5-1968

Improvement of Beef Cattle through Breeding Methods. Summary of Results from Regional Project NC-1

Larry V. Cundiff
Keith E. Gregory

Follow this and additional works at: http://digitalcommons.unl.edu/ardhistrb

Part of the Agriculture Commons, and the Other Animal Sciences Commons

Cundiff, Larry V. and Gregory, Keith E., "Improvement of Beef Cattle through Breeding Methods. Summary of Results from Regional Project NC-1" (1968). Historical Research Bulletins of the Nebraska Agricultural Experiment Station (1913-1993). 216. http://digitalcommons.unl.edu/ardhistrb/216

This Article is brought to you for free and open access by the Agricultural Research Division of IANR at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Historical Research Bulletins of the Nebraska Agricultural Experiment Station (1913-1993) by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.
Improvement of Beef Cattle Through Breeding Methods

Summary of Results From Regional Project NC-1

by
Larry V. Cundiff
Keith E. Gregory

Agricultural Experiment Stations of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, Wisconsin, in cooperation with Agricultural Research Service, United States Department of Agriculture.

University of Nebraska College of Agriculture
The Agricultural Experiment Station
E. F. Frolik, Dean; H. W. Ottoson, Director
PERSONNEL ON REGIONAL PROJECT NC-1

Administrative Adviser                                      Roy M. Kottman*
Investigations Leader, NC-1                                L. V. Cundiff**
Illinois                                                   H. W. Norton
Indiana                                                    T. G. Martin
Iowa                                                       R. L. Willham
Kansas                                                     W. H. Smith
Michigan                                                   W. T. Magee
Minnesota                                                  W. J. Boylan
Missouri                                                   J. E. Comfort and J. F. Lasley
Nebraska                                                   R. M. Koch
North Dakota                                               M. L. Buchanan
Ohio                                                       E. W. Klosterman
Oklahoma                                                   J. V. Whiteman and R. R. Frahm
South Dakota                                               C. A. Dinkel
U.S. Meat Animal Research Center                          K. E. Gregory***
Wisconsin                                                  E. R. Hauser

*Dean, College of Agriculture, Ohio State University, Columbus, Ohio, and Director, Ohio Agricultural Research and Development Center, Wooster, Ohio.
**Beef Cattle Research Branch, Animal Husbandry Research Division, ARS, USDA, 217 Marvel Baker Hall, University of Nebraska, Lincoln, Nebraska.
***Director, U.S. Meat Animal Research Center, Animal Husbandry Research Division, ARS, USDA, Box 166, Clay Center, Nebraska.

Additional copies of this publication may be obtained from the above personnel at the Animal Science Department of the Universities indicated.
CONTENTS

Foreword ............................................................................................................. 2

Introduction ....................................................................................................... 3

Results and Discussion ....................................................................................... 4
  Reproduction Performance or Fertility ............................................................. 4
  Birth Weight .................................................................................................... 6
  Mothering Ability and Weaning Weight ............................................................ 6
  Growth Weight ................................................................................................ 9
  Efficiency of Gain ............................................................................................ 11
  Longevity .......................................................................................................... 12
  Carcass Merit .................................................................................................. 13
  Inbreeding and Heterosis .................................................................................. 16
  Genotype-Environment Interactions ............................................................... 19
  Heritabilities and Genetic Correlations ........................................................... 21
  Breeding and Selection Procedures .................................................................. 22
  Hereditary Defects ............................................................................................ 22

Application of Results and Perspective ............................................................ 23

Publications from Regional Project NC-1 ........................................................... 24
FOREWORD

This Research Bulletin is published under the auspices of Regional Project NC-1, "Improvement of Beef Cattle Through Breeding Methods," with approval of the Directors of the Agricultural Experiment Stations of the North Central Region and Oklahoma and the Animal Husbandry Research Division, Agricultural Research Service, United States Department of Agriculture.

Regional Project NC-1 is cooperative between the Agricultural Research Service, United States Department of Agriculture, and the Agricultural Experiment Stations of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota and Wisconsin. The primary objective of Regional Project NC-1 is to obtain information that beef cattle breeders can use to make maximum genetic improvement in traits of economic value in beef cattle. This project involves the search for new facts that can be used by breeders to improve the inherent productive efficiency and carcass merit of beef cattle.

This publication is a revision of North Central Regional Publication 120, published by the Nebraska Agricultural Experiment Station (Research Bulletin 196) in July, 1961. It summarizes the more important results from this project during its first 19 years of operation. It is by no means complete and includes only what is considered to be the "highlights" of findings at this time. A bibliography of all publications that provided the basis for this summary statement is included.

This publication is in the nature of a progress report on many aspects of beef cattle breeding research. Although it is based on considerably more research than the original North Central Regional Publication 120, it is expected that additional knowledge gained by a continued dynamic research program will serve to sharpen the interpretation of the results and give a clearer perspective to presently perplexing problems. While the interpretations of the research results presented seem logical in light of available information, additional knowledge may lead to changes or modifications.

The purpose of this publication is to provide Administrators, Animal Science Research, Teaching and Extension personnel and others with a brief review of some of the accomplishments of this project and an evaluation of its present status and plans for the future.

This Research Bulletin was prepared by Larry V. Cundiff, Investigations Leader, NC-1, and Keith E. Gregory, Director, U.S. Meat Animal Research Center, in collaboration with other members of the Technical Committee listed under Personnel on Regional Project NC-1.
Cows and calves in the research herd at the Fort Reno Livestock Research Station, El Reno, Oklahoma.

Summary of Results from Regional Project NC-1

IMPROVEMENT OF BEEF CATTLE THROUGH BREEDING METHODS

Larry V. Cundiff and Keith E. Gregory

INTRODUCTION

The major purpose of this project is to obtain information that beef cattle breeders can use to maximize improvement in all traits of economic value in beef cattle. The search for new breeding facts that can be used to genetically improve productive efficiency and desirability of product is the primary concern of this research effort. The breeding of superior cattle in research herds for use by the industry is not a primary objective; however, some germ plasm useful to breeders may evolve from some of the research projects.

