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

Keith E. Gregory

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Improvement of Beef Cattle Through Breeding Methods

Summary of Results From Regional Project NC-1

by

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; A. W. Epp, Acting Director
PERSONNEL ON REGIONAL PROJECT NC-1

Administrative Adviser*  
Regional Coordinator**  
Illinois  
Indiana  
Iowa  
Kansas  
Michigan  
Minnesota  
Missouri  
Nebraska  
North Dakota  
Ohio  
Oklahoma  
South Dakota  
Wisconsin

Roy M. Kottman  
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R. E. Comstock  
J. E. Comfort and J. F. Lasley  
M. L. Buchanan  
E. W. Klosterman  
Doyle Chambers  
C. A. Dinkel  
E. R. Hauser

*Dean, College of Agriculture, Ohio State University, Columbus, Ohio, and Director, Ohio Agricultural Experimental Station, Wooster, Ohio.


Additional copies of this publication may be obtained from the above personnel at the Animal Husbandry Departments of the State Colleges or State Universities indicated.
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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 of beef cattle. This project involves the search for new facts that can be used by breeders to improve the inherent productive efficiency and carcass desirability of beef cattle.

This publication provides a summary of some of the more important results from this project during its first 12 years of operation. The results summarized in this publication are by no means complete and include 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.

The relatively short time that this project has been active prohibits the drawing of many general conclusions at this time. This publication is in the nature of a progress report on many aspects of beef cattle breeding research. 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 "keener" perspective to presently perplexing problems. While the interpretations of the research results presented seem logical in light of the available information, it is to be expected that additional knowledge may change or modify some of the results and interpretations.

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

This research bulletin was prepared by Keith E. Gregory, regional coordinator, in collaboration with the other members of the Technical Committee listed under Personnel on Regional Project NC-1.
Summary of Results from Regional Project NC-1

IMPROVEMENT OF BEEF CATTLE THROUGH BREEDING METHODS

Keith E. Gregory

INTRODUCTION

The major purpose of this project is to obtain information that beef cattle breeders can use to make maximum genetic 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 quality or 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 major objectives of NC-1 are the following: (1) to determine the traits of economic importance in beef cattle; (2) to assess their relative value; (3) to develop reliable methods and procedures for measuring and evaluating them; (4) to obtain estimates of their heritabilities; (5) to obtain estimates of the genetic and phenotypic correlations among all economically important traits; (6) to evaluate the effects and uses of inbreeding and heterosis; and (7) to measure the importance of genetic-environmental interactions.

Further objectives are to determine the effectiveness of different breeding and selection procedures for making genetic improvement in the traits of economic value. An additional objective is to determine the mode of inheritance of defects, lethals, and semi-lethals and methods of controlling them. Answers to these important questions should result in more effective breeding practices, contributing to reduced production costs and a more desirable product.
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; selection methods and procedures; and the estimation of heritabilities and genetic correlations from long-term selection experiments.

In the development of this project, a period of several years has been involved in 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 5,000 cattle (largely purebreds) in the 12 contributing projects. 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 is in progress which will provide information on all objectives, and increased emphasis is being given to the areas that need additional attention. Reasonable progress is being made on most of the objectives, and each station is effectively using its facilities, personnel, etc., through a coordinated effort in attacking 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 many studies for some of the economically important traits of beef cattle are presented in Table 1.
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>30</td>
</tr>
<tr>
<td>Rib Eye Area</td>
<td>70</td>
</tr>
<tr>
<td>Tenderness</td>
<td>60</td>
</tr>
<tr>
<td>Cancer Eye Susceptibility</td>
<td>30</td>
</tr>
</tbody>
</table>

*Averages include studies in addition to those made in NC-1.

Reproductive Performance or Fertility

Results indicate that the heritability of this trait is quite low (Calving Interval, Table 1). The low heritability is in agreement with results from other species and probably should be anticipated since natural selection for this trait has occurred since cattle evolved; thus, the additive genetic variance has probably been greatly reduced.

With a 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 dependent on reasonably high reproductive rates since the proportion produced that are needed for replacement does affect the intensity of selection.

