and doe feed efficiency were estimated to be .72, .27 and .17, respectively. The high repeatability for doe weight at kindling may be indicative of considerable additive genetic variation for the character. Lukefahr (1983) obtained a larger estimate of repeatability for doe feed intake of .58, while a more comparable estimate of .27 was found for doe feed efficiency.

Residual Correlations. In table 20, residual correlations among milk production and associative traits are presented. Included in the table are total number born and litter birth weight, traits analyzed in a previous paper (Lukefahr et al., 1983b). The neonatal traits, total number born and litter birth weight, were associated with milk production. Since litters were not standardized at kindling to a common litter size, the observed correlations of .48 between total number born and milk production and .64 between litter birth weight and milk production may reflect both prenatal and postnatal litter effects on lactational performance of the dam. Markoff and Talamantes (1981) demonstrated that in the mouse, fetal placental lactogen levels were highly associated (r = .73) with fetal number. In crossfostering studies in which litter size was standardized, Skjervold (1977) and Nagai (1978) observed positive relationships between litter size at birth and milk yield in mice, whereas no such relationship was reported to exist in mice by Eisen et al. (1980) nor in swine by Lewis et al. (1978). Therefore, the association involving fetal number and placental lactogen on increasing lactational output by the dam is not firmly established in litter bearing species. In addition, the postnatal effects of a larger litter size may evoke greater tactile stimulation of the teats and indirectly enhance milk secretion through increased prolactin release. Also, increased suckling intensity in larger litters may allow more complete evacuation of residual milk, through greater oxytocin release due to increased afferent nerve stimulation of the teats. Effects of prolactin and oxytocin administration on increased milk synthesis and mammary epithelium permeability at various stages of lactation have been demonstrated in the rabbit (Cowie, 1969; Linzell et al., 1972).

Litter 21 d weight was shown to be an excellent criterion of the lactational performance of the doe, based on the correlation coefficient of .99. Consistent with our estimate, correlations of .90 (Lebas, 1969), .91 (de Blas and Galvez, 1973) and .93 (Niehaus and Kocak, 1973) have been documented. Since litter 21 d weight and litter size at 21 d are also correlated (r = .80), path coefficient analysis (Li, 1975) was used to determine the percentages of variation in litter 21 d weight attributable to the direct effects of milk production and of litter size at 21 d and to their joint effect. Results indicated that 88.9, 0.5 and 10.5% of explained variation in litter 21 d weight were due to the above effects. Therefore, milk production level of the dam was the chief determinant of litter 21 d weight rather than litter size at 21 d or the interaction. It should, however, be acknowledged that the milk production level and/or nursing behavior of the dam could well influence the suckling behavior of the litter.

Improved efficiency in conversion of milk to body gains in litters consuming more milk was observed (r = .52), although a part-whole relationship is involved. Despite the clear among-breed relationship between body weight and milk production (table 18), on a within-breed basis the relationship is less marked. Doe weight at kindling was lowly correlated (r = .10) with milk production, which is in agreement with the correlation of .18 reported by Niehaus and Kocak (1973) involving does of the CC breed. Nagai (1978) reported moderate correlations ($.18 < r < .27$) between dam body weight and 12 d litter weight (an indicator of milk yield) in four lines of mice, in which standardization at birth to eight pups per litter was practiced. Reduced variation in litter weights, attributable to standardizing the litter size, may have resulted in the higher correlations as mentioned above. In another mouse crossfostering experiment, Nagai and Sarkar (1978) obtained a pooled within-line correlation coefficient of .32 between metabolic body weight of the dam and milk yield.

A greater lactational output in does was associated (r = .63) with an increase in feed intake. However, the exact biological cause and effect relationship, i.e. increased feed intake influencing milk yield or vice versa, cannot be determined based on present results. Within each crossfostering set, Nagai and Sarkar (1978) transferred litters at birth between four lines of mice, so that each female reared two pups of her own plus two pups from each of the other three lines. Between-line genetic differences in litter size and suckling intensity were therefore minimized due to their crossfostering procedure. From their study, the correlation coefficient between milk production and feed intake of the dam from 1-12 d was .44. This result suggests that factors other than litter size and suckling intensity influenced the lactational output and hence feed intake. Acknowledging the part-whole relationship between milk production and doe feed efficiency (milk production/feed intake), does that produced more milk were likewise more feed efficient (r = .81).

CHAPTER 7

BREED, HETEROTIC AND DIET EFFECTS ON POSTWEANING LITTER GROWTH AND MORTALITY IN RABBITS[1]

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Summary

The effects of sire breed, dam genetic group and diet on post-weaning litter growth and mortality were evaluated in 208 litters of rabbits. Sire breeds were New Zealand White (NN), Californian (CC) and Flemish Giant (FG). Dam genetic groups were NN and CC straightbred and Californian x New Zealand White (CN) and New Zealand White x Californian (NC) reciprocal crossbreds. Litters were fed either a commercial diet or a 74% alfalfa ration. Litter size and weight at 56 d and litter gain (the difference between 56 and 28 d litter weights) tended to be lower in NN compared to CC sired litters; while feed intake was significantly lower and mortality was higher in progeny of NN sires. Litter 56 d weight, litter gain and litter feed efficiency (gain/feed intake) were improved ($P < .05$) in litters sired by FG vs NN or CC bucks. Direct heterosis (CN and NC compared to NN and CC litters) for litter size, growth and feed-related traits was generally low (< 11% in absolute value), while moderate heterosis levels (-21 and -22%) were observed for diarrheal-related and total mortality. Differences between NN and CC straightbred dams for litter size and weight at 56 d and litter gain were small but in favor of NN dams. Diarrheal-related and total mortality were higher ($P < .05$) in litters reared by NN vs CC straightbred dams. Significant maternal heterosis was found for litter feed intake and efficiency (feed intake was increased and feed efficiency was poorer) and total mortality (difference of 5.5% and in favor of litters from

straightbred dams) in litters. Litter size at 56 d was 1.29 rabbits larger in litters reared by CN vs NC crossbred dams; hence, litter 56 d weight, litter gain and feed efficiency were improved ($P < .05$). In addition, total mortality was reduced by 6.1% in litters of CN vs NC maternity. Litters fed the 74% alfalfa diet had larger litter size at 56 d and feed intake was increased compared to litters fed the commercial diet ($P < .05$). Mortality from diarrhea was higher on the 74% alfalfa diet ($P < .05$). Residual correlations revealed that in larger litters (more rabbits per litter), weight at 56 d, gain, feed intake and feed efficiency were improved. Weak relationships were observed between within-litter uniformity (coefficient of variation among litter mates for 56 d weight) and all other traits. Experimental results suggest the utilization of FG bucks and CN crossbred does to improve postweaning litter growth and feeding performance in meat rabbits.
(Key Words: Rabbits, Breeds, Heterosis, Diets, Growth, Mortality.)

Introduction

The roles of breed selection and(or) crossbreeding and nutrition on postweaning litter growth and mortality are less established in rabbits than in other livestock species. Studies (Heckmann and Mehner, 1970; Heckmann et al., 1971; Carregal, 1980; Lukefahr, 1983) demonstrating breed differences for postweaning traits have been documented. Secondly, the use of large terminal sire breeds has been shown to increase postweaning gains (Heckmann and Mehner, 1970; Heckmann et al., 1971; Ouhayoun, 1978; Carregal, 1980).

The objectives of this study were to examine the effects of additive breed, maternal breed, direct and maternal heterosis and diet source on postweaning growth and mortality in litters involving large and medium weight sire breeds and straightbred and crossbred dam genetic groups. A second objective was to determine, through computation of residual correlations, the associations among various postweaning litter traits.

Materials and Methods

Postweaning performance records of 208 litters (N = 1,479 rabbits) representing three sire breeds, four dam genetic groups and two diet sources were collected throughout a 15 mo study (November, 1980 to February, 1982). Sire breeds evaluated in the study were New Zealand White (NN), Californian (CC) and Flemish Giant (FG). Dam genetic groups were NN and CC straightbreds and Californian x New

Zealand White (CN) and New Zealand White x Californian (NC) reciprocal crossbreds. Two pelleted diets, a commercial control diet[4] and a 74% alfalfa (IRN no. 1-00-111) diet, were fed to litter groups throughout the duration of the experiment. The 74% alfalfa diet, which contained no cereal grains, had higher fiber and lower energy levels (2527 vs 2605 kcal/kg of digestible energy) than the control diet. The rationale for developing the bulkier diet was to limit the amount of soluble carbohydrates reaching the hindgut and thereby to prevent excessive microbial fermentation, diarrhea, toxicosis and subsequent death in weanling rabbits, according to the carbohydrate-overload hypothesis of Cheeke and Patton (1980). In addition, the crude protein content was higher in the 74% alfalfa diet (22.1 vs 18.8%) than in the control diet. Chemical and ingredient composition for both diets were presented by Harris (1982).

Management and housing of the experimental population and genetic and environmental effects on doe reproduction and preweaning litter traits were presented by Lukefahr et al. (1983a,b). Postweaning litter management consisted of an early weaning schedule (28 d) with litters remaining as a group in the same cage through the ensuing 4 wk postweaning growth phase. Since dams of litters were originally allocated at random to the two diet sources at breeding age (154 d), all litters produced by a given dam received the same diet, fed ad libitum, through the preweaning and postweaning periods.

[4]Carnation Albers' Milling Co., Portland, OR (Commercial Family Ration).

Postweaning litter traits included litter size and weight at 56 d of age, within-litter uniformity (the coefficient of variation for individual 56 d weights of rabbits belonging to the same litter), litter gain (the difference between 56 and 28 d litter weights), litter feed intake from 28 to 56 d and litter feed efficiency (gain/feed intake). In addition, mortality traits recorded between 28 and 56 d of age in litters were diarrheal-related deaths (number of rabbits found dead with symptoms of diarrhea divided by total number weaned in the litter) and total deaths. Enteric diseases included enterotoxemia, mucoid enteritis and hemorrhagic cecitis, as diagnosed in rabbits submitted for post-mortem examination following a diarrheal-related death. Other less-prevalent causes of mortality were heat stroke, malnutrition, pasteurellosis, physical injury, pneumonia and unknown.

Data were subjected to least-squares analysis of variance (Harvey, 1975), according to the following mathematical model:

$$Y_{ijklmn} = \mu + S_i + G_j + (SG)_{ij} + D_k + (SD)_{ik} + (GD)_{jk} + P_l + Se_m + (DSe)_{km} + E_{ijklmn} \qquad (7)$$

where

Y_{ijklmn} = observation on the n^{th} litter born in the m^{th} season from the l^{th} parity class of the k^{th} diet source of the j^{th} dam genetic group and the i^{th} sire breed, and where

μ = overall mean,

S_i = effect of the i^{th} sire breed (i=1,2,3),

G_j = effect of the j^{th} dam genetic group (j=1,2,3,4),

$(SG)_{ij}$ = effect due to the interaction of sire breed and dam genetic group,

D_k = effect of the k^{th} diet source (k=1,2),

$(SD)_{ik}$ = effect due to the interaction of sire breed and diet source,

$(GD)_{jk}$ = effect due to the interaction of dam genetic group and diet source,

P_l = effect of the l^{th} parity class (l=1,2,3,4) where the first through fourth classes included first, second, third and fourth and fifth through eighth parities, respectively,

Se_m = effect of the m^{th} season of birth of the experiment (m=1,2,...5), where each season included three consecutive months,

$(DSe)_{km}$ = effect due to the interaction of diet source and season of birth and

E_{ijklmn} = random error.

All of the above effects were assumed to be fixed with the exception of the random error term. In preliminary analyses of the data, the dam genetic group x parity class and the diet source x parity class interaction effects were found to be negligible, so these sources were not included in the above model. Other two and three factor interactions were assumed not to be important. In the analysis of within-litter uniformity, six records were eliminated from the data set since a coefficient of variation for individual 56 d weights did not exist in those litters which contained a single surviving rabbit. Residual correlations among postweaning growth and feed-related traits were obtained from the same analyses.

To quantify differences according to sire breed and dam genetic group of litters and diet, orthogonal linear contrasts were made. Specific estimations of additive breed, maternal breed and direct and maternal heterotic effects were derived through these contrasts. Each single degree of freedom contrast was tested for significance by the Student's t-test.

Results and Discussion

Analysis of Variance. Sire breed or dam genetic group significantly affected all postweaning litter traits with the exception of within-litter uniformity. Diet source was important ($P < .05$) for litter size at 56 d, litter feed intake and mortality from diarrhea. Some of the breed and diet influences could be carry-over effects of those same sources on preweaning litter performance. Interactions involving sire breed and dam genetic group of litters with diet source were never important ($P > .05$).

Parity class of dam influenced ($P < .05$) litter 56 d weight, litter feed intake and efficiency and diarrheal-related and total mortality. In general, growth and feed intake were greater and mortality incidence was lower in litters from dams of the third parity class (third or fourth litters), which is identical to results of

Rouvier et al. (1973) from an experiment involving 5,942 litters. Important parity and(or) age of dam effects on litter size and weight at 56 d have previously been reported (Rollins et al., 1963). Rollins and Casady (1967), however, demonstrated no association between parity of dam and diarrheal and pneumonia related mortality of progeny from 15 to 56 d of age. However, weaning of litters at 56 d of age was practiced in their study. This may have eliminated the stress associated with earlier weaning (as in the present study), as it possibly relates to disease during the immediate postweaning phase.