The objectives of this project are to: (1) determine the traits and their biological components that contribute to net merit in beef cattle; (2) assess the relative values of economic traits; (3) develop the most effective methods and procedures for measuring and evaluating traits that contribute to net merit; (4) obtain estimates of heritabilities of traits that contribute to net merit and of the genetic and phenotypic correlations among all economically important traits; (5) evaluate the effects and uses of inbreeding and heterosis; (6) evaluate the importance of different types of genotype-environment interactions; (7) compare different breeding and selection procedures in effectiveness for making genetic improvement in the traits of economic value; (8) de-

1 LARRY V. CUNDIFF is Associate Professor of Animal Science, Beef Cattle Research Branch, Animal Husbandry Research Division, ARS, USDA, University of Nebraska. KEITH E. GREGORY is Professor of Animal Science, Director, U.S. Meat Animal Research Center, Animal Husbandry Research Division, ARS, USDA, Clay Center, Nebraska.
termine the mode of inheritance of defects, lethals and semi-lethals, and develop methods of controlling them.

NC-1 is a long term research effort. Because of the long generation interval and the inherently low reproductive rate of beef cattle, results on many phases of the project come relatively slowly. These include comparative data on breeding systems and procedures, comparative selection methods and procedures, and estimates of direct and correlated response realized in long term selection experiments.

In the evolution of this project continual effort has been devoted to acquiring and developing facilities, increasing staff and obtaining cattle to pursue the research effectively. This has been a gradual and effective process. There are now approximately 9,000 cattle in the twelve contributing projects. With the exception of the U.S. Meat Animal Research Center which is currently being developed, cattle at most stations are approaching maximum numbers consistent with the available facilities.

Each contributing project has research in progress that will yield information on one or more of the objectives of the regional project. Research in progress will provide information on all objectives, and increased emphasis is being given to the areas that need additional attention. Reasonable progress is being made toward most objectives, and each station is effectively using its facilities and personnel in a coordinated effort to attack these objectives.

RESULTS AND DISCUSSION

The major traits that contribute to the efficient production of highly desirable beef are: (1) reproductive performance or fertility, (2) mothering or nursing ability, (3) growth rate, (4) efficiency of growth, (5) longevity and (6) carcass desirability.

The average heritability estimates obtained from NC-1 studies for some of the economically important traits of beef cattle are presented in Table 1.

Reproduction Performance or Fertility

With a long time trend toward marketing cattle at younger ages, a higher proportion of our beef cattle population is composed of brood cows. Thus, breeding efficiency is a trait of increasing economic importance from an industry-wide standpoint. However, it is a very complex trait with the percentage calf crop depending upon many factors or components. The tremendous economic importance of this trait justifies further research in this area. Genetic improvement in the other economically important traits is largely dependent on reproductive rate because the proportion of those produced that is needed for replacement limits the intensity of selection.
Table 1. Heritability estimates of some economically important traits.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Heritability (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calving Interval</td>
<td>10</td>
</tr>
<tr>
<td>Birth Weight</td>
<td>40</td>
</tr>
<tr>
<td>Weaning Weight</td>
<td>30</td>
</tr>
<tr>
<td>Cow Maternal Ability</td>
<td>40</td>
</tr>
<tr>
<td>Feedlot Gain</td>
<td>45</td>
</tr>
<tr>
<td>Pasture Gain</td>
<td>30</td>
</tr>
<tr>
<td>Efficiency of Gain</td>
<td>40</td>
</tr>
<tr>
<td>Final Feedlot Weight</td>
<td>60</td>
</tr>
<tr>
<td>Conformation Score:</td>
<td></td>
</tr>
<tr>
<td>Weaning</td>
<td>25</td>
</tr>
<tr>
<td>Slaughter</td>
<td>40</td>
</tr>
<tr>
<td>Carcass Traits:</td>
<td></td>
</tr>
<tr>
<td>Carcass Grade</td>
<td>40</td>
</tr>
<tr>
<td>Rib Eye Area</td>
<td>70</td>
</tr>
<tr>
<td>Tenderness</td>
<td>60</td>
</tr>
<tr>
<td>Fat Thickness</td>
<td>45</td>
</tr>
<tr>
<td>Retail Product (%)</td>
<td>30</td>
</tr>
<tr>
<td>Retail Product, lbs</td>
<td>65</td>
</tr>
<tr>
<td>Cancer Eye Susceptibility</td>
<td>30</td>
</tr>
</tbody>
</table>

Results indicate that the heritability of this trait is quite low (calving interval, Table 1). This is in agreement with results from other species and is probably to be expected because natural selection has operated effectively on reproduction throughout the evolution of the species. The low heritability means that nonadditive genetic variance and environmental variation are largely responsible for the variation observed in reproductive performance. The role of nonadditive genetic variation is discussed in the section on heterosis.

Some research has been conducted to determine methods of increasing reproductive performance through control of environmental effects. One study indicated that the conception rate of cows is very sensitive to level of energy intake in the weeks from calving to breeding.

When fed either 9 pounds of TDN (total digestible nutrients) per head daily or 4.5 pounds of TDN per head daily prior to calving followed by 16 pounds of TDN per head per day from calving through the breeding season, 95% of the cows were diagnosed pregnant.

Only 77% were diagnosed pregnant in the group fed 9 pounds of TDN per head per day prior to calving and 8 pounds of TDN per head per day following calving.

Only 20% of the cows fed 4.5 pounds of TDN per day prior to calving and 8 pounds per day following calving, were diagnosed pregnant. Differences among these groups were largely the result of differences in the proportions of cows showing estrus.

Results indicate that level of energy provided to replacement heifers in the weeks just prior to the breeding season strongly affects their calving performance as two year olds.
Too little energy results in delayed sexual maturity, low percent calf crop, late calves, small weak calves, poor milk production and light weaning weights.

Too much energy is uneconomic, increases calving difficulty, depresses milk producing ability and shortens productive life.

To be bred to calve at two years of age, replacement heifers should be fed to gain approximately .75 lb. per day during their first winter, be provided with ample summer grazing and be fed in the second winter to lose no more than 50 lb. through calving.

It has been revealed that growth rate has a significant effect on age at puberty in heifers. In one study age at puberty decreased 8.5 days for each .1 pound increase in preweaning average daily gain. In another study when heifers were wintered on a relatively low level of energy to gain an average of about .5 pound per day, age at puberty decreased 18.7 days for each .1 pound increase in average daily gain from weaning to 396 days, but when wintered to gain about .9 pound per day, differences in postweaning growth rate had little effect on age at puberty (−1 day per .1 lb. average daily gain).