Season of birth influenced ($P < .05$) all postweaning litter traits, except for within-litter uniformity. Disease incidence tended to increase as the experiment progressed. Since the study was initiated in a new facility, a cumulative rise in pathogen levels with time could have accounted for this trend. A higher mortality rate, within litters, could automatically result in decreased litter growth and feed intake.

A diet source x season of birth interaction was detected ($P<.05$) for litter feed intake. Due to poor pellet quality of the 74% alfalfa diet, litter feed intake and wastage were unreasonably high in the first two seasons of the experiment.

Breed and Heterotic Effects. Overall means, sire breed means and selected contrasts, direct heterotic contrasts, tests of significance, residual mean squares and degrees of freedom for postweaning litter traits are provided in tables 21 and 22. The first sire breed contrasts comparing litters of NN vs CC paternity revealed a .9 rabbit advantge in litter size at 56 d in litters sired by CC bucks (table 21). Hence, litter 56 d weights and litter gains were improved and feed intake was increased in CC-sired litters. On an individual rabbit basis, similar postweaning gains for NN and CC straightbreds have been reported by Heckmann et al. (1971) and Carregal (1980). Since litter size at 28 d was comparable for both sire-breed litter groups, our finding is the result of a higher mortality rate in NN sired litters (table 22). Small sire breed differences existed for diarrheal-related and total mortality, in favor of CC vs NN sired litters. Other breed comparison studies (Heckmann and Mehner, 1970; Heckmann et al., 1971; Whitney et al., 1976) have reported higher postweaning mortality in NN straightbred rabbits. Litter feed efficiency was similar for CC and NN groups.

The second sire breed contrasts of [FG - 1/2(NN+CC)] quantifies differences in litter traits between a large breed and the average of two medium weight sire breeds. Litter 56 d weight was heavier, litter gain was improved and feed efficiency was improved in litters of FG vs NN and CC paternity ($P < .05$). More rapid individual postweaning gains of progeny of large vs medium weight sire breeds is well established in the scientific literature (Heckmann and Mehner, 1970; Heckmann et al., 1971; Ouhayoun, 1978; Carregal, 1980). Also consistent with present findings, Heckmann et al. (1971) reported lower feed to gain values of Light Great Silver (a large breed) compared to NN and CC straightbreds. Incidence of diarrheal-related deaths was similar but total deaths were 3% lower in litters sired by FG vs NN and CC bucks (table 22). This observation, however, could be due to direct heterosis, as well as to additive breed effects, since all FG sired litters were fully crossbred. Alternatively, only one-quarter of litter groups sired by NN or CC bucks were themselves fully crossbred. In a separate study, Lukefahr (1983) observed total mortality levels of 5.9 and 8.3% in FG-sired crossbreds and NN straightbreds, while FG straightbreds had 10.0% mortality.

From information on litters of straightbred and crossbred NN and CC breeding, estimates of direct heterosis for postweaning traits were obtained (tables 21 and 22). For growth and feed-related traits, direct heterosis was small (< 11%) but in consistent favor of crossbred vs straightbred litters. Of practical interest, variation among full-sibs in individual 56 d weights was reduced (difference in coefficient of variation of -10.9%) in crossbred compared to straightbred litters, <u>ergo</u> heterosis. Moderate estimates of heterosis were found for diarrheal-related and total mortality, also in favor of crossbred vs straightbred litters (table 22). Reports on heterosis for postweaning litter traits are not available for comparison.

Least-squares dam genetic group means and selected contrasts and tests of significance for postweaning litter traits and mortality are shown in tables 23 and 24. Litter 56 d weight, litter gain and litter feed intake tended to be increased in litters reared by NN vs CC straightbred dams (table 23). These results do not parallel those obtained in the NN-CC sire breed comparison, suggesting the existence of maternal breed influences. Lukefahr et al. (1983a,b) observed important breed differences between NN and CC dams (in favor of NN) for litter size and milk production, which could explain the above findings. Litter size at 56 d, within-litter uniformity and litter feed efficiency were similar in litters of NN and CC straightbred dams. Although litter size at weaning (28 d) was 1.06 rabbits larger in litters reared by NN vs CC dams, by 56 d of age the breed difference was reduced to .20 rabbits, due to higher mortality among rabbits of NN maternity (table 24). An 8.7% increase in diarrheal-related deaths in litters of NN maternity was found, accounting for 88% of all deaths in this group, compared to litters of CC maternity.

Maternal heterosis was significant for litter feed intake and efficiency and for total mortality. A .47 rabbit advantage in litter size at 56 d was observed in litters of crossbred vs straightbred dams. This difference alone (although not significant) could explain the 3.6 kg increase in litter feed intake (table 23). Maternal heterosis percentage was higher for litter size and weight at weaning (28 d) than for the same traits expressed at 56 d, as expected. A simple explanation for the poorer feed conversion in litters reared by crossbred vs straightbred dams is not available, based on present results. Total mortality in litters of crossbred dams was 5.5% higher ($P < .05$) than in litters of straightbred dams (table 24).

Most deaths being related to diarrhea, moderate maternal heterosis for total mortality in litters reared by crossbred vs straightbred dams may have been due to the substantially lower mortality incidence in litters of straightbred CC dams.

Suggestive of the presence of important maternal breed effects on postweaning traits, litter size and weight at 56 d, litter gain and feed efficiency were improved ($P < .05$) in litters of CN vs NC crossbred dams, in favor of NN grandmaternity (table 23). Quite possibly, these observations were the result of a larger litter size at birth and increased milk flow in CN compared to NC crossbred does, as reported by Lukefahr et al. (1983a,b). CN does also were heavier than NC does (Lukefahr et al., 1983b). Although not statistically significant, differences between litters of CN and NC crossbred dams for the mortality traits were also in favor of the maternal environment provided by CN dams (table 24).

Diet Comparisons. Presentation of least-squares diet means and tests of significance are found in tables 23 and 24. Litter size at 56 d was larger and litter feed intake and mortality from diarrhea were increased in litters fed the 74% alfalfa ration ($P < .05$). Since diets differed in fiber level, in energy concentration, in protein content, in minerals and in vitamins, specific reasons for observed differences cannot be ascertained. The effect of diet on a larger litter size at 56 d was due to a larger litter size at birth of 9.86 vs 7.98 rabbits (Lukefahr et al., 1983b). The difference in litter size at weaning alone could explain the increase in litter feed intake during the postweaning period and the tendency for a heavier 56 d litter weight. Within-litter uniformity and litter feed efficiency were similar for both diets. Diarrheal-related deaths were increased by 5.3% in litters receiving the 74% alfalfa ration, but the difference between diets for total mortality was smaller (2.8%). In an experiment involving 4,485 young rabbits, Sinkovics et al. (1980) demonstrated that as dietary alfalfa levels increased from 0 to 45%, mortality due to diarrhea was elevated (7.5 to 16.4% deaths). This is not in agreement with the results from a smaller study by Cheeke and Patton (1978) in which the reverse trend was observed.

Residual Correlations. Residual correlations among postweaning litter traits are provided in table 25. Since there was no mortality in a preponderance of the litters, mortality traits are not included in the table. Litter size at 56 d was strongly related to litter 56 d weight, litter gain and litter feed intake, as expected. Similar to our estimate of .91, correlations of .88 (Rouvier et al., 1973) and .93 (Lukefahr, 1983) between litter size and weight at 56 d have been reported. Also, litter size at 56 d was moderately related (r = .53) to litter feed efficiency (gain/feed intake). More rapid litter gains were associated with an increase in litter feed intake (r = .75), a heavier 56 d litter weight (r = .98) and an improvement in litter feed efficiency (r = .77); although these trends may be a reflection of a larger litter size. Within-litter uniformity (coefficient of variation of full-sibs in 56 d weights) was lowly related to growth and feed intake of litters (all correlations <.17 in absolute value). Lukefahr (1983) likewise obtained weak correlations between within-litter uniformity and similar litter traits. Litter feed intake and litter feed efficiency were lowly related (r = .24), possibly due to wastage of feed in some litters.

Conclusions. From a genetic standpoint, it is evident that additive and maternal breed and direct and maternal heterotic effects contributed to detected differences among genetic groups in postweaning litter performance. The combined potential advantages of utilizing a large terminal sire breed on litter growth, of direct heterosis on disease resistance and of the superior maternal productivity of CN crossbred does on litter size are suggested from experimental results. Due to carry-over effects from the preweaning phase, litter size and hence litter weight at 56 d were increased, although mortality from diarrhea was elevated, in litters fed the 74% alfalfa diet compared to litters fed the control diet. Based on residual correlation estimates, litter size appears to be a major determinant of total litter growth and feeding performance during the postweaning period.

CHAPTER 8

APPRAISAL OF NINE GENETIC GROUPS OF RABBITS FOR CARCASS QUALITY AND LEAN YIELD TRAITS[1]

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Summary

Carcass data on 137 rabbits representing nine genetic groups and both sexes were analyzed to determine the effects of medium and large sire breeds and of straightbred and hybrid does on carcass quality and lean yield characteristics. Three sire breeds were Californian (C), New Zealand White (N) and Flemish Giant (F). Dam genetic groups were C and N straightbred and CxN reciprocal hybrid (H) does. The genetic group effect was important ($P < .05$) for all traits except proportion of the carcass in forequarter and loin and percentages of meat in primal cuts. Sex and genetic group x sex interaction were never important ($P > .05$) sources of variation. Age of rabbit at slaughter influenced ($P < .05$) nearly all carcass traits. Progeny from C sires or dams had lighter preslaughter and carcass weights, higher dressing percentages and a smaller hindquarter proportion than progeny from N sires or dams. Also, percentages of bone in forequarter, loin and hindquarter cuts were consistently lower, meat to bone ratio was higher but cooking losses were greater in rabbits from C vs N sires or dams. Progeny from F sires had heavier ($P < .01$) preslaughter and carcass weights, tended to deposit less abdominal fat, had a smaller giblet percentage and had a larger hindquarter proportion, compared to the average of progeny of C and N sires. In addition, percentages of bone in forequarter and hindquarter cuts were greater ($P < .01$) while percentage of bone in the loin cut did not differ between F vs combined C and N sire progeny groups. Meat to bone ratio was less and cooking loss percentage was reduced in F- vs the average of C and N-sired progeny. However, no sire breed differences were observed for total meat percentage. Maternal heterotic and direct heterotic effects on carcass traits were generally negligible except that carcass weights were heavier ($P < .05$) in F-sired rabbits reared by hybrid vs straightbred dams. Residual correlations showed positive relationships between carcass weight, abdominal fat percentage and dressing percentage. Meat percentage of each primal cut was highly correlated with total meat percentage of the carcass. Experimental results suggest the utilization of a large terminal-sire breed with hybrid doe stock to increase carcass weights of market rabbits. In regards to meat percentage of carcasses, all genetic groups evaluated were suitable.

(Key Words: Rabbits, Breeds, Crossbreeding, Carcass Traits, Meat Yield.)

Introduction

Carcass studies involving rabbits have been concerned primarily with net carcass yield rather than proportion and quality of major cuts and composition of lean, fat and bone. Among-breed differences for carcass component traits, e.g. percentage of the carcass in cuts from the forequarter, loin and hindquarter regions, have been reported (Rouvier, 1970; Heckmann et al., 1971; Bednarz and Frindt, 1975). Also, the use of large terminal-sire breeds of rabbits (Kawinska et al., 1969; Heckmann et al., 1971; Ouhayoun and Rouvier, 1973; Ouhayoun, 1980; Lukefahr et al., 1982) has been shown to increase postweaning weight gains and hence slaughter weights of progeny. Characterization of domestic meat rabbit breeds through detailed carcass investigations is imperative to ascertain suitable breeds or breed combinations to be produced and marketed in commercial operations for eventual human consumption.

This study was conducted to evaluate nine genetic groups representing two medium and one large sire breed and two straightbred and the crossbred dam genetic group and to determine the effects of sex of rabbit and age at slaughter on carcass quality and lean yield traits. In addition, residual correlations among carcass traits were examined.

Materials and Methods

A total of 137 rabbits, representing nine genetic groups and both sexes, were appraised for carcass quality and lean yield traits.

The experimental design was a 3x3 factorial, consisting of three sire breeds cross-classified with three dam genetic groups. The sire breeds were Californian (C), New Zealand White (N) and Flemish Giant (F). The N is the most popular commercial meat breed in the United States, while the C and F breeds are more typically raised for exhibition purposes. More extensive utilization of the C breed for meat production occurs in Europe. Dam genetic groups included in the experiment were C and N straightbred does and CxN reciprocal hybrid (H) does. Population management, housing and genetic and environmental effects on doe reproduction and preweaning litter trait performance were reported by Lukefahr et al. (1983a,b).

A commercial pelleted diet[4] was fed to all rabbits involved in the carcass study. Litters were weaned at 28 d of age by transferring the dam to a different cage. The litter remained as an intact group through the postweaning growth phase. Rabbits are generally regarded to attain a minimal market weight of 1.81 kg by 56 d but can still be marketed as fryers at heavier weights of 2.49-2.72 kg.

Within each of the nine genetic groups, rabbits destined for carcass appraisal were randomly sampled on a within litter and within sex basis. A minimum of one and a maximum of four rabbits (two of each sex) were sampled from the same litter. Fifty-one litters, sired by 12 C, 9 N and 8 F bucks, were actually involved. Rabbits ranged in age from 57 to 79 d on the day of slaughter (mean of

[4]Carnation Albers' Milling Co., Portland, OR (Commercial Family Ration.

66.0 d). Twelve slaughter days or replications were involved in the study. All rabbits were processed at the Clark Meat Science Laboratory, Oregon State University.

Carcass traits were: preslaughter and carcass weights, percentages of abdominal fat and giblets (heart, kidneys and liver), dressing percentage and proportions of the carcass consisting of the forequarter, loin and hindquarter cuts. Rabbits were killed through cervical dislocation. The head, pelt, viscera, feet and tail were discarded and the hot carcass weight was recorded. Abdominal fat and giblets were weighed and later expressed as a percentage of carcass weight. Dressing percentage was calculated as total carcass weight (hot carcass weight + abdominal fat weight + giblet weight) divided by live weight prior to slaughter. All rabbits were fasted for approximately 24 h prior to slaughter. Separation of the forequarters from the loin and separation of the loin from the hindquarters were achieved by making transverse cuts at the last rib and at the posterior lumbar-anterior pelvic region, using a bandsaw. The rack and forelegs comprised the forequarter cut, while the rump and hindlegs comprised the hindquarter cut. Each of the three primal cuts was expressed as a percentage of the carcass weight (minus abdominal fat and giblets).

Lean yield traits were: percentages of bone and meat of the forequarter, loin and hindquarter cuts, overall meat to bone ratio and cooking loss and total meat percentage of the carcass. Carcasses, consisting of the three primal cuts, were individually placed in plastic bags and were steam cooked for 2 h at 68-71 C. Upon cooking, separation of meat from bone tissue of each of three cuts was made by hand and weights of both tissues were recorded. Meat to bone ratio was calculated as total meat weight divided by total bone weight of the carcass. Cooking loss percentage was the difference between carcass weight (minus abdominal fat and giblets) and total weight of bone and meat tissues, divided by the carcass weight. Total meat percentage was derived as total meat weight divided by carcass weight. All of the above percentage traits were multiplied by 100. A schematic representation of the various carcass traits and the part-whole relationships involved are shown in figure 3.

Data were analyzed through least-squares procedures as described by Harvey (1975), according to the following mathematical model:

$$Y_{ijk} = \mu + G_i + S_j + (GS)_{ij} + b(A_{ijk} - \bar{A}) + E_{ijk} \qquad (8)$$

where

Y_{ijk} = observation on the k^{th} rabbit of the j^{th} sex of the i^{th} genetic group,

μ = overall mean,

G_i = effect of the i^{th} genetic group ($i=1,2,...9$),

S_j = effect of the j^{th} sex of rabbit ($j=1,2$),

$(GS)_{ij}$ = effect due to the interaction of genetic group and sex,

A_{ijk} = age of rabbit at slaughter in days,

b = linear regression coefficient of Y_{ijk} on A and

E_{ijk} = random error.

The above effects were assumed to be fixed except for the random error. In preliminary analysis of the data, the replication effect was shown to be of negligible importance for nearly all traits examined in the study. Therefore, this effect was not included in the above model. Residual correlations were obtained from the least-squares analyses of variance.

A selected set of orthogonal linear contrast comparisons was made to quantify differences attributable to sire breed, dam genetic group and direct heterotic effects. Each single degree of freedom contrast was tested for significance by the Student's t-test.

Results and Discussion

Analysis of Variance. All carcass traits differed ($P < .05$) among genetic groups, except for proportion of the carcass of forequarter and loin cuts and percentages of meat in primal cuts. The sex of rabbit and the genetic group x sex interaction sources of variation were never important ($P > .05$). Previous studies (Kawinska and Niedzwiadek, 1973; Ouhayoun et al., 1974; Bednarz and Frindt, 1975, 1979) also reported minor differences due to sex (when rabbits were slaughtered at approximately 2 kg live weight) in carcass quantity and quality traits.

As expected, age at slaughter influenced ($P < .05$) preslaughter and carcass weights in a positive direction. The same linear trend was found for percentage of abdominal fat, dressing percentage and the lean yield traits: percentages of meat in forequarter, loin and hindquarter, meat to bone ratio and total meat percentage of the carcass. A negative linear relationship existed between age at slaughter and percentages of giblets, proportion of hindquarter of the carcass and percentages of bone in forequarter, loin and hindquarter cuts. Carcass yield and meat composition, therefore, generally tended to improve as age increased from 8 to 12 wk. This is in agreement with other reports (Rao et al., 1978, Bednarz and Frindt, 1979) involving rabbits of comparable age and genetic background. Proportion of forequarter and loin cuts of the carcass and cooking loss percentage were not affected ($P > .05$) by age at slaughter.

Genetic Group Means and Comparisons for Carcass Quality Traits. Overall means, coefficients of variation and least-squares genetic group means and orthogonal comparisons for carcass quality traits are found in table 26. In the first sire breed contrast, C-sired rabbits were lighter than N-sired rabbits for preslaughter and carcass weight, although the differences were not significant. Heckmann et al. (1971) and Bednarz and Frindt (1975) reported similar results for breed ranking for live weight prior to slaughter. While differences were small between C- and N-sired progeny for percentages of abdominal fat and giblets, dressing percentage was significantly improved (1.1% advantage) in C-sired rabbits, which is consistent with earlier reports (Heckmann et al., 1971; Bednarz and Frindt, 1975; Niedzwiadek, 1979). The proportions of carcass of forequarter, loin and hindquarter cuts, as obtained in our study, closely parallel those reported by Kawinska and Niedzwiadek (1973) involving N straightbreds and Bednarz and Frindt (1975) involving C and N straightbred and crossbred rabbits. The hindquarter proportion in carcasses of rabbits from C sires was decreased ($P < .01$) compared to carcasses of rabbits from N sires. However, proportions of forequarter and loin cuts were only slightly changed between C and N progeny groups. Heckmann et al. (1971) also showed a slightly smaller proportion in hindquarter cuts in C vs N straightbreds, while Bednarz and Frindt (1975) reported opposite results.

The second sire breed contrast of F minus the average of C and N (large breed minus the average of medium weight breeds), showed F-sired rabbits to be heavier in preslaughter and carcass weights ($P < .01$). These observations are consistent with previous findings (Kawinska et al., 1969; Heckmann et al., 1971; Ouhayoun and Rouvier, 1973; Ouhayoun, 1980; Lukefahr et al., 1982). Percentages of abdominal fat and giblets were reduced, while dressing percentage was comparable in F- vs the averge of C and N-sired rabbits. Other studies (Kawinska et al., 1969; Ouhayoun, 1980) have reported dressing percentage to be lowest in rabbits of large vs medium and small breeds, while Heckmann et al. (1971) reported Light Great Silver rabbits (a large breed) to surpass N and C straightbred rabbits for the same trait. In a previous experiment, Lukefahr et al. (1982) reported dressing percentage values of 52.0 and 50.4 for straightbred F and N rabbit fryers. In the present study, average dressing percentage values of 54.0, 53.4 and 54.5 for F, N and C sire progeny groups indicate nonetheless that all three groups are quite comparable. Proportion of forequarter and loin cuts were slightly decreased while proportion of hindquarter was significantly increased in carcasses of F vs combined C and N sire groups. Breed means for percentage of hindquarters of 33.1, 31.0 and 31.1 for Light Great Silver (large breed), C and N rabbit carcasses were reported by Heckmann et al. (1971), which are in agreement with present findings.

The first dam genetic group contrast compared rabbits reared by C vs N dams. The same trends as shown for C-N sire breed progeny differences were revealed for C-N dam breed effects, except that pre-slaughter weights were more reduced ($P < .05$) and percentage of giblets was significantly decreased in rabbits of C maternity. This similarity between sire and dam breed effects suggests that maternal effects on carcass quality traits are of minor importance.

Carcass characteristics of F-sired rabbits reared by crossbred vs the average of straightbred C and N dams were examined in the second dam genetic group contrast. This contrast is also a comparison of three breed terminal-cross performance minus two breed terminal-cross performance in carcass traits. Differences mainly reflect increased vigor or heterosis on the part of the crossbred dam which may influence performance for carcass traits through increased mothering ability (Lukefahr et al., 1983a,b). Rabbits of crossbred maternity were heavier prior to slaughter, yielded a heavier ($P< .05$) carcass and tended to have an improved dressing percentage compared to rabbits of straightbred maternity. For the remaining carcass quality and lean yield traits, no such effect was important ($P > .05$).

The direct heterosis contrast compares crossbred (NC and CN) vs straightbred (CC and NN) fryers. Significant direct heterosis was observed ($P < .05$) for dressing percentage and proportion of hindquarter of carcasses. However, when the heterosis deviations were expressed on a percentage basis, heterosis was less than 3% for both characters. In agreement with present results, Bednarz and Frindt (1975) and Niedzwiadek (1979) reported heterosis to be less than 10% for dressing percentage, also involving C and N straightbreds and crossbreds.

Genetic Group Means and Comparisons for Lean Yield Traits. Presentation of overall means, coefficients of variation and least-squares genetic group means and orthogonal comparisons for lean yield traits are found in table 27. Rabbits sired by C bucks had lower percentages of bone in all primal cuts of the carcass, especially in the forequarter (difference of 2.0%), than rabbits sired by N bucks. Similar results were reported by Heckmann et al. (1971). Differences in percentage of meat in the primal cuts were small but consistently negative (in favor of N progeny groups), meat to bone ratio was significantly improved but cooking loss percentage was greater in C- vs N-sired progeny ($P < .05$). An appreciably lower percentage of bone, as opposed to lower cooking losses, may account for the more favorable meat to bone ratio in carcasses of C-sired rabbits. Total meat percentage was comparable between rabbits of C and N paternity, which is in agreement with the percentages of lean in carcasses of C- and N-sired rabbits of 82 and 81%, as reported by Niedzwiadek (1979).

Percentages of bone in forequarter and hindquarter cuts were higher ($P < .01$) while percentage of bone in the loin cut did not differ between F- vs the average of C and N-sired progeny groups. Studies reporting increased percentages of bone in the hindquarter (Heckmann et al., 1971) and in the total carcass (Lukefahr et al., 1982) in rabbits of large vs medium weight breeds agree with present findings. On the other hand, percentages of meat in primal cuts and total meat percentage were comparable ($P > .05$) in rabbits of F vs combined C and N paternity. This may be attributable to a significantly lower percentage cooking loss in F-sired progeny groups. Overall meat to bone ratio was lower (difference of -.27, $P < .01$) in rabbits of F vs the average of C and N sire breed groups. In studies involving direct sire breed comparisons between large and medium weight breeds, Ouhayoun (1980) observed Blanc de Bouscat-sired progeny to have a reduced muscle to bone tissue ratio compared to N-sired progeny; while Lukefahr et al. (1982) observed similar meat to bone ratios of carcasses of F and N straightbreds.

Observed sire breed differences in bone percentages, in meat to bone ratio and in cooking loss (an indication of lipid and moisture content of muscle tissue) of carcasses may reflect differential growth rates to a constant age associated with the physiological stage of maturity. Rabbit fryers of large sire breeds have been found to possess a higher proportion of bone and less lean and fat in carcasses than fryers of medium or small sire breeds, due to the delayed age to maturity (Ouhayoun and Rouvier, 1973; Ouhayoun, 1980).

Differences in percentages of bone and meat in primal cuts between rabbits reared by C vs N dams were similar to findings from the C vs N sire breed contrast, except that percentage of meat in the hindquarter cut was decreased modestly in rabbits of C vs N dams. Comparable results between C-N sire and dam breed contrasts were likewise observed for meat to bone ratio and cooking loss and total meat percentages, which is suggestive of minor maternal breed effects on lean yield traits. Differences attributable to maternal and direct heterotic effects were never significant for lean yield traits.

Residual Correlations. Selected residual correlations among carcass quality and lean yield traits are presented in table 28. On a within-genetic group basis, a heavier carcass was related to a greater deposition of abdominal fat, a higher dressing percentage and meat to bone ratio, a lower cooking loss percentage and a higher total meat percentage. The positive association between hot carcass weight and dressing percentage may be due to reduced visceral percentage in heavier rabbits (Rao et al., 1978). Rouvier (1970) and Lukefahr et al. (1982) similarly reported moderate to high correlations between hot carcass weight and meat to bone ratio. The decrease in cooking loss percentage in heavier carcasses may be attributable to a lower moisture content, indicative of physiological changes associated with maturity (Ouhayoun, 1980). A between-breed correlation coefficient of -.99 was reported by Ouhayoun and Rouvier (1973) between the natural logarithmic values of moisture content and the degree of maturity (live body weight) in young rabbits. As hot carcass weight increased, changes in the proportion of forequarter, loin and hindquarter regions were observed. The data suggest that larger rabbits, within the same genetic group, have reduced hindleg proportion. A fatter carcass was associated with an increase in dressing percentage, meat to bone ratio and total meat percentage; while the hindquarter proportion and the cooking loss percentage generally decreased. Ouhayoun and Rouvier (1973) obtained a between-breed correlation coefficient of -.99 between the natural logarithmic values of lipid and moisture contents of the carcass, which possibly suggests that a heavier carcass, although fatter, has a reduced cooking loss percentage due to lower moisture content. Correlations between the forequarter proportion and dressing percentage and between the loin proportion and dressing percentage were small, while the hindquarter proportion decreased as dressing percentage improved.