**Birth Weight**

Numerous studies have shown that birth weight is moderately to highly heritable (30-50%). The results also show a positive genetic correlation between birth weight and postnatal growth rate. However, direct selection for birth weight may be undesirable because of the possibility of increasing calving difficulty. Direct selection for traits of major economic importance should favor selection toward optimum birth weight. Because of the high positive genetic correlation with postnatal gain, birth weight may be useful progeny test information in deciding which sires to use for their second breeding season since there is no other progeny information available at that time.

**Mothering Ability and Weaning Weight**

Weaning weight is a complex trait since the calf's own genetic impulse for growth and the dam's nursing ability both influence the calf's weaning weight. Since half of the genetic ability of the calf for growth comes from the dam, this confounding may not be a serious handicap in evaluating maternal ability if the genetic correlation between nursing ability and preweaning growth rate is low or positive. Selection for weaning weight then would result in both improved nursing ability and improved preweaning growth rate.

However, one recent study in the region suggests that the genetic relationship may be negative. A significant negative phenotypic correlation was observed between weaning weight of the dam and her subsequent production of butterfat during her first 60 days of lacta-
tion. Negative phenotypic correlations were also observed between weaning weight of the cow and other measures of her subsequent milk production.

On the other hand, significant positive phenotypic correlations were observed between the measures of milk production in the dam and weaning weight of the calf. These results suggest that either a negative genetic or environmental correlation between weaning weight of the dam and the maternal environment she provides for her calf may exist.

Other indirect evidence that either negative genetic or environmental correlations may exist between preweaning growth rate and maternal ability stems from heritability estimates obtained by different procedures. Paternal half-sib analysis and regression of offspring on sire indicate that the heritability of weaning weight is from 25 to 30%. A heritability estimate of mothering ability as measured by calf weaning weight based on paternal half-sib analysis was quite high in one study (40%).

However, estimates of the heritability of weaning weight based on regression of offspring on dam have been low (12 to 19%). This suggests that some genetic or environmental components of the dam's weaning weight are negatively correlated with traits having a positive influence on the calf's weaning weight. Further research is needed in this area to determine the genetic and environmental relationships involved.

Research results indicate that differences in mothering ability can be evaluated about as accurately on the basis of 112-day calf weight as on the conventional weaning age of approximately 200 days. Variation in weaning weights of creep-fed and noncreep-fed calves has been similar in several studies. This can be interpreted to mean that creep feeding does not interfere with the evaluation of differences in cows for mothering ability.

However, creep feeding may increase the accuracy of measurement of genetic differences between calves for growth. Calves may consume energy in proportion to their genetic potential for growth. Calves out of poor milking cows may tend to eat more feed than calves with comparable genetic potential for growth out of better milking cows. This situation could result in approximately equal variation under the two regimes, yet the accuracy of measurement of differences in mothering ability may be reduced and compensated for by an increase in accuracy of measurement of differences in the genetic potential for growth of the calves.

The results of a recent study indicates that this is the case. Weaning weight and preweaning gain were more significantly affected by butterfat production of the dam during the first 60 days of lactation than by volume of milk produced during the same period or butterfat and milk production during the subsequent period from 60 to 240
days. This was attributed to the calf’s need for a highly concentrated source of energy at a time when its consumption is limited.

In this study calves were creep fed from 60 days to weaning at 240 days. The failure of milk production and butterfat production subsequent to 60 days to exert a significant influence on weaning weight and preweaning gain, and the fact that amount of creep feed consumed had a significant effect, suggests that calves do compensate for differences in milk production of their dams by consuming creep feed in relation to their genetic impulse for growth. Therefore, differences in mothering ability from 60 days to weaning do not have much effect on weaning weight when calves are creep fed during that period.

Another interpretation may be that cows which give the greatest amount of milk during the first 60-90 days give their calf a better start so that they are big enough to consume enough feed from 90 days to weaning to gain well and satisfy their genetic potential for growth. Research in progress should help to determine the effects of creep feeding on the expression of genetic differences among calves and expression of differences among cows for mothering ability. Also, the effect of creep feeding on subsequent production of calves as cows has not been determined. Research in progress should yield data from which this early postnatal environmental influence can be evaluated.

Differences in weaning weight are 25 to 30% heritable if nutrition and management conditions are well standardized and adequate adjustments are made for age of calf, age of dam and sex of calf. Development and determination of appropriate measures of preweaning growth and procedures of adjusting for age of dam and sex have received considerable attention in Regional Project NC-1.

The procedure of computing 200-day weaning weight adjusted for age of calf as birth weight + 200 x (average daily gain from birth to weaning) is reasonably accurate if there is not more than a three- to four-month spread in the age of calves at weaning.

Numerous studies have shown that age of dam has a significant effect on weaning weight and should be taken into account in adjusting weaning weights. Several reports indicate no significant interaction between age of dam and sex of calf.

In one study, interactions of age of dam with breed (Angus versus Hereford), season of birth, type of management (creep versus no creep) and type of pasture (native versus improved) were small and not significant. Thus, it appears that the same age of dam adjustments are appropriate regardless of sex, breed, season of birth, type of management and type of pasture. One report indicates that additive adjustments are more appropriate than multiplicative in adjusting for age of dam.

Results indicate that multiplicative corrections are most appropriate for adjusting weaning weight for the effect of sex. One study has indicated that a multiplicative adjustment not only equalizes vari-
ances within males and females better than additive adjustments but also accounts for the interaction between sex and type of management (creep versus no creep).

**Growth Rate**

Growth rate is of primary economic importance to the beef industry because of its high association with efficiency of gain and with pounds of retail trimmed beef produced. It is also important from the standpoint of its relationship to reduction in fixed costs such as veterinary, building, labor, interest, taxes and other expenses that are charged on a per unit of time basis.

Postweaning growth rate is moderately to highly heritable (30-60%). When postweaning growth rate has been measured in relatively long periods (up to 168 days) and with moderate-to high-energy rations, estimates of heritability have tended to be high. Heritability estimates for postweaning gains on pasture or in a relatively short feeding period with low levels of energy have tended to be lower. This may be due to the inadequacy of the lower level of energy intake to permit full expression of genetic differences, or to the increased importance of random or chance environmental variables under pasture and high-roughage ration conditions, or both. When several studies are considered, it appears that a shorter postweaning feeding period can be used to evaluate differences in growth rate on a high-energy ration but that a longer period is required when a ration relatively low in net energy is fed.

Final weight computed by adding postweaning gain during a standard time constant postweaning test to weaning weight adjusted for age of dam and age of calf is more highly heritable, and therefore a

*Yearling bull from Selection Experiment at the Fort Robinson Beef Cattle Research Station, Crawford, Nebraska.*
better measure of genetic differences in growth rate than any of its components (birth weight, preweaning gain or postweaning gain).

Estimates of genetic correlations among components of final weight are positive but the environmental correlations are negative. This should cause final weight to have a higher heritability than any of its components because the positive genetic covariances among the components tend to increase the percentage of variation in final weight which is accounted for by differences in breeding value among individuals, and the negative environmental covariances among the components act to reduce the environmental variation when the components are combined into one trait, final weight.

Paying some attention to weaning weight in addition to that resulting from attention to final weight may be justified to the extent that it is a better measure of maternal ability than final weight. However, recent experimental results provide indirect evidence that final weight may be as good a measure of maternal ability as weaning weight. It was observed that the effect of age of dam on postweaning gain was negligible. This is an interesting phenomenon in view of the negative environmental correlations that have been observed between pre- and postweaning gains and the observations from routine feeding trials that animals on a poor feed supply in one period may exhibit compensatory gains, and conversely, a higher than normal level of feeding tends to be followed by reduced response to high feed intake in a subsequent period.

If inherent differences in maternal ability behave in the same manner as differences in maternal ability associated with age of dam, then selection for final weight obtained by adding postweaning gain to weaning weight adjusted for age of calf and dam should put almost as much selection pressure on maternal ability as selection based on weaning weight alone. Additional research is needed to evaluate age-of-dam effects and other maternal effects on postweaning gain, and the possible compensating biological mechanisms involved.

The use of final weight has one other very important advantage as a selection trait. The major goal of the beef industry is to produce the maximum amount of lean meat of acceptable quality at the lowest possible cost. In a recent study, net merit was defined in these terms. Net merit was computed in four similar ways, one of which was \[ \text{85¢ plus or minus 1¢ per pound per one-third of a grade deviation from average choice quality grade times pounds of retail product minus feed cost from weaning to slaughter}. \] The results indicated that selecting for final weight alone is 90% as effective in selecting for net merit as selecting for an index combining preweaning and postweaning gain with feed consumption and an accurate measure of fat thickness.

Studies of the effects of age of calf on postweaning gains show that, when variation in age of individuals is not more than 60 to 90 days,
as would be the case with restricted breeding and calving seasons, age differences can be ignored.

**Efficiency of Gain**

Efficiency of gain has usually been studied as a function of the gain in body weight resulting from the consumption of a given amount of feed, or its inverse. Variation in composition of gains (fat, lean or bone) and in maintenance requirements prevent this measure from being a precise estimate of energy conversion rate.

The most useful criterion for evaluating efficiency of feed use by beef animals may be the amount of edible product produced for a given amount of energy intake, rather than the fraction of energy in the feed which was converted to animal tissue.

In most studies, only data on live weight gains have been available to measure efficiency of feed use. At a relatively young age, with adjustments for differences in weight (maintenance), variation in composition of gain may not be of serious consequence. However, additional research to determine the relative influence of appetite, maintenance and composition of gain on feed efficiency is needed.

Several methods of measuring feed efficiency based on live weight gains have been evaluated. One study involved three methods of measuring feed efficiency: (1) feed consumption adjusted for differences in gain and weight, (2) gain adjusted for differences in feed consumption and weight, and (3) the ratio of gain to feed consumed adjusted for weight.

Bull calves on individual self feeders at the Missouri Station.
It was concluded that gain after regression adjustment to equal feed consumption and weight was the most accurate method of measuring the cause and effect relationships involved in feed efficiency and had the highest heritability of the three measures studied (62%).

However, further results indicated that about 80% as much change in feed efficiency may be expected from selection for postweaning growth rate as by selection for feed efficiency itself because of the high genetic correlation between rate and efficiency of gain. However, the extra effort and expense of individual feeding required for measurement of feed efficiency may not be justified in most breeding programs.

In another study an estimate of feed consumed from weaning to 1000 pounds live weight was used to measure feed efficiency. From an industry-wide standpoint perhaps this measure of feed efficiency is more closely related to the real economic trait than any other measure used. It was observed that selecting for an index combining weaning weight and postweaning average daily gain would result in 75% as much improvement in net merit as an index which also included individual feed consumption.

Net merit was defined in terms of the cost of producing a 1000 pound beef animal taking into account weaning weight, postweaning gain and feed consumed. It was concluded that considerable genetic progress could be made in producing beef at a lower cost by selecting for weaning weight and postweaning gain.

Feed efficiency should be considered beyond growth and fattening to include the full life cycle of the beef animal. This is because 70 to 80% of the feed intake by our total beef cattle inventory is used to meet maintenance requirements and about 40 to 50% of the total feed intake is used to maintain breeding animals and to produce replacements. A high proportion of the feed intake of the beef cow is used to meet maintenance requirements.

However, little is known about genetic and environmental influences on maintenance requirements. The effect of size of cow on productive level relative to feed units required for maintenance and production is not known. Neither is the genetic correlation between efficiency of growth at a young age and maintenance requirements at maturity. Increased research is needed to evaluate genetic and phenotypic relationships among maintenance requirements, maternal ability and units of production including composition of growth. Some research is underway in this area and more is being planned.

**Longevity**

Longevity is an important trait from the standpoint of total industry efficiency. There is automatic selection for this trait because the animals that live longer tend to leave more offspring for possible re-
placements. For mass selection to be effective, reliable indicators of longevity in young breeding cattle must be developed. Since there has been very little research in this area, the feasibility of selection for longevity through indicators is unknown, nor is the effectiveness of pedigree selection known.

It is doubtful that deliberate selection through indicators or by pedigree information would result in appreciable genetic improvement in longevity because of the large number of factors, many of which seem to be environmental (accidents, disease, infections) that may reduce length of productive life. Also because of natural selection, it is not likely that much additive genetic variation remains. However, structural soundness, which may effect length of productive life, seems to be moderately to highly heritable.

One factor that reduces length of productive life is cancer eye. Research has shown that the incidence of cancer eye increases with age and that the heritability of susceptibility to cancer eye is moderate (30%). Also, incidence of lid cancers is associated with lack of eyelid pigmentation and the heritability of eyelid pigmentation is quite high.