As proportion of the carcass in forequarter cuts increased, the proportion in loin cuts decreased, while weak associations existed between the other primal cuts. Moderate relationships involving forequarter and hindquarter proportions with total meat percentage were observed, although no relationship was found between the loin proportion and total meat percentage. Therefore, it does not appear that proportion changes in any one primal cut relates strongly with total meat percentage. This result may be due to limited variation for these characters (tables 26 and 27). Meat to bone ratio improved and cooking loss percentage was reduced in carcasses having a smaller proportion of hindquarter. Moreover, as the meat to bone ratio improved, total meat percentage increased, quite possibly through a reduction in cooking loss. As expected, carcasses that lost more weight upon cooking yielded less meat on a percentage basis.

Residual correlations between percentages of bones and meat among and within primal cuts of the carcass and with total lean percentage are provided in table 29. Overall, correlations were moderate ($.29 < r < .40$) among percentages of bones while correlations were high ($r \geq .64$) among percentages of meat in the primal cuts. Also, correlations between percentages of bones and meat among primal cuts were consistently small ($-.20 < r < .05$). On a within primal cut basis, correlations between percentages of bone and meat in the forequarters and hindquarters were negative, as expected. In contrast, a small but positive correlation was observed between percentages of bones and meat in the loin cut, apparently due to a lower bone tissue composition of the region and/or higher cooking losses. Of primary interest, percentage of meat in each primal cut was highly related to total meat percentage of the carcass, while correlations involving percentage of bones with total meat percentage were small and negative. These relationships indicate that, on a percentage basis, determination of meat content of a single major cut is a good indicator of the overall meat yield of the carcass.

SUMMARY

Based upon results reported in the thesis, the following recommendations as to optimal choice of breeds or breed combinations for intensive commercial breeding operations are made:

1) Rabbit producers that, for various reasons, prefer straightbreeding to crossbreeding should benefit economically by raising New Zealand White rather than Californian stock. New Zealand White does were clearly superior to Californian does for maternal characters. In addition, litter 56-day weights tended to be heavier in litters reared by New Zealand White compared to litters reared by Californian does. Even though additive breed effects of the Californian breed were generally more favorable on postweaning growth and survival and for carcass quality traits, the New Zealand White appeared to be the better breed.

2) Rabbit producers that wish to utilize only medium weight meat breeds should observe improved mothering ability, due to maternal heterosis and favorable maternal breed influences, in Californian x New Zealand White does of New Zealand White maternity. By mating Californian bucks to crossbred does, desirable additive breed effects on postweaning litter survival and carcass quality, as expressed in terminal-crossbred progeny, should result.

3) Rabbit producers that are interested in maximal herd productivity may realize major advantages of breed complementation and heterosis from mating bucks of a large sire breed to Californian x

New Zealand White does of New Zealand White maternity. The large breed will transmit genes for rapid growth and possibly will create direct heterosis for disease resistance in terminal-cross progeny. Crossbred does will have beneficial effects on litter size and other maternally influenced traits.

4) In populations of Californian and/or New Zealand White breeding, doe culling based on litter size at weaning (number of young weaned per litter) should be effective in improving mean herd productivity, due to moderate repeatability for this trait and a positive phenotypic relationship to litter growth rate.

These recommendations are dependent, to some extent, on the environment in which production is to occur, the financial and physical resources, the managerial ability and practices and the goals of the commercial meat rabbit enterprise.

TABLE 1. LEAST-SQUARES ANALYSIS OF VARIANCE RESULTS FOR DOE AND PREWEANING LITTER TRAITS

	Sources of variation								
Trait	Breed (B)	Doe/B	Age of dam (linear regr.)	Age of dam (quadratic regr.)	Age of dam (B x quad)	Month of service (linear regr.)	Residual mean square	Coef. of var. (%)[a]	Residual df
Litter interval, d		*					77.5	17.1	38
Litter wt at 21 d, kg	†	*		**	*	**	.229	17.9	45
Doe feed intake (1 to 21 d), kg	**	**	**			**	.798	9.94	48
Doe feed efficiency (1 to 21 d)		*		**	**	*	.002	18.2	45
Litter size born	**			*			4.89	22.5	60
% born alive	†	**					478.	25.6	66
Litter birth wt, g	**			**			11,853.	19.0	60
Average birth wt, g	**		*				106.	17.4	63
Litter weaning wt, kg	†	†		**	*	*	.753	19.6	45
Average weaning wt (adjusted)[b], g	*	**	**			**	4,059.	10.9	42
Litter daily gain, g		*		**	*	**	838.	21.1	45
Litter size at weaning	*			**			4.69	27.0	48
% survival rate		†			**		130.	12.9	48
Doe and litter feed intake (1 to 28 d), kg	**	*		*			3.23	13.0	54
Doe and litter feed efficiency (1 to 28 d)		**		**	**	**	.002	14.9	45

[a]Coefficient of variation computed as the residual standard deviation divided by the overall least-squares means of a given trait.

[b]Average weaning weight adjusted for the quadratic effect (P<.01) of litter size at weaning.

†P<.10.

*P<.05.

**P<.01.

TABLE 2. LEAST-SQUARES MEANS AND STANDARD ERRORS FOR DOE AND PREWEANING LITTER TRAITS

Trait	Overall mean	Genetic group means: FG	NZW	TX
Doe wt at breeding age (154 d), kg	4.11 ± .06	5.19^{c} ± .11	3.88^{b} ± .09	3.25^{a} ± .11
Nipple no.	8.46 ± .08	8.27^{a} ± .16	8.19^{a} ± .13	8.92^{b} ± .15
Litter interval, d	51.6 ± 1.7	55.2 ± 3.4	51.6 ± 2.6	47.9 ± 2.4
Litter wt at 21 d, kg	2.67 ± .08	2.81^{b} ± .21	2.82^{b} ± .16	2.38^{a} ± .15
Doe feed intake (1 to 21 d), kg	8.99 ± .24	9.69^{b} ± .44	9.28^{b} ± .38	8.01^{a} ± .38
Doe feed efficiency (1 to 21 d)	.23 ± .01	.22 ± .02	.23 ± .01	.24 ± .01
Litter size born	9.82 ± .25	9.96^{ab} ± .65	10.9^{b} ± .52	8.56^{a} ± .47
% born alive	85.3 ± 3.7	73.5^{a} ± 7.0	89.0^{b} ± 6.0	93.3^{b} ± 5.9
Litter birth wt, g	572. ± 14.	$661.^{b}$ ± 40.	$609.^{b}$ ± 30.	$448.^{a}$ ± 28.
Average birth wt, g	59.2 ± 1.1	66.1^{b} ± 2.2	53.4^{a} ± 1.9	58.1^{a} ± 1.7
Litter weaning wt, kg	4.43 ± .14	4.73^{b} ± .36	4.63^{b} ± .28	3.93^{a} ± .25
Average weaning wt (adjusted)[d], g	585. ± 13.	$643.^{b}$ ± 30.	$561.^{a}$ ± 29.	$553.^{a}$ ± 25.
Litter daily gain, g	137. ± 4.9	146. ± 13.	144. ± 9.6	123. ± 8.9
Litter size at weaning	8.01 ± .26	7.56^{a} ± .70	9.24^{b} ± .52	7.24^{a} ± .45
% survival rate	88.5 ± 1.8	89.7 ± 4.5	84.6 ± 3.4	91.3 ± 3.1
Doe and litter feed intake (1 to 28 d), kg	13.8 ± .32	15.0^{b} ± .80	14.5^{b} ± .62	12.1^{a} ± .57
Doe and litter feed efficiency (1 to 28 d)	.28 ± .01	.27 ± .02	.28 ± .02	.28 ± .01

[a,b,c]Genetic group means in the same row bearing unlike superscripts differ (P<.05).

[d]Average weaning weight adjusted for the quadratic effect (P<.01) of litter size at weaning.

TABLE 3. POOLED WITHIN GENETIC GROUP REPEATABILITY ESTIMATES (t) FOR DOE AND PREWEANING LITTER TRAITS

Trait	t
Litter interval, d	.27 ± .15
Litter wt at 21 d, kg	.25 ± .14
Doe feed intake (1 to 21 d), kg	.58 ± .10
Doe feed efficiency (1 to 21 d)	.27 ± .14
Litter size born	.05 ± .12
% born alive	.33 ± .11
Litter birth wt, g	.09 ± .13
Average birth wt, g	.04 ± .11
Litter weaning wt, kg	.22 ± .14
Average weaning wt (adjusted)[a], g	.41 ± .13
Litter daily gain, g	.25 ± .14
Litter size at weaning	.02 ± .13
% survival rate	.18 ± .14
Doe and litter feed intake (1 to 28 d), kg	.28 ± .13
Doe and litter feed efficiency (1 to 28 d)	.36 ± .13

[a]Average weaning weight adjusted for the quadratic effect ($P<.01$) of litter size at weaning.

TABLE 4. RESIDUAL CORRELATIONS AMONG DOE AND PREWEANING LITTER TRAITS

Trait	2[a]	3	4	5	6	7	8	9	10	11	12	13	14
(1) Litter wt at 21 d, kg	.62[b]	.86	.45	.49	.49	-.29	.89	-.48	.88	.75	.32	.65	.79
(2) Doe feed intake (1 to 21 d), kg		.21	.31	.35	.37	-.18	.59	-.28	.59	.43	.07	.75	.26
(3) Doe feed efficiency (1 to 21 d)			.24	.46	.19	-.28	.69	-.37	.71	.62	.42	.31	.86
(4) Litter size born				.37	.82	-.70	.56	-.81	.50	.78	-.40	.55	.35
(5) % born alive					.32	-.35	.48	-.62	.47	.62	-.19	.36	.47
(6) Litter birth wt, g						-.26	.59	-.72	.50	.74	-.21	.57	.29
(7) Average birth wt, g							-.39	.67	-.39	-.53	.34	-.36	-.35
(8) Litter weaning wt, kg								-.55	.99	.85	.29	.81	.81
(9) Average weaning wt[c], g									-.50	-.86	.18	-.48	-.42
(10) Litter daily gain, g										.81	.34	.80	.83
(11) Litter size at weaning											.13	.69	.70
(12) % survival rate												.12	.36
(13) Doe and litter feed intake (1 to 28 d), kg													.36

[a]Numbers in column headings correspond to like numbered traits in rows. Trait 14 is doe and litter feed efficiency (1 to 28 d).

[b]All correlations greater than /.29/ and greater than /.37/ are different from zero at P<.05 and P<.01, respectively.

[c]Average weaning weight, unadjusted for litter size weaned is included in the table to demonstrate its association with litter size related traits.

TABLE 5. LEAST-SQUARES MEANS (LSM) AND COEFFICIENTS OF VARIATION (CV) AND ANALYSES OF VARIANCE RESULTS FOR THE EFFECTS OF GENETIC GROUP, AGE OF DAM AND MONTH OF BIRTH ON SEVERAL LITTER GROWTH TRAITS AND MORTALITY RATES

Trait	LSM	CV	Breed-type	Age of dam	Month of birth
Litter size at weaning, no.	7.90	27.8	**		
Litter weaning wt, kg	4.47	20.2	*	*	
Average weaning wt/rabbit, g	538.	25.1	**		
Litter size at marketing, no.	7.24	32.0	*		
Litter market wt, kg	12.2	29.0			
Average market wt/rabbit, kg	1.74	11.8	**		*
Coefficient of variation for individual market wt, %	8.94	49.3			
Total litter feed intake, kg	23.5	26.8	*		
Average daily feed intake/rabbit, g	123.	17.2			
Average daily gain/rabbit, g	38.0	15.8			*
Litter feed efficiency (gain/feed intake)	0.324	19.5			*
Respiratory deaths, %	0.67	561.	**		
Enteric deaths, %	4.62	167.			
Total deaths, %	8.04	126.			

*Significantly different at P<.05; **significantly different at P<.01.