Carcass Merit

The American public desires beef with a high percentage of lean relative to outside fat and bone and that lean must be tender, flavorful and juicy. Thus, carcass merit is a function of carcass composition and quality of the edible portion.

Equations based on carcass measurements have been developed which predict carcass composition quite accurately, accounting for a high percentage of the variation in either pounds of percent of muscle or closely trimmed retail cuts from the higher priced cuts. However, if
mass selection for carcass merit is to be effective, reliable indicators of carcass traits in live cattle are needed. It has been estimated that under practical conditions, mass selection would be approximately four times more effective in improving carcass traits than selection based on progeny test information if differences could be accurately measured in live cattle. This has stimulated investigation of indicators of carcass merit in live animals.

Beef cattle breeders have traditionally used subjective evaluation of conformation to exert selection pressure on carcass merit. Research in Regional Project NC-1 has indicated that experienced appraisers can subjectively estimate group means for carcass grade, cutability (percent of closely trimmed, boneless, beef from round, loin, rib and chuck relative to carcass weight) and other carcass traits with reasonable accuracy provided the graders have knowledge of the feeding and management program to which the cattle have been subjected and a knowledge of live weights.

With cattle of the same sex within a herd that are fairly uniform in age and have been fed and managed alike, as is the case in practice, 25 to 30% of the variation in actual cutability can be accounted for on the basis of live estimates of cutability by experienced appraisers. Although the very poorest cattle can probably be identified, this precision is less than desired for making individual prospective breeding cattle for differences in cutability.

Selection for growth rate will do more to increase pounds of edible meat at a constant age than selection for any other trait. Final weight accounts for 80 to 88% of the variation in pounds of boneless retail trimmed beef on an age constant basis. These studies were conducted on a within herd and sex basis where feeding and management conditions were standardized, the conditions under which selection should occur.

Variation in live weight adjusted for age is many times more important than variation in dressing percent and composition in determining pounds of edible product. Also, results indicate that variation and the heritability of differences in carcass composition within a herd and breed on a weight constant basis is low (10-15%). Thus, as far as pounds of edible meat is concerned, growth rate is the major trait that needs to be measured and selected for.

Results have indicated that an accurate live animal measure of fat thickness would increase slightly (5-8%) the accuracy of selection for pounds of retail product, above that from selection for final weight at a constant age alone.

An extensive study has been conducted to evaluate the use of the thermistor probe technique of measuring fat thickness. In several experiments, correlation coefficients between live and carcass measurements over the *longissimus dorsi* at the 12-13th rib were moderate to high (.5-.8) when computed on a within breed and sex basis. The live-
probe estimate of fat thickness increased the accuracy of predicting weight of muscle in the carcass 6% over that of live weight alone.

Ultrasonic measurements have about the same degree of accuracy as the thermistor probe in measuring differences in carcass fat thickness. However, results of one study indicated that ultrasonic estimates of fat thickness did not contribute to the accuracy of predicting pounds of retail product above that of live weight alone \( (R^2=.89) \). Other approaches that are being evaluated for measuring carcass characteristics of live cattle include liquid scintillation counter and biopsy techniques.

Carcass traits have been measured and expressed in many ways. Ratios and percents have been used frequently in expressing various measures of fat, lean and bone in the carcass. Results of one study indicate that expressing traits such as pounds of retail product as a percent of carcass weight does not adjust for differences in carcass weight. It merely changes the sign of the correlation between the trait and weight and therefore is not a satisfactory weight adjustment procedure in breeding programs. In other words, the use of percent does not reflect differences that would have been observed in two animals had they been slaughtered at the same weight. Regression procedures do this more adequately and should be used to adjust for differences in carcass weight in breeding or production-oriented programs.

Beef cattle breeders should be concerned with selection for the maximum amount of lean meat of acceptable quality at the lowest possible cost. In the study where net merit was defined in these terms, weight of retail product at a constant age accounted for 96% of the variation in net merit. Thus, it appears that considerably more attention should be given to differences in weight of retail product or edible portion at a constant age in breeding programs than to differences in proportion of fat, lean and bone. The use of ratios and percents should probably be limited to the packing and retail segment of the industry where they are useful in establishing retail value of beef carcasses.

Differences in carcass quality have been found to be moderately to highly heritable. The heritability for carcass quality grade, which is determined primarily by marbling, is 40%. Differences in tenderness appear to be even more highly heritable (60%). A selection experiment where herd bulls are selected on the basis of tenderness and then used by artificial insemination is in progress. One of the important research responsibilities is that of evaluating and providing new tools for improved methods of evaluating carcass composition and quality if ap-

---

1 The thermistor probe is a needle which has thermistor beads located within it near its tip which detect and relay temperature to a temperature dial. A hide puncture is made with a bleeding needle, then the thermistor needle is inserted in the hide puncture. Since the temperature of muscle is about three degrees higher than that of fat in the live animal, the needle can be used to measure fat thickness.
preciable genetic improvement is to be made in carcass merit. Continued emphasis is being given to these items in NC-1 investigations.

**Inbreeding and Heterosis**

Performance in most economically important traits declines with inbreeding. Fertility and mothering ability show the greatest decline. Effects of inbreeding on growth and carcass characteristics are less severe. The use of inbreeding depends largely on the amount of heterosis or hybrid vigor that can be obtained from the systematic crossing of inbred lines perhaps through a rotational sires program.

Preliminary results from crossing Hereford lines that are at relatively low levels of inbreeding indicate that heterosis may be appreciable in specific crosses. The performance of some of these lines in top cross evaluations, when compared to outbred stocks, indicates that within line selection has been effective in improving traits that have an appreciable amount of additive genetic variation.

The development of inbred lines is continuing in order to study problems associated with their development, to evaluate heterosis further, and to determine the possibilities of using heterosis through the systematic crossing of inbred lines.

Comprehensive analyses have been made on the data from the first phase of an extensive crossbreeding experiment involving the Hereford, Angus and Shorthorn breeds. In the first phase of the experiment the three straightbreds and all reciprocal crosses among them were produced. Heterosis or hybrid vigor was evaluated by comparing the crossbreds with the average of the straightbreds for all major economic traits involved from conception through growth and onset of puberty for heifers and through growth and slaughter of the steers.

*Straightbred and crossbred cows of Angus, Hereford, and Shorthorn breeds with their crossbred calves in the experiment at Fort Robinson to evaluate heterosis in fertility and mothering ability.*
The effects of heterosis were significant for most of the traits evaluated. A 3% greater calf crop was weaned in the crossbred calves than in the straightbred calves because of differences in early postnatal mortality.

The heterosis effect for weaning weight was 24 pounds (5.8%) in heifers and 16 pounds (3.6%) in steers. The heterosis effect in heifers on a low level of feeding was 52 pounds (7.3%) for 550-day weight. This was greater than that of 29 pounds (3.3%) for 452-day weight in steers on a growing and fattening ration.

There are two plausible explanations for this difference. One is that heterosis is related to level of feeding, having a greater influence when feed intake is restricted. The second is that heterosis is greater in heifers than in steers in both preweaning and postweaning growth. An experiment has been initiated to distinguish between these causes. Heterosis for growth rate tended to decrease with increasing age after approximately one year of age in both sexes.

Heterosis effect on age at first heat was 41 and 35 days for low and moderate levels of feeding, respectively. After adjusting age at puberty for the effects of average preweaning and postweaning gains, approximately one-half to three-fourths of the heterosis effect on age at puberty remained. Thus, heterosis affected age at puberty independent of its effects through average daily gains.

The advantage of the crossbred steers in feed efficiency was small. Crossbred steers produced slightly fatter carcasses when killed at the same age. However, when adjusted for the effect of weight there was no difference in carcass composition. In net merit (value of boneless, closely trimmed retail meat, adjusted for quality grade, minus feed costs from weaning to slaughter based on price levels in 1965) the advantage of crossbred steers over straightbred steers was $8.81 per
carcass and this did not take into account the 3% advantage in calf crop weaned.

For growth, feed efficiency and carcass traits, the heterosis effect was greater in the Hereford-Angus and Hereford-Shorthorn combinations than in the Angus-Shorthorn combination, and for age and weight at puberty, the heterosis effect was greatest for the Hereford-Shorthorn reciprocal crosses. In evaluating all traits, it can be concluded that heterosis results in earlier maturity.

The first phase of another experiment in which straightbreds and reciprocal crosses of the Hereford and Charolais breeds were produced has recently been completed. Crossbred calves had an advantage of 4% over straightbreds for growth. There was no apparent hybrid vigor in amount of feed needed to produce a unit of gain. There was little heterosis in carcass traits except that crossbreds tended to be fatter than the average of the Herefords and Charolais.
Charolais calves had faster growth rates and produced heavier carcasses with more edible portion and less fat trim than Herefords. Hereford carcasses had higher marbling scores and grades than Charolais. Most of the calving difficulties were encountered with two-year-old heifers. Herefords bred to Charolais bulls were the most troublesome. As a result, only slightly higher calving percentages were obtained from cross-breed matings. Only limited calving problems were experienced following the first calf regardless of breed or cross.

The low heritability of fertility and the moderate heritability of mothering ability suggest that these are the traits on which heterosis (non-additive genetic variance) will have its most important effect. The second phase of these experiments designed to evaluate heterosis in fertility and mothering ability are now in progress. Preliminary results from the experiment involving the Hereford, Angus and Short-horn breeds indicate considerable heterosis for reproduction and mothering ability.

Results of a preliminary analysis on data obtained in the first five years in this experiment indicate that approximately 7% more calves (9.1% heterosis) have been weaned by crossbred dams (80.2%) than by straightbred dams (73.5%). Crossbred calves out of crossbred dams have on the average had 5% heavier weaning weights than crossbred calves out of straightbred dams. When both of these traits are considered, a 15% advantage in favor of crossbred cows has been realized for pounds of calf weaned per cow bred. It appears that systematic crossbreeding programs could be used by commercial cattlemen which could increase their production 15 to 20% per cow bred above that of programs involving straightbreds.

In addition to the experiments described above, extensive crossbreeding studies involving the Hereford, Angus and Charolais, the Angus and Milking Shorthorn and the Angus, Hereford, Holstein and Brown Swiss breeds have recently been initiated. Plans are being made to evaluate different procedures and crossbreeding systems for utilization of heterosis in commercial beef production programs.

Research is needed to characterize breeds for their additive and non-additive genetic merit relative to all traits of economic importance in the full life cycle of beef cattle. Increased emphasis is being given to research in this area in NC-1 investigations.

**Genotype-Environment Interactions**

Beef cattle provide a means of utilizing feed resources over a wide range of climatic conditions and in various types of production programs. The industry is characterized by a great amount of exchange of breeding stock among widely varying climates. Little is known about
the range in adaptability of the different families, breeds, types, etc., to the different climatic conditions and environmental regimes in which beef cattle are produced.

One recent experiment did pertain to this objective. In Phase I of the heterosis experiment involving the Charolais and Hereford breeds, two management systems were evaluated. Half of the calves were creep fed, fed out and slaughtered at a relatively young age of about 14 months and the others were wintered on a growing ration, grazed for 60 days, fattened in drylot and slaughtered at about 20 months.

A number of traits measuring rate and efficiency of growth and carcass composition and quality were evaluated. Significant breeding group x management system interactions were detected only for edible portion per day of age and marbling score.

Charolais calves produced more edible portion per day of age than Hereford calves and this difference was greater when they were creep-fed than when they were managed by the deferred system. Hereford and crossbred calves slaughtered at the younger age had higher marbling scores than those on the deferred system while the opposite was true with the Charolais calves.

Some experiments under way or being planned will yield further information on the importance of genotype-environment interactions. An evaluation of the importance of such interactions, and of the importance of selection for adaptability to specific climatic conditions and production programs, is needed in making correct decisions regarding the most effective breeding plans. Increased research is needed to answer some of these important questions.
Heritabilities and Genetic Correlations

Estimates of heritabilities and of genetic and phenotypic correlations among economically important traits have been discussed in previous sections. With the exception of fertility, traits of economic importance are moderately to highly heritable (Table 1). The high and favorable genetic correlations among growth rates in different phases of the life cycle, between growth rate and pounds of edible product, and between postweaning growth and efficiency of feed conversion have been discussed.

Important genetic antagonisms have not been detected among most performance traits. A possible exception to this involves estimates of the genetic correlation between marbling score (traces=3, slight=4, . . . , abundant=10) and cutability (% closely trimmed boneless retail cuts from round, loin, rib and chuck) reported to be −0.8 and −0.85. However, a more recent estimate of the genetic correlation between marbling and weight of edible product with carcass weight held constant by regression was slightly positive. Further investigations are needed to elucidate the genetic relationship between these traits.