TABLE 6. GENETIC GROUP LEAST-SQUARES MEANS AND STANDARD ERRORS FOR LITTER GROWTH TRAITS AND MORTALITY RATES

Trait	Flemish Giant		New Zealand White		Terminal Cross	
	LSM	SE	LSM	SE	LSM	SE
Litter size at weaning, no.	6.9[a]	.60	9.1[b]	.58	7.7[a]	.52
Litter weaning wt, kg	4.37[a,b]	.25	4.83[b]	.24	4.23[a]	.21
Average weaning wt/rabbit, g	634.[b]	37.	484.[a]	36.	496.[a]	32.
Litter size at marketing, no.	6.1[a]	.64	8.4[b]	.62	7.2[a,b]	.56
Litter market wt, kg	11.4	.97	13.7	.93	11.7	.83
Average market wt/rabbit, kg	1.90[b]	.06	1.65[a]	.05	1.67[a]	.05
Coefficient of variation for individual market wt, %	9.0	1.2	10.1	1.2	7.7	1.0
Total litter feed intake, kg	20.8	1.7	26.1	1.7	23.6	1.5
Average daily feed intake/rabbit, g	127.	5.8	116.	5.6	124.	5.0
Average daily gain/rabbit, g	40.9	1.6	37.0	1.6	36.2	1.4
Litter feed efficiency (gain/feed intake)	.332	.02	.331	.02	.309	.02
Respiratory deaths, %	3.9[b]	1.2	[a,d]	1.2	[a,d]	1.0
Enteric deaths, %	3.1	2.1	5.8	2.0	5.0	1.8
Total deaths, %	10.0	2.8	8.3	2.7	5.9	2.4

[a,b,c] Row means accompanied with a different superscript are different (P<.05).

[d] Negative least-squares means were obtained due to near zero incidence of respiratory deaths in these groups.

TABLE 7. RESIDUAL CORRELATIONS AMONG POSTWEANING LITTER TRAITS

Trait	2[a]	3	4	5	6	7	8	9	10	11
1) Litter size at weaning, no.	.82[b]	-.34	.94	.85	-.65	.16	.87	-.52	-.12	.33
2) Litter weaning wt, kg		-.00	.78	.83	-.28	-.08	.80	-.32	.01	.23
3) Average weaning wt/rabbit, g			-.31	-.15	.44	-.36	-.20	.32	.17	-.13
4) Litter size at marketing, no.				.93	-.57	.14	.89	-.62	.11	.52
5) Litter market wt, kg					-.28	-.04	.86	-.55	.36	.63
6) Average market wt/rabbit, kg						-.35	-.45	.50	.61	.02
7) Coefficient of variation for individual market wt, %							.08	-.05	-.28	-.09
8) Total litter feed intake, kg								-.24	.08	.23
9) Average daily feed intake/rabbit, g									-.15	-.75
10) Average daily gain/rabbit, g										.70

[a] Numbers in column headings correspond to like-numbered traits in rows. Trait 11 is litter feed efficiency (gain/feed intake).

[b] All correlations greater than /.24/ and greater than /.32/ are different from zero at $P<.05$ and $P<.01$, respectively.

TABLE 8. BREED TYPE LEAST-SQUARES MEANS (LSM) AND STANDARD ERRORS (SE) FOR CARCASS CHARACTERS[a]

Breed:	Flemish Giant		New Zealand White		Terminal-Cross	
Character:	LSM	SE	LSM	SE	LSM	SE
Preslaughter wt, g	1,745.[c]	47.	1,622.[b]	45.	1,586.[b]	43.
Body length, cm	31.4[d]	.32	28.0[b]	.31	29.2[c]	.29
Body loin width, cm	9.71[b]	.18	9.65[b]	.17	10.3[c]	.16
Hot carcass wt, g	829.[c]	27.	739.[b]	26.	755.[b]	25.
Carcass length, cm	29.6[c]	.30	27.0[b]	.29	27.5[b]	.27
Carcass loin width, cm	9.23[b]	.17	9.04[b]	.17	9.48[b]	.16
% abdominal fat	.89[b]	.13	1.36[c]	.13	1.68[d]	.12
% giblets	8.20[b]	.19	8.50[b]	.19	8.20[b]	.18
Dressing %	52.0[c]	.52	50.4[b]	.50	52.6[c]	.48
% chill shrinkage	3.48[b]	.14	3.51[b]	.14	4.24[c]	.13
Cooked meat wt, g	576.[c]	19.	430.[b]	19.	541.[c]	18.
% meat	68.3[c]	1.0	56.5[b]	.97	70.6[d]	.92
% bone	21.3[d]	.54	18.3[c]	.52	17.0[b]	.49
% cooking loss	10.4[b]	1.23	25.2[c]	1.2	12.5[b]	1.1
Meat to bone ratio	3.24[b]	.11	3.12[b]	.10	4.23[c]	.10
Lean meat yield expressed as a % of preslaughter wt	33.1[c]	.57	26.5[b]	.55	34.0[c]	.52
Warner-Bratzler shear, kg/cm^2	2.60[b]	.36	3.25[b,c]	.35	3.92[c]	.33
% moisture	72.7[c]	.61	69.7[b]	.59	69.9[b]	.56
% ash	3.71[c]	.08	3.22[b]	.08	3.35[b]	.07
% protein	64.7[c]	1.3	56.7[b]	1.3	58.7[b]	1.2
% ether extract	29.5[b]	1.6	36.8[c]	1.5	36.1[c]	1.4

[a]Sample sizes were 20, 22 and 23 rabbits for the Flemish Giant, New Zealand White and Terminal-Cross groups, respectively.

[b,c,d]Means in the same row with different superscripts differ ($P<.05$).

TABLE 9. LINEAR CONTRAST COMPARISONS AND STANDARD ERRORS (SE) FOR FLEMISH GIANT- VS NEW ZEALAND WHITE-SIRED PROGENY AND FOR THREE-BREED TERMINAL-CROSSES VS FLEMISH GIANT AND NEW ZEALAND WHITE PUREBREDS

Character	$\frac{FG^a + TX^a}{2} - NZW^a$	SE	$TX^a - \frac{FG^a + NZW^a}{2}$	SE
Preslaughter wt, g	43.8	57.5	-65.0	37.
Body length, cm	2.33**	.39	-.35	.25
Body loin width, cm	.36	.22	.41**	.14
Hot carcass wt, g	52.5	33.	-19.7	21.
Carcass length, cm	1.54**	.36	-.56*	.23
Carcass loin width, cm	.31	.21	.23	.14
% abdominal fat	-.08	.16	.37**	.10
% giblets	-.30	.24	-.10	.15
Dressing %	1.87**	.65	.95*	.40
% chill shrinkage	.34*	.18	.49**	.11
Cooked meat wt, g	129.**	24.	25.2	15.
% meat	13.0**	1.2	5.45**	.80
% bone	.88	.65	-1.89**	.42
% cooking loss	-13.8**	1.5	-3.55**	.95
Meat to bone ratio	.62**	.13	.71**	.08
Lean meat yield expressed as a % of preslaughter wt	7.05**	.70	2.82**	.44
Warner-Bratzler shear, kg/cm^2	.01	.45	.67*	.28
% moisture	1.60*	.75	-.88	.48
% ash	.31**	.10	-.08	.06
% protein	5.05**	1.7	-1.34	1.1
% ether extract	-4.05*	1.9	1.96	1.2

[a]FG = Flemish Giant; TX = three-breed Terminal-Cross; NZW = New Zealand White.

*P<.05.

**P<.01.

TABLE 10. POOLED, WITHIN-BREED RESIDUAL CORRELATIONS BETWEEN BODY MEASUREMENT AND CARCASS TRAITS

	2[a]	3	4	5	6	7	8	9	10	11	12	13	14
(1) Preslaughter wt, g	.45[b]	.66	.97	.63	.69	.34	.59	-.52	.88	-.06	-.35	.21	.27
(2) Body length, cm		.50	.49	.24	.38	.20	.47	-.19	.36	-.12	-.37	.26	.24
(3) Body loin width, cm			.72	.21	.67	.44	.66	-.03	.59	-.12	-.34	.25	.24
(4) Hot carcass wt, g				.62	.75	.37	.76	-.48	.90	-.09	-.42	.26	.33
(5) Carcass length, cm					.33	-.10	.39	-.64	.64	.11	-.06	-.06	.12
(6) Carcass loin width, cm						.43	.72	-.14	.60	-.23	-.44	.38	.27
(7) % abdominal fat							.49	.06	.23	-.26	-.29	.34	.11
(8) Dressing %								-.20	.64	-.16	-.51	.36	.38
(9) % chill shrinkage									.58	-.24	.02	.19	-.13
(10) Cooked meat weight, g										.32	-.25	-.15	.39
(11) % meat											.19	-.90	.39
(12) % bone												-.59	-.81
(13) % cooking loss													.04

[a] Numbers in column headings correspond to like-numbered traits in rows. Trait 14 is Meat to bone ratio.

[b] All correlations greater than |.26| and greater than |.34| are different from zero at $P<.05$ and $P<.01$, respectively.

TABLE 11. EXPERIMENTAL DESIGN AND NUMBER OF OBSERVATIONS FOR ATTEMPTED MATINGS

Breed of:[a]		Diet	
Sire	Dam	Control	74% Alfalfa
NN	NN	24	20
CC	NN	25	16
FG	NN	25	26
Subtotal		74	62
NN	CC	16	25
CC	CC	13	30
FG	CC	18	24
Subtotal		47	79
NN	CN	13	21
CC	CN	14	19
FG	CN	16	21
Subtotal		43	61
NN	NC	10	13
CC	NC	10	09
FG	NC	10	12
Subtotal		30	34
Total		194	236

[a]Doe breed group abbreviations are New Zealand White (NN), Californian (CC), Californian sire x New Zealand White dam (CN) and New Zealand White sire x Californian dam (NC). Sire breed abbreviations of NN, CC and FG code for straightbred New Zealand White, Californian and Flemish Giant bucks. Totals for sire breed were 142 for NN, 136 for CC, and 152 for FG, respectively.

TABLE 12. DEGREES OF FREEDOM, RESIDUAL MEAN SQUARES AND TESTS OF SIGNIFICANCE FROM THE LEAST-SQUARES ANALYSES OF VARIANCE FOR DOE AND PREWEANING LITTER TRAITS

Source of variation:	df	Fertility, %	Number born	Early survival, %	Litter birth wt, g	Number weaned, 28 d	Late survival, %	Litter weaning wt, kg	Doe and litter feed intake, kg	Doe and litter feed efficiency
Treatment (T)	7		**	**	**	**	**	**	**	*
Doe/T		**	**	*	**	**	**		**	
Doe/T, df		107	95	95	95	74	79	74	74	74
Sire breed (S)	2			**	**					
TxS	14			*						
Month	14				**			**	**	**
Age of dam-- linear and quad. regr.	2				**					
Residual mean square		18.1	4.50	724	11,322	4.05	401	.907	5.96	.003
Residual, df		285	147	147	145	114	120	114	114	114

*P<.05.

**P<.01.

TABLE 13. LEAST-SQUARES BREED AND DIET MEANS AND STANDARD ERRORS FOR DOE BREEDING WEIGHT AND LONGEVITY, AND SELECTED ORTHOGONAL CONTRASTS

Item:	Doe breeding wt, kg	Longevity, d
Doe breed group mean[a]		
NN	3.83 ± .06	166 ± 24
CC	3.41 ± .06	162 ± 24
CN	3.83 ± .07	227 ± 30
NC	3.62 ± .08	135 ± 36
Straightbred contrast		
NN-CC	.42** ± .08	4 ± 34
Heterosis contrast		
1/2{(CN+NC) - (NN+CC)}	.11 ± .07	17 ± 29
(heterosis percentage)	(3.0)	(10)
Reciprocal contrast		
CN-NC	.21* ± .10	93 ± 47
Diet mean	---[b]	
Commercial control		147 ± 19
74% alfalfa		197 ± 20

[a]See footnote in table 11 for identification of doe breed group abbreviations.

[b]The diet effect on doe breeding wt was not relevant since does were first assigned to a diet regime at 154 days.

*$P<.05$.

**$P<.01$.

TABLE 14. LEAST-SQUARES BREED AND DIET MEANS AND STANDARD ERRORS FOR DOE AND PREWEANING LITTER TRAITS, AND SELECTED ORTHOGONAL CONTRASTS

Item:	Fertility, %	Number born	Early survival, %	Litter birth wt, g	Number weaned, 28 d	Late survival, %	Litter weaning wt, kg	Doe and litter feed intake, kg	Doe and litter feed efficiency
Doe breed group mean[a]									
NN	64.1 ± 6.8	8.91 ± .54	85.2 ± 6.0	497 ± 31	6.94 ± .54	82.6 ± 5.1	3.66 ± .20	13.5 ± .6	.229 ± .01
CC	70.5 ± 6.8	8.04 ± .53	76.0 ± 5.9	412 ± 29	5.89 ± .57	67.5 ± 5.2	2.55 ± .22	11.5 ± .7	.187 ± .01
CN	71.8 ± 7.9	10.6 ± .63	85.8 ± 6.9	575 ± 36	7.93 ± .58	79.2 ± 5.6	3.73 ± .21	14.6 ± .6	.218 ± .01
NC	71.8 ± 9.5	8.13 ± .80	88.2 ± 8.7	471 ± 45	6.44 ± .80	83.6 ± 7.8	3.12 ± .29	12.7 ± .9	.207 ± .02
Straightbred contrast									
NN-CC	-6.4 ± 6.4	.86 ± .47	9.2 ± 5.4	85** ± 26	1.06 ± .54	15.1** ± 4.9	1.11** ± .21	2.0** ± .6	.042** ± .01
Heterosis contrast									
1/2{(CN+NC) - (NN+CC)}	4.5 ± 5.2	.89* ± .39	6.4 ± 4.4	68** ± 21	.77 ± .41	6.3 ± 3.9	.32* ± .16	1.2* ± .5	.004 ± .01
(heterosis percentage)	(6.7)	(10.5)	(7.9)	(15)	(12.)	(8.4)	(10.3)	(9.6)	(1.9)
Reciprocal contrast									
CN-NC	0.0 ± 8.2	2.47** ± .60	-2.4 ± 6.9	104** ± 33	1.50* ± .62	4.4 ± 6.0	.61* ± .24	1.9** ± .7	.011 ± .01
Diet mean									
Commercial control	67.3 ± 7.9	7.98^{b} ± .64	75.0^{b} ± 7.2	444^{b} ± 36	5.89^{b} ± .67	70.9^{b} ± 6.2	2.89^{b} ± .26	11.5^{b} ± .8	.207 ± .01
74% alfalfa	71.7 ± 7.6	9.86^{c} ± .61	92.7^{c} ± 6.6	534^{c} ± 34	7.71^{c} ± .58	85.5^{c} ± 5.6	3.63^{c} ± .21	14.6^{c} ± .7	.213 ± .01

[a]See footnote in table 11 for identification of doe breed group abbreviations.

[b,c]Diet column means bearing unlike superscripts differ (P<.01).

*P<.05.

**P<.01.

TABLE 15. LEAST-SQUARES SIRE BREEO MEANS ANO STANOARO ERRORS FOR PREWEANING LITTER TRAITS, ANO SELECTEO ORTHOGONAL CONTRASTS

Item:	Fertility, %	Number born	Early survival, %	Litter birth wt, g	Number weaned, 28 d	Late survival, %	Litter weaning wt, kg	Ooe and litter feed intake, kg	Ooe and litter feed efficiency
Sire breed mean									
New Zealand White (NN)	69.8 ± 4.3	8.97 ± .38	72.6 ± 4.4	474 ± 20	6.63 ± .39	73.7 ± 3.8	3.11 ± .17	13.0 ± .5	.201 ± .01
Californian (CC)	63.2 ± 4.4	8.69 ± .37	87.5 ± 4.4	468 ± 20	6.77 ± .37	80.4 ± 3.6	3.21 ± .16	13.0 ± .4	.211 ± .01
Flemish Giant (FG)	75.6 ± 4.2	9.11 ± .36	91.4 ± 4.2	525 ± 19	7.00 ± .34	80.6 ± 3.3	3.47 ± .14	13.2 ± .4	.218 ± .01
Sire breed contrast									
NN-CC	6.5 ± 5.6	.29 ± .46	-14.9* ± 5.8	7 ± 23	-.14 ± .50	-6.7 ± 5.2	-.10 ± .24	.0 ± .6	-.011 ± .01
FG-1/2(NN+CC)	9.1* ± 4.6	.28 ± .36	11.3* ± 4.5	54** ± 18	.30 ± .40	3.5 ± 3.9	.31 ± .19	.3 ± .5	.013 ± .01

*P<.05.

**P<.01.

TABLE 16. REPEATABILITIES (t) WITH ASSOCIATED STANDARD ERRORS (se) FOR DOE AND PREWEANING LITTER TRAITS[a]

Trait:	t		se
Fertility, %	.09	±	.05
Number born	.26	±	.07
Early survival, %	.16	±	.08
Litter birth wt, g	.33	±	.07
Number weaned, 28 d	.23	±	.08
Late survival, %	.22	±	.08
Litter weaning wt, kg	.07	±	.08
Doe and litter feed intake, kg	.19	±	.08
Doe and litter feed efficiency	.05	±	.08

[a]Effective number (K) of repeat doe records was estimated at 2.4 for each of the above traits with the exception of fertility (K≃3.4).

TABLE 17. DEGREES OF FREEDOM, RESIDUAL MEAN SQUARES AND TESTS OF SIGNIFICANCE FROM THE LEAST-SQUARES ANALYSES OF VARIANCE FOR MILK PRODUCTION AND ASSOCIATIVE TRAITS

Source of variation:	df	Milk production, kg	Litter 21 d wt, kg	Litter milk efficiency	Litter size at 21 d	Doe wt at kindling, kg	Doe feed intake, kg	Doe feed efficiency
Treatment (T)	7	**	**		**	**	**	
Doe/T	74				**	**	**	*
Month	14				*	*	**	
Age of dam --								
linear regr.	1							*
linear and quad. regr.	2						*	
Residual mean square		.845	.389	.011	4.21	.037	2.35	.006
Residual, df		114	114	114	114	114	112	113

*P<.05.

**P<.01.

TABLE 18. LEAST-SQUARES GENETIC GROUP AND DIET MEANS AND STANDARD ERRORS FOR MILK PRODUCTION AND ASSOCIATIVE TRAITS, AND SELECTED ORTHOGONAL COMPARISONS

Item	Milk production, kg	Litter 21 d wt, kg	Litter milk efficiency	Litter size at 21 d	Doe wt at kindling, kg	Doe feed intake, kg	Doe feed efficiency
Doe genetic group mean[a]							
NN	3.97 ± .16	2.72 ± .11	.519 ± .02	7.05 ± .55	3.98 ± .11	8.51 ± .44	.455 ± .02
CC	3.06 ± .19	2.07 ± .13	.503 ± .02	6.17 ± .58	3.43 ± .10	7.66 ± .46	.393 ± .02
CN	4.03 ± .17	2.72 ± .11	.508 ± .02	8.19 ± .58	3.91 ± .13	9.30 ± .47	.441 ± .02
NC	3.65 ± .24	2.52 ± .16	.543 ± .03	7.08 ± .81	3.76 ± .16	8.11 ± .64	.442 ± .03
Straightbred contrast							
NN-CC	.91[**] ± .18	.64[**] ± .12	.016 ± .02	.88 ± .55	.54[**] ± .09	.85 ± .44	.062[**] ± .02
Heterosis contrast							
1/2[(CN+NC)-(NN+CC)]	.32[*] ± .13	.23[*] ± .09	.014 ± .01	1.02[*] ± .42	.13 ± .07	.61 ± .33	.018 ± .01
(heterosis percentage)	(9.2)	(9.6)	(2.7)	(15.4)	(3.5)	(7.5)	(4.2)
Reciprocal contrast							
CN-NC	.38 ± .20	.20 ± .14	-.036[*] ± .02	1.12 ± .63	.15 ± .11	1.19[*] ± .50	-.002 ± .02
Diet mean							
Commercial control	3.42[b] ± .22	2.32[b] ± .15	.512 ± .02	6.27[b] ± .67	3.79 ± .13	7.55[b] ± .54	.436 ± .02
74% alfalfa	3.94[c] ± .17	2.70[c] ± .11	.525 ± .02	7.98[c] ± .59	3.76 ± .12	9.24[c] ± .47	.430 ± .02

[a] Doe genetic group abbreviations are New Zealand White (NN), Californian (CC), Californian sire x New Zealand White dam (CN) and New Zealand White sire x Californian dam (NC).

[b,c] Diet column means bearing unlike superscripts differ ($P<.01$).

[*] $P<.05$.

[**] $P<.01$.

TABLE 19. REPEATABILITIES (t) AND ACCOMPANYING STANDARD ERRORS (se) FOR MILK PRODUCTION AND ASSOCIATIVE TRAITS[a]

Trait:	t	se
Milk production, kg	-.02	± .08
Litter 21 d wt, kg	-.03	± .08
Litter milk efficiency	-.19	± .07
Litter size at 21 d	.23	± .08
Doe wt at kindling, kg	.72	± .04
Doe feed intake, kg	.27	± .08
Doe feed efficiency	.17	± .09

[a]Effective number of repeat doe records for each of the above traits was approximately 2.4, from a total of 225 records.

TABLE 20. RESIDUAL CORRELATIONS AMONG MILK PRODUCTION AND ASSOCIATIVE TRAITS

Trait:	2[a]	3	4	5	6	7	8	9
(1) Milk production, kg	.48[b]	.64	.99	.52	.78	.10	.63	.81
(2) Total number born[c]		.81	.45	-.03	.68	-.12	.32	.39
(3) Litter birth wt[c], g			.62	.00	.72	-.01	.49	.46
(4) Litter 21 d wt, kg				.58	.80	.11	.63	.79
(5) Litter milk efficiency					.38	.14	.27	.53
(6) Litter size at 21 d						.11	.51	.65
(7) Doe wt at kindling, kg							.07	.04
(8) Doe feed intake, kg								.11
(9) Doe feed efficiency								

[a]Numbers in column headings correspond to row-numbered traits.

[b]Correlations greater than .19 and greater than .25 in absolute value are different from zero at P<.05 and P<.01, respectively.

[c]Analyses of variance results and breed and diet means for number born and litter birth weights have been reported elsewhere (Lukefahr et al., 1983b).

TABLE 21. LEAST SQUARES SIRE BREED MEANS AND SELECTED CONTRASTS, TESTS OF SIGNIFICANCE AND RESIDUAL MEAN SQUARES AND DEGREES OF FREEDOM FROM ANALYSES OF VARIANCE RESULTS FOR POSTWEANING LITTER GROWTH TRAITS

Item	Litter size at 28 d[a]	Litter 28 d wt, kg[a]	Litter size at 56 d	Litter 56 d wt, kg	Within-litter uniformity, %[b]	Litter gain, kg	Litter feed intake, kg	Litter feed efficiency[c]
μ	6.80 ± .24	3.26 ± .09	5.95 ± .20	8.66 ± .30	11.7 ± .5	5.30 ± .24	22.8 ± .6	.222 ± .01
Sire breed mean								
New Zealand White (NN)	6.63 ± .39	3.11 ± .17	5.46 ± .36	7.86 ± .55	12.2 ± 1.0	4.70 ± .44	20.5 ± 1.1	.204 ± .01
Californian (CC)	6.77 ± .37	3.21 ± .16	6.36 ± .33	8.57 ± .50	11.8 ± .9	5.14 ± .41	23.6 ± 1.1	.219 ± .01
Flemish Giant (FG)	7.00 ± .34	3.47 ± .14	6.03 ± .29	9.55 ± .44	11.0 ± .8	6.07 ± .35	24.3 ± .9	.244 ± .01
Sire breed contrast								
NN-CC	-.14 ± .50	-.10 ± .24	-.90 ± .48	-.71 ± .72	.4 ± 1.3	-.45 ± .58	-3.2* ± 1.5	-.015 ± .02
FG-1/2(NN+CC)	.30 ± .40	.31 ± .19	.12 ± .37	1.34* ± .57	-1.0 ± 1.0	1.15* ± .46	2.3 ± 1.2	.033* ± .01
Sire breed x dam breed contrast								
1/2((CN+NC)-(NN+CC))[d]	.28 ± .87	.23 ± .37	.26 ± .64	.42 ± .96	-.6 ± 1.7	.10 ± .77	.2 ± 2.0	-.0 ± .02
(direct heterosis percentage)	(4.3)	(7.5)	(4.5)	(5.2)	(-10.9)	(2.0)	(1.1)	(-0.1)
Residual MS	4.05	.907	5.61	12.8	37.0	8.34	55.8	.008
Residual, df	114	114	179	179	173	179	179	179

[a]Analyses of variance results and breed comparisons for litter size and weight at weaning (28 d) were previously reported by Lukefahr et al. (1983b).

[b]Within litter uniformity is the coefficient of variation of full-sibs for 56 d weight.

[c]Litter feed efficiency is the ratio of gain to feed intake from 28 to 56 d.

[d]Sire breed x dam breed contrast estimates direct heterosis in CN and NC crossbred litters, expressed as a deviation from NN and CC straightbred litter performances.

*P<.05.

TABLE 22. LEAST-SQUARES SIRE BREED MEANS AND SELECTED CONTRASTS, TESTS OF SIGNIFICANCE AND RESIDUAL MEAN SQUARES AND DEGREES OF FREEDOM FROM ANALYSES OF VARIANCE RESULTS FOR POSTWEANING LITTER MORTALITY TRAITS

Item	Diarrheal-related deaths, %[a]	Total deaths, %
μ	10.5 ± 1.2	13.4 ± 1.3
Sire breed mean		
New Zealand White (NN)	12.2 ± 2.2	16.0 ± 2.4
Californian (CC)	9.5 ± 2.1	12.8 ± 2.2
Flemish Giant (FG)	9.7 ± 1.8	11.4 ± 1.9
Sire breed contrast		
NN-CC	2.7 ± 2.9	3.1 ± 3.2
FG-1/2(NN+CC)	-1.1 ± 2.3	-3.0 ± 2.5
Sire breed x dam breed contrast		
1/2{(CN+NC)-(NN+CC)}[b]	-1.9 ± 3.9	-2.4 ± 4.2
(direct heterosis percentage)	(-22.4)	(-20.7)
Residual MS	215.	249.
Residual, df	179	179

[a]Diarrheal-related deaths represents the number of rabbits belonging to the same litter that died as a result of intestinal disease expressed on a percentage basis.

[b]Sire breed x dam breed contrast estimates direct heterosis in CN and NC crossbred litters, expressed as a deviation from NN and CC straightbred litter performances.