Estimates of genetic correlation among a number of traits and their biological components that contribute to net merit in beef cattle are still needed to develop the most effective selection procedures.

The more pertinent unanswered questions are: What is the genetic correlation between growth rate and maternal ability? What are the genetic correlations among growth rate, mature cow size, maintenance requirements in different phases of the life cycle, and units of production by the cow? What are the genetic correlations among growth rate, appetite, feed efficiency independent of appetite, and composition of gain both on an age constant and on a weight constant basis? Answers to these important questions are being sought in NC-1 investigations.

Even though heritabilities of most of the economically important traits seem high enough for selection to be reasonably effective and few important genetic antagonisms exist, the effectiveness of mass selection for these traits remains to be demonstrated experimentally. Selection experiments for specific traits with measurement of correlated response in other traits have been initiated in the NC-1 project. These are controlled experiments so that genetic and environmental time trends can be partitioned. Although these experiments have not yet been underway long enough to evaluate the effectiveness of selection, they are designed to provide direct estimates of heritability and correlated response for economically important traits, an important objective of Regional Project NC-1.
Breeding and Selection Procedures

A thorough knowledge of measurement procedures for all economically important traits, and reliable estimates of their genetic parameters (heritabilities, genetic correlations, inbreeding effects, heterosis effects and genotype-environment interactions), are needed to plan and conduct effective research programs to evaluate selection and breeding procedures experimentally. As such knowledge accumulates, increased emphasis will be placed on evaluation of breeding and selection procedures with samples of actual cattle populations and with electronic computers and simulated populations. Such research will provide beef cattle breeders with information on the most effective breeding practices to make the most rapid genetic improvement in the traits that contribute to productive efficiency and carcass merit. This information is essential if beef cattle breeding is to be fully exploited in the development of the most efficient agriculture.

Hereditary Defects

A large number of hereditary defects of possible economic importance have been reported in all breeds of beef cattle and also among dairy breeds. The hereditary defect most familiar to beef cattle breeders is “snorter” dwarfism, which occurred at troublesome frequency in some herds in the late 1940’s and early 1950’s. Concern about “snorter” dwarfism stimulated research to develop procedures for identifying of “carriers” of this defect.

Procedures which have been evaluated in NC-1 include radiography, median head profile readings, and differential physiological response (blood constituents, etc.) with and without the use of stress agents. Though these studies have revealed differences in means of “clean” and “carrier” groups, the overlap has been too great to warrant their use as a basis for the guarantee of a dwarf-free breeding herd.

Even though the research to develop a technique approaching 100% accuracy for detection of “carriers” of snorter dwarfism has not been completely successful, research has established that the inheritance of this kind of dwarfism is due to a simple autosomal recessive. This knowledge has enabled scientists to counsel with the industry on effective ways of reducing the frequency of this gene in seedstock herds. The “snorter” type of dwarfism has been authentically reported in the Angus and Hereford breeds.

Other types of dwarfism have also been investigated in NC-1. Research indicates that “long-head” dwarfism is also inherited as a simple autosomal recessive distinct from “snorter” dwarfism. This type of dwarfism has been identified in the Angus breed. Results suggest that the “comprest” condition is due to the action of a pair of genes which do not show dominance. The three phenotypes and genotypes are: normal (NN), “comprest”(Nn), and extreme dwarf (nn). The “com-
prest” condition in Herefords and the “compact” condition in Short-horns are probably due to the same gene.

A lethal form of hydrocephalus has been shown to be inherited as a simple autosomal recessive. This condition has occurred at a frequency high enough in some herds to cause concern and scientists are counseling with breeders and producers on ways of reducing the frequency of this gene in individual herds.

One experiment is being conducted to provide information on the mode of inheritance of “double muscling.” Sufficient data are not available to establish the mode of inheritance for this trait.

A spastic lethal has been identified in a closed line of Hereford cattle. Results indicate that it is inherited as a simple autosomal recessive. The inheritance of a sublethal achondroplasia, characterized primarily by malocclusion of the incisors resulting from a misshapen mandible, was also investigated and is probably inherited as a simple autosomal recessive.

APPLICATION OF RESULTS AND PERSPECTIVE

Approximately 400 scientific and technical reports have been published on research conducted in Regional Project NC-1. These publications contribute greatly to our knowledge of procedures for measuring most economically important traits and provide estimates of their heritabilities and genetic correlations. This knowledge has made it possible for beef cattle breeders to adopt Record of Performance Programs aimed at genetic improvement in the traits that contribute to productive efficiency and desirability of product.

Education programs to inform beef cattle producers of the methods of achieving genetic improvement have been initiated under the leadership of NC-1 scientists and Extension specialists in most states in the region. Subject matter for these programs comes primarily from research findings in this project. Record of Performance Programs applying the results of this research under the guidance of State Agricultural Extension Services are underway in most of the states cooperating in NC-1.

Each major beef cattle breed association has initiated a Record of Performance Program for its membership. Information provided by Record of Performance Programs is making it possible for breeders to increase the accuracy of their selections, thus accelerating rate of genetic improvement and giving them greater control over their operations. Activity in this area continues to show an increase. Increasing interest by the commercial segment of the industry in crossbreeding throughout the region is largely due to results reported from heterosis experiments in Regional Project NC-1.

The entire beef cattle industry has indicated keen interest in the NC-1 research program. Prompt application of the results evolving
from this effort is indicative of the need for increased knowledge on beef cattle breeding. While the results already obtained from this project have had a marked influence on the breeding programs in many of our seed stock herds, it must be emphasized that much remains to be done to provide the basic information necessary to guide the beef cattle industry in attaining maximum efficiency in producing the most desirable beef.

A principal accomplishment of NC-I has been to focus attention on the impact that research on beef cattle breeding can have on reducing production costs and improving the desirability of product through the application of knowledge that comes only from well-organized and properly conducted research.

It is not realistic to expect short-term results of a sensational nature from research in this area because knowledge necessarily accumulates slowly but it is evident that this project has already made significant contributions to increased knowledge and that this knowledge has had a substantial impact on the beef cattle industry.

Regional Project NC-I aims always at reliable answers to the more pertinent unanswered questions, one question well answered being considered worth several partially answered. Contributing projects have been effectively adapted to regional objectives and to the available resources, with sound experimental designs that will yield interpretable results.