TABLE 23. LEAST-SQUARES DAM GENETIC GROUP AND DIET MEANS AND SELECTED CONTRASTS AND TESTS OF SIGNIFICANCE FOR POSTWEANING LITTER GROWTH TRAITS

Item	Litter size at 28 d[a]	Litter 28 d wt, kg[a]	Litter size at 56 d	Litter 56 d wt, kg	Within-litter uniformity, %[b]	Litter gain, kg	Litter feed intake, kg	Litter feed efficiency[c]
Dam genetic group mean[d]								
NN	6.94 ± .54	3.66 ± .20	5.81 ± .33	9.06 ± .50	11.3 ± .9	5.50 ± .40	22.2 ± 1.1	.235 ± .01
CC	5.89 ± .57	2.55 ± .22	5.61 ± .42	7.79 ± .63	11.7 ± 1.1	4.90 ± .51	19.8 ± 1.3	.251 ± .02
CN	7.93 ± .58	3.73 ± .21	6.83 ± .32	9.77 ± .49	11.1 ± .8	6.10 ± .39	25.6 ± 1.0	.236 ± .01
NC	6.44 ± .80	3.12 ± .29	5.54 ± .47	8.03 ± .71	12.6 ± 1.3	4.72 ± .57	23.6 ± 1.5	.167 ± .02
Straightbred contrast								
NN-CC	1.06 ± .54	1.11** ± .21	.20 ± .52	1.27 ± .79	-.3 ± 1.4	.59 ± .64	2.3 ± 1.7	-.016 ± .02
Maternal heterosis contrast								
1/2[(CN+NC)-(NN+CC)]	.77 ± .41	.32* ± .16	.47 ± .39	.47 ± .59	.3 ± 1.0	.21 ± .47	3.6** ± 1.2	-.042** ± .01
(maternal heterosis percentage)	(12.)	(10.3)	(8.2)	(5.6)	(2.7)	(4.0)	(17.2)	(-17.3)
Maternal breed contrast								
CN-NC	1.50* ± .62	.61* ± .24	1.29* ± .56	1.74* ± .85	-1.5 ± 1.5	1.37* ± .69	1.9 ± 1.8	.069** ± .02
Diet treatment mean								
Commercial control	5.89[e] ± .67	2.89[e] ± .26	5.37[e] ± .31	8.15 ± .47	11.8 ± .8	5.04 ± .38	20.7[e] ± 1.0	.233 ± .01
74% alfalfa	7.71[f] ± .58	3.63[f] ± .21	6.52[f] ± .25	9.17 ± .37	11.6 ± .6	5.56 ± .30	24.9[f] ± .8	.211 ± .01

[a]Analysis of variance results and breed comparisons for litter size and weight at weaning (28 d) were previously reported by Lukefahr et al. (1983b).

[b]Within litter uniformity is the coefficient of variation of full-sibs for 56 d weight.

[c]Litter feed efficiency is the ratio of gain to feed intake from 28 to 56 d.

[d]NN = New Zealand White, CC = Californian, CN = Californian sire x New Zealand White dam and NC = New Zealand White sire x Californian dam.

[e,f]Diet means in the same column bearing unlike superscripts differ (P<.05) through analyses of variance F-test.

*P<.05.

**P<.01.

TABLE 24. LEAST-SQUARES DAM GENETIC GROUP AND DIET MEANS AND SELECTED CONTRASTS AND TESTS OF SIGNIFICANCE FOR POSTWEANING LITTER MORTALITY TRAITS

Item	Diarrheal-related deaths, %[a]	Total deaths, %
Dam genetic group mean[b]		
NN	12.5 ± 2.0	14.2 ± 2.2
CC	3.8 ± 2.6	7.2 ± 2.8
CN	11.3 ± 2.0	13.1 ± 2.2
NC	14.2 ± 2.9	19.2 ± 3.1
Straightbred contrast		
NN-CC	8.7** ± 3.2	7.0* ± 3.5
Maternal heterosis contrast		
1/2{(CN+NC)-(NN+CC)}	4.6 ± 2.4	5.5* ± 2.6
(maternal heterosis percentage)	(56.4)	(51.2)
Maternal breed contrast		
CN-NC	-2.9 ± 3.5	-6.1 ± 3.8
Diet treatment mean		
Commercial control	7.8[c] ± 1.9	12.0 ± 2.1
74% alfalfa	13.1[d] ± 1.5	14.8 ± 1.6

[a]Diarrheal-related deaths represents the number of rabbits belonging to the same litter that died as a result of intestinal disease expressed on a percentage basis.

[b]NN = New Zealand White, CC = Californian, CN = Californian sire x New Zealand White dam and NC = New Zealand White sire x Californian dam.

[c,d]Diet means in the same column bearing unlike superscripts differ (P<.05) through analyses of variance F-test.

*P<.05.

**P<.01.

TABLE 25. RESIDUAL CORRELATIONS AMONG POSTWEANING LITTER GROWTH AND FEEDING PERFORMANCE TRAITS

Trait	2[a]	3	4	5	6
(1) Litter size at 56 d	.91[b]	.04	.88	.84	.53
(2) Litter 56 d wt, kg		-.15	.98	.81	.67
(3) Within-litter uniformity, %[c]			-.17	-.05	-.17
(4) Litter gain, kg				.75	.77
(5) Litter feed intake, kg					.24

[a] Numbers in column headings correspond to like-numbered traits in rows. Trait 6 is litter feed efficiency (litter gain/feed intake).

[b] Correlations greater than .18 in absolute value are different from zero at $P<.01$.

[c] Within-litter uniformity is the coefficient of variation of full-sibs for 56 d weight.

TABLE 26. LEAST-SQUARES GENETIC GROUP MEANS AND STANDARD ERRORS FOR CARCASS QUALITY TRAITS, AND SELECTED ORTHOGONAL COMPARISONS

		Trait							
Item	No.	Preslaughter weight, g	Carcass wt, g	% abdominal fat	% giblets	Dressing %	% forequarters	% loin region	% hindquarters
μ		1,774 ± 20	866 ± 11	.92 ± .03	4.24 ± .04	54.0 ± .14	42.6 ± .19	19.2 ± .16	39.0 ± .11
Coef. of var., %		13	14	32.8	10.6	3.0	5.0	9.3	3.3
Genetic group mean[a]									
CC	15	1,695 ± 59	839 ± 32	1.05 ± .08	4.19 ± .12	54.6 ± .42	43.4 ± .56	19.3 ± .46	38.0 ± .33
NC	10	1,801 ± 72	891 ± 39	1.05 ± .09	4.26 ± .14	54.7 ± .51	43.3 ± .68	18.7 ± .57	37.9 ± .40
FC	14	1,786 ± 62	877 ± 33	.88 ± .08	4.04 ± .12	53.9 ± .44	41.6 ± .58	19.1 ± .48	39.6 ± .35
CN	16	1,783 ± 61	876 ± 33	1.05 ± .08	4.50 ± .12	54.4 ± .44	43.0 ± .58	19.2 ± .48	38.1 ± .35
NN	18	1,877 ± 54	892 ± 29	.91 ± .07	4.58 ± .11	52.7 ± .38	42.1 ± .51	19.3 ± .42	40.1 ± .30
FN	15	1,933 ± 59	939 ± 32	.79 ± .07	4.31 ± .12	53.5 ± .42	42.5 ± .56	19.0 ± .46	39.8 ± .33
CH	17	1,523 ± 60	754 ± 33	.85 ± .08	4.11 ± .12	54.4 ± .43	41.7 ± .57	19.9 ± .48	38.5 ± .34
NH	15	1,581 ± 60	758 ± 32	.76 ± .08	4.11 ± .12	52.7 ± .42	42.3 ± .56	19.4 ± .46	39.7 ± .34
FH	17	1,983 ± 55	987 ± 30	.88 ± .07	4.02 ± .11	54.6 ± .39	43.1 ± .52	19.2 ± .44	39.7 ± .31
Sire breed contrast									
C-N		-86 ± 51	-24 ± 27	.08 ± .06	-.06 ± .10	1.1** ± .36	.2 ± .47	.4 ± .39	-1.0** ± .28
F-1/2(C+N)		191** ± 42	99** ± 23	-.09 ± .05	-.17* ± .08	.1 ± .30	-.2 ± .40	-.2 ± .33	1.0** ± .24
Dam genetic group contrast									
C-N		-103* ± 50	-33 ± 27	.08 ± .06	-.29** ± .10	.8* ± .36	.2 ± .47	-.2 ± .39	-.8** ± .28
FH-1/2(FC+FN)[b]		124 ± 70	79* ± 38	.05 ± .09	-.15 ± .14	.8 ± .49	1.1 ± .66	.2 ± .55	-.0 ± .39
Direct heterosis contrast									
1/2[(NC+CN)-(CC+NN)]		6 ± 62	18 ± 33	.07 ± .08	-.01 ± .12	.9* ± .44	.5 ± .58	-.3 ± .49	-1.0** ± .35

[a]Breed of sire is listed first, where C, N, F and H represent Californian, New Zealand White and Flemish Giant breeds and Californian x New Zealand White reciprocal hybrid dams, respectively.

[b]Three breed terminal-cross performance minus two breed terminal-cross performance involving Flemish Giant-sired progeny groups, which is also a comparison of crossbred vs straightbred dams.

*P<.05. **P<.01.

TABLE 27. LEAST-SQUARES GENETIC GROUP MEANS AND STANDARD ERRORS FOR LEAN YIELD TRAITS, AND SELECTED ORTHOGONAL COMPARISONS

		Trait								
		Primal Cut								
		Forequarters		Loin		Hindquarters				
Item	No.	% bone	% meat	% bone	% meat	% bone	% meat	Meat to bone ratio	Cooking loss, %	Total meat, %
$\hat{\mu}$		22.1 ± .22	62.2 ± .32	10.1 ± .13	72.3 ± .33	17.3 ± .13	70.6 ± .33	3.79 ± .04	14.7 ± .29	67.9 ± .27
Coef. of var.,%		11.1	5.9	14.6	5.2	8.6	6.5	10.6	22.6	4.5
Genetic group mean[a]										
CC	15	18.4 ± .64	61.7 ± .95	8.8 ± .39	70.3 ± .97	15.7 ± .39	68.5 ± 1.00	4.28 ± .10	18.6 ± .85	66.4 ± .79
NC	10	21.5 ± .78	63.3 ± 1.16	9.4 ± .47	73.4 ± 1.18	17.1 ± .47	71.3 ± 1.19	3.93 ± .13	14.3 ± 1.04	68.2 ± .96
FC	14	23.0 ± .67	62.6 ± 1.00	10.3 ± .41	72.6 ± 1.02	17.9 ± .41	71.0 ± 1.02	3.67 ± .11	13.8 ± .89	68.0 ± .82
CN	16	21.4 ± .67	62.8 ± .99	9.8 ± .41	73.9 ± 1.01	16.8 ± .40	72.6 ± 1.02	3.98 ± .11	14.1 ± .89	68.9 ± .82
NN	18	22.9 ± .59	63.5 ± .87	10.8 ± .36	73.6 ± .89	17.2 ± .36	71.6 ± .90	3.76 ± .10	12.9 ± .78	69.6 ± .72
FN	15	23.6 ± .64	61.7 ± .95	10.6 ± .39	72.1 ± .97	18.0 ± .38	70.3 ± .97	3.59 ± .10	14.1 ± .85	67.8 ± .78
CH	17	21.8 ± .66	61.6 ± .97	10.3 ± .40	71.6 ± .99	17.3 ± .40	70.5 ± 1.00	3.79 ± .11	15.2 ± .88	67.1 ± .80
NH	15	23.3 ± .65	60.1 ± .97	10.7 ± .39	70.6 ± .98	17.6 ± .39	68.8 ± .99	3.55 ± .11	15.6 ± .85	66.3 ± .80
FH	17	23.4 ± .60	62.3 ± .89	10.6 ± .36	72.5 ± .91	18.2 ± .36	70.3 ± .91	3.58 ± .10	13.7 ± .80	68.7 ± .74
Sire breed contrast										
C-N		-2.0** ± .55	-.3 ± .82	-.7* ± .33	-.6 ± .83	-.7* ± .33	-.1 ± .84	.27** ± .09	1.7* ± .72	-.6 ± .68
F-1/2(C+N)		1.8** ± .46	.0 ± .68	.5 ± .28	.1 ± .69	1.1** ± .28	.0 ± .70	-.27** ± .07	-1.3* ± .61	.4 ± .56
Dam genetic group contrast										
C-N		-1.7** ± .55	-.2 ± .81	-1.0** ± .33	-1.1 ± .83	-.5 ± .33	-1.2 ± .83	.18* ± .09	1.9* ± .72	-1.3 ± .67
FH-1/2(FC+FN)[b]		.2 ± .76	.1 ± 1.13	.1 ± .46	.2 ± 1.15	.3 ± .46	-.3 ± 1.16	-.05 ± .12	-.3 ± 1.01	.8 ± 1.43
Direct heterosis contrast										
1/2[(NC+CN)-(CC+NN)]		.8 ± .68	.4 ± 1.00	-.2 ± .41	1.7 ± 1.00	.5 ± .41	1.9 ± 1.03	-.07 ± .11	-1.6 ± .90	.6 ± .83

[a] Breed of sire is listed first, where C, N, F and H represent Californian, New Zealand White and Flemish Giant breeds and Californian x New Zealand White reciprocal hybrid dams, respectively.