Though the accomplishments of the past 19 years are impressive, current progress toward answering some of the major fundamental questions indicates that the most important contributions of Regional Project NC-I lie ahead.

PUBLICATIONS FROM REGIONAL PROJECT NC-I

I. Journal Articles


27. Fowle, K. E., J. H. Cline, E. W. Klosterman and C. F. Parker.  

28. Gregory, K. E.  

1951. Correction factors for adjusting weaning weights of range calves to the constant age of 190 days. J. Animal Sci. 10:371.
42. Klosterman, Earle W., L. G. Sanford and C. F. Parker.  
43. Koch, Robert M.  
49. Lindley, C. E., G. T. Easley, J. A. Whatley, Jr. and D. Chambers.  

II. Research Bulletins, Station Bulletins, Station Circulars, Miscellaneous Publications, etc.

   1953. Weaning weight of calf as a measure of mothering ability of the
   1956. Selection of beef bulls based upon records of performance and visual
   1962. Efficiency of gains by beef calves as influenced by weight and rate
    1956. Selection of beef bulls based upon records of performance and visual
    1962. Efficiency of gains by beef calves as influenced by weight and rate
14. Chambers, Doyle, L. S. Pope, J. A. Whatley, Jr., G. Bratcher and D. F.
    Stephens.
    1966. Factors to take into account when adjusting weaning weights of
        Series 67-10.
        140. Brookings, S. D.
        Brookings, S. D.
        Circ. 130. Brookings, S. D.
        Sta., Brookings, S. D.
    1960. Blood sugar level in normal and dwarf beef cattle before and after


29. Gregory, K. E.  

30. Gregory, Keith E.  

31. Gregory, K. E.  


35. Klosterman, Earle W.  


37. Klosterman, Earle W., V. R. Cahill, C. F. Parker and Walter R. Harvey.  

38. Knutson, R. D.  


41. Lasley, J. F., J. E. Comfort and J. O. Butcher.  

42. Lasley, J. F. and Bill N. Day.  

43. Magee, W. T.  

44. Magee, W. T.  


III. Progress Reports

1. Adams, C. H.

2. Adams, C. H.


6. Arthaud, V. H.


11. Comfort, J. E.


19. Dinkel, C. A.  

20. Dinkel, C. A.  


22. Dinkel, C. A.  


24. Dinkel, C. A.  


59. Koch, Robert M.

60. Koch, Robert M.


64. Lasley, J. F. and J. E. Comfort.


70. Lasley, J. F., J. E. Comfort, Joe Sagebiel, Robert Sibbit and Larkin Langford.


72. Magee, W. T.


74. Martin, T. G.

75. Martin, T. G., W. M. Beeson, M. T. Mohler and T. W. Perry.
76. Martin, T. J., L. W. Douglass and V. A. Garwood.  

77. Martin, T. G. and Martin Stob.  

78. Martin, T. G., Martin Stob, M. T. Mohler and H. L. Pearson.  


83. Smith, R. O.  


IV. Abstracts


1961. Synchronization of estrus in heifers with 6 Alpha-Methyl 17 Alpha Acetoxyprogesterone and its effect on subsequent ovulation and fertility. J. Dairy Sci. 44. (Abstr.)


21. Dinkel, C. A.  
28. Hicks, Barbara J. and L. N. Hazel.  
1962. Heterotic effects of age and weight at puberty in beef heifers. Western Section, American Society of Animal Science. (Abstr.)
37. Lindley, C. E., J. A. Whatley, Jr., G. T. Easley and D. Chambers.  
39. Magee, W. T.  


V. Theses

16. Conley, Gary O.  

17. Cooper, R. E.  

18. Cundiff, Larry V.  

19. Curl, Sam E.  

20. Dearborn, Delwyn.  

21. Delcour, Ivy L.  

22. Dev, V. Gangathara.  

23. Douglass, L. W.  

24. Drewry, K. J.  

25. Dunn, Richard.  

26. Eaton, L. W., Jr.  

27. Evans, Lee.  

28. Fitzgerald, Marion.  

29. Foley, C. W.  

30. Foote, W. D.  

31. Fowle, K. E.  


33. Gottlieb, H. A.  
34. Gregory, K. E.
   1949. A study of some of the factors influencing the birth and weaning weights of beef calves. M. S. Thesis, Univ. of Nebraska Library. Lincoln, Nebr.

35. Greiman, Byron J.

36. Hansen, Carl.

37. Hawkins, D. R.

38. Heins, R. G.

39. Hicks, Barbara J.

40. Hoover, C. Dale.

41. Howarth, Birkett, Jr.

42. Jacobs, D.

43. Johnson, L. J.

44. Kattestad, Roger.

45. Kelley, Archibald N.

46. Kieffer, Nat M.

47. Knutson, R. D.

48. Koch, R. M.

49. Koch, Robert M.

50. Kress, D. D.

51. Lindley, C. E.
52. Lucas, Leo E.  

53. Lucas, Leo E.  

54. Luttrell, Harlon E.  

55. Minyard, J. A.  

56. Moore, Delbert G.  

57. Orme, L. E.  

58. Pepito, Narciso Noval.  

59. Perks, D. R.  

60. Pherigo, Dan L.  

61. Rankin, B. J.  

62. Rankin, B. J.  

63. Ranney, Royal W.  

64. Ray, D. E.  

65. Rothlisberger, John A.  

66. Sanford, L. G.  

67. Saubidet, C. A. L.  

68. Sewell, H. B.  

69. Skinner, P. E.  

70. Smith, Charles.  

71. Srivastava, L. M.  
72. Srivastava, P. K.

73. Srivastava, P. K.

74. Stanley, Marion E.

75. Stark, C. F.

76. Stufflebeam, C. E.

77. Stufflebeam, C. E.

78. Subramanian, R.

79. Swiger, L. A.

80. Tallis, G. M.

81. Taylor, R. E.

82. Temple, R. S.

83. Turner, J. W.

84. Turvey, W. Allen.

85. Williams, David C.

86. Wilson, L. L.

87. Wilson, L. L.
1965. Environmental and genetic influences on various blood constituents and relationship of these constituents to traits of economic importance in beef cattle. M. S. Thesis, Univ. of Missouri. Columbia, Mo.

88. Wilson, L. L.

89. Zoellner, Keith O.