[b] Three breed terminal-cross performance minus two breed terminal-cross performance involving Flemish Giant-sired progeny groups, which is also a comparison of crossbred vs straightbred dams.

*P<.05. **P<.01.

TABLE 28. SELECTED RESIDUAL CORRELATIONS AMONG CARCASS QUALITY AND LEAN YIELD TRAITS

Trait	2[a]	3	4	5	6	7	8	9
(1) Hot carcass wt, g	.47[b]	.57	-.08	.22	-.47	.52	-.20	.35
(2) % abdominal fat		.48	.13	.04	-.55	.45	-.22	.34
(3) Dressing %			-.17	.19	-.31	.36	-.15	.21
(4) % forequarters				-.41	-.14	.03	.07	.23
(5) % loin region					-.03	-.04	.16	.02
(6) % hindquarters						-.49	.29	-.29
(7) Meat to bone ratio							-.24	.55
(8) Cooking loss, %								-.80

[a]Numbers in column headings correspond to trait row headings. Trait 9 is Total meat percentage of the carcass.

[b]Correlations greater than .17 and greater than .23 in absolute value are different from zero at $P<.05$ and $P<.01$, respectively.

TABLE 29. RESIDUAL CORRELATIONS BETWEEN PERCENTAGES OF BONE AND MEAT FOR CARCASS COMPONENT TRAITS

	Primal cut						
	Forequarters		Loin		Hindquarters		
Primal cut	% bone	% meat	% bone	% meat	% bone	% meat	Total meat, %
Forequarters							
% bone	1.0[a]	-.44	.32	-.09	.29	.05	-.13
% meat	-.44	1.0	.02	.64	-.20	.69	.78
Loin							
% bone			1.0	.12	.40	.03	-.05
% meat			.12	1.0	-.14	.66	.70
Hindquarters							
% bone					1.0	-.26	-.17
% meat					-.26	1.0	.84

[a]Correlations greater than .17 and greater than .23 in absolute value are different from zero at P<.05 and P<.01, respectively.

FIGURE 1. A FREQUENCY DISTRIBUTION OF LITTER SIZE AT MARKETING AGE (56 DAYS) OF FG (TOP), NZW (MIDDLE), AND TX (BOTTOM) GENETIC GROUPS

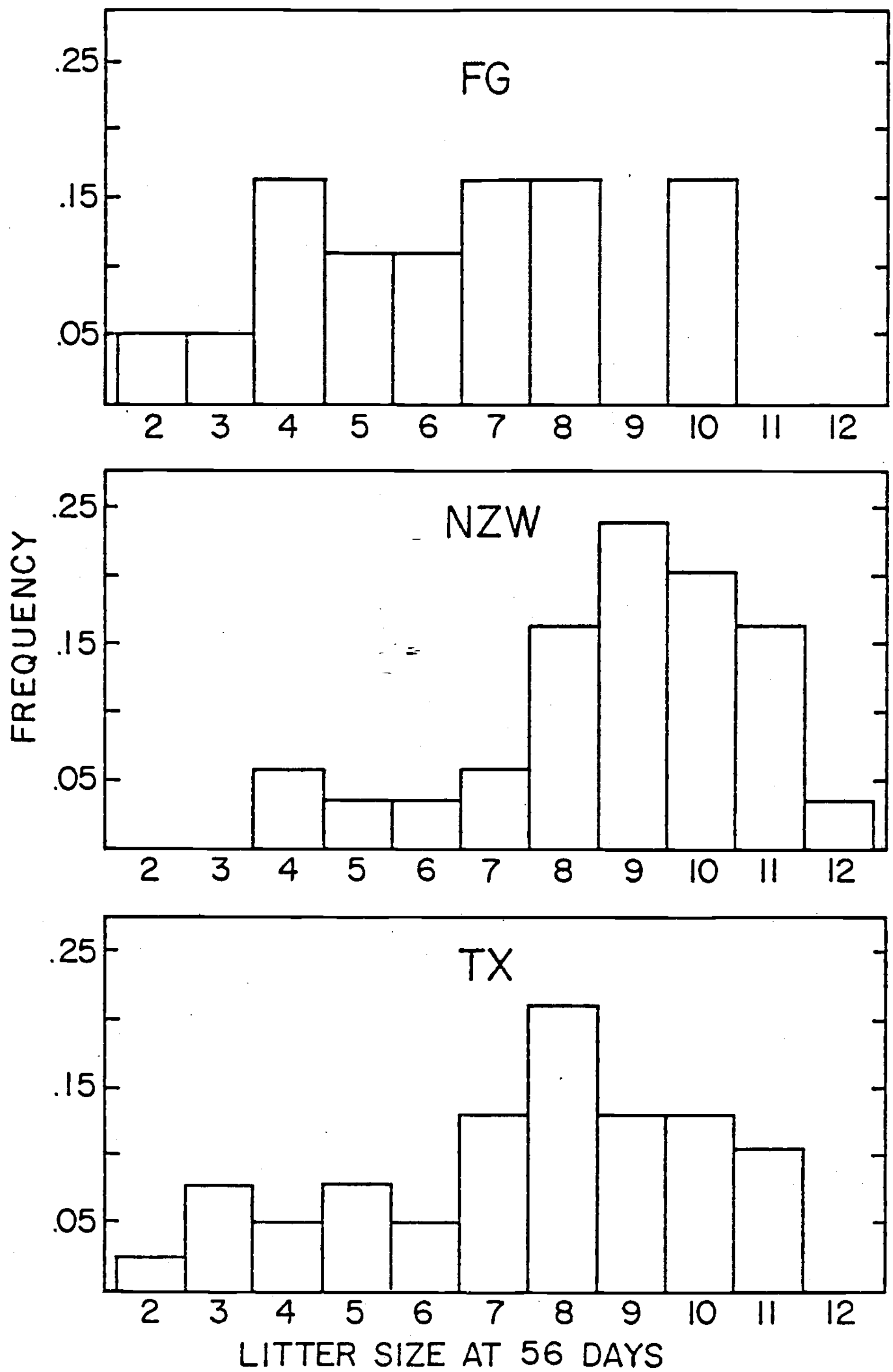


FIGURE 2. MEAN MILK PRODUCTION LEVELS OF STRAIGHTBRED AND RECIPROCAL CROSSBRED DOES DURING THE FIRST THREE WEEKS OF THE LACTATIONAL PERIOD

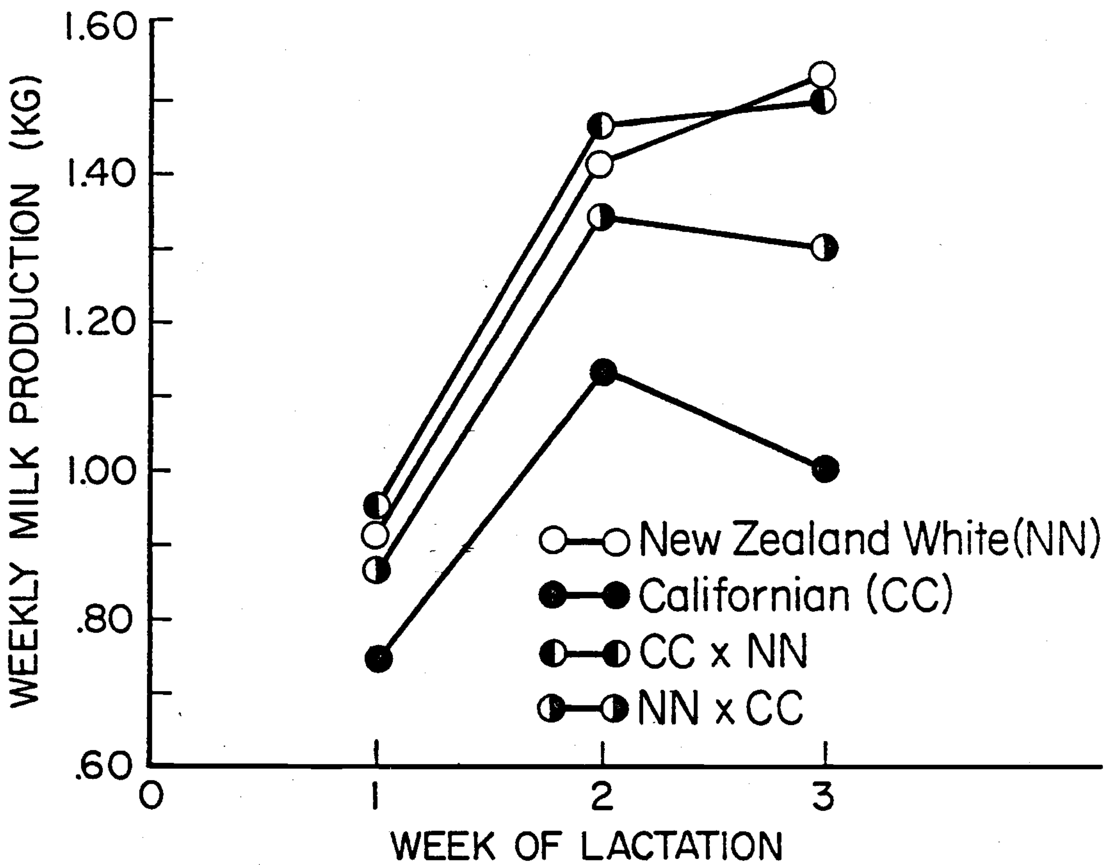
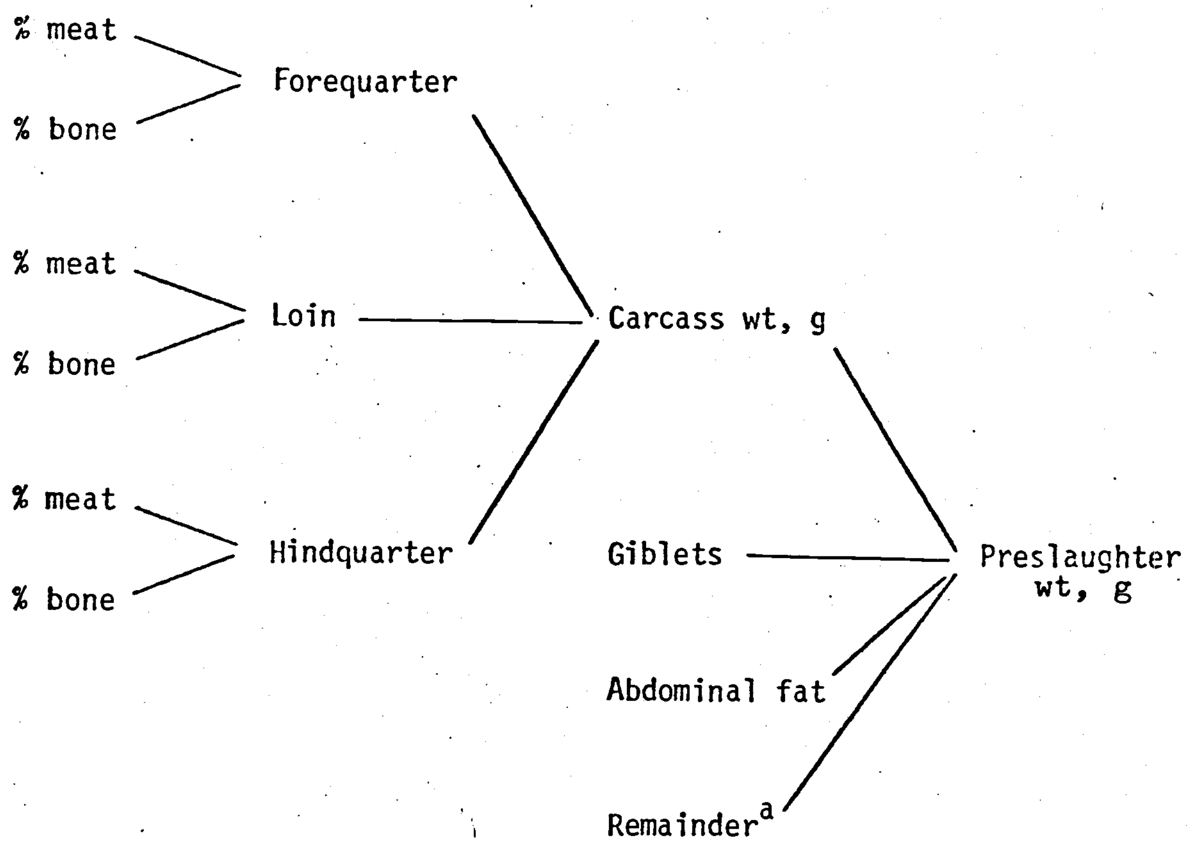


FIGURE 3. SCHEMATIC DIAGRAM REPRESENTING CARCASS TRAITS AND PART-WHOLE RELATIONSHIPS



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[a]The remainder consisting of the head, feet, tail, pelt, viscera and blood, was not quantified in the study.

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