Research is underway in this project to develop improved measures of this trait for both males and females and to provide additional information on the additive and non-additive genetic variation in the more important components of fertility in the female. These components of fertility include age at puberty, interval from calving to first estrus, conception rate, and embryonic mortality. Results from other species indicate that heterosis (non-additive genetic variance) has an important effect on this trait. The influence of heterosis on the fertility of beef cattle has not been sufficiently evaluated to permit conclusions at this time.
**Birth Weight**

Numerous studies have revealed birth weight to be rather highly heritable (30-50%). The results also show a positive genetic correlation between birth weight and post-natal rate of gain. However, direct selection for heavier birth weights would not seem desirable because of the increased likelihood of calving difficulty. Selection for traits that are of major economic importance should favor selection toward the optimum birth weight. Because of the high positive genetic correlation between birth weight and post-natal gain, it may be useful progeny test information in deciding which sires to use for their second breeding season since this is all of the progeny information available at this time.

**Mothering or Nursing Ability**

As measured by weaning weight of the calf, selection for this trait should be reasonably effective in that the repeatability of weaning weights seems to be reasonably high (30-50%). The calf's own genetic impulse for growth and its dam's nursing ability are confounded in weaning weight. This should not be a serious handicap in practice, since half of the growth impulse of the calf is transmitted by the dam. A heritability estimate of mothering ability, as measured by calf weaning weights, was quite high in one study (40%).

Research results indicate that differences in mothering ability can be evaluated about as accurately on the basis of 112-day calf weights as on the conventional weaning age of approximately 200 days. Coefficients of variation of the weaning weights of creep-fed and noncreep-fed calves have been comparable. At first glance this may be interpreted to mean that creep-feeding does not interfere with the appraisal of differences in cows for mothering ability. However, there is a possibility that creep-feeding may increase the accuracy of the measurement of the calf's own genetic impulse for growth, in that calves out of poor milking cows may tend to eat more feed than calves with a comparable growth impulse out of better milking cows. This situation could result in approximately equal coefficients of 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 growth impulse of the calves.

More research is needed in this area to determine the effects of creep-feeding on the expression of genetic differences among calves for growth and the expression of real differences among cows for mothering ability. Research is in progress that should help to clarify these questions. Because of the tendency of marketing cattle at younger ages, weaning weight is an increasingly important trait in that a larger percentage of a slaughter animal's life is in the pre-weaning period.
Adjustment factors for differences in age of calf, age of dam, and sex of calf have been developed at most stations. Because these items influence weaning weight, comparisons are more accurate if adjustments are made for variations in them. The heritability of differences in growth rate prior to weaning seems to be approximately 20-30%.

**Growth Rate**

Numerous studies have revealed that post-weaning growth rate is a highly hereditary trait in beef cattle (30-60%). In general, preliminary results indicate a positive genetic correlation between pre-weaning and post-weaning growth rate.

The beef cattle industry is interested in growth rate from the standpoint of its association with efficiency of gain and the reduction in fixed costs such as veterinary, building, labor, interest, taxes, etc., that tend to be on a per head or a per unit of time basis. In the main, growth rate has been measured in time-constant, post-weaning feeding tests; however, two stations have been feeding to a constant fatness or condition.

In general, results indicate that the heritability of growth rate is larger in longer feeding tests (up to 168 days) than in shorter feeding tests. However, there is some evidence indicating that under high levels of feeding, with the tests starting immediately after weaning, differences in genetic worth for growth may be evaluated almost as precisely with a shorter feeding period. Preliminary results indicate that a reasonably high level of feeding is desirable to appraise growth rate most accu-
rately, especially if a short feeding period is used. Final weight at 12-18 months of age seems to be a better measure of differences in growth rate than any of the components of final weight (i.e., birth weight, pre-weaning gains, and post-weaning gains).

There are still many unanswered questions regarding the most accurate appraisal of differences in growth. These questions are concerned with optimum level of feeding, optimum length of feeding period, and the different types of post-weaning tests, such as time-constant, age-constant, weight-constant, etc. Research is in progress which should answer most of these important questions.

Research indicates that high levels of concentrate feeding of heifers, which may be desirable to obtain the most accurate measure of differences in growth rate, may tend to interfere with future productivity; that is, reproductive performance and mothering ability. Because such a high percentage of heifers are needed for replacements (approximately 40%), there is not much opportunity to select among heifers for differences in growth rate. Hence, very little can be gained from the heavy feeding of heifers from this standpoint.

Efficiency of Gain

Preliminary results indicate a rather high genetic correlation between rate and efficiency of gain. Since weight and age influence efficiency of gain, adjustments must be made for differences in these variables when measuring differences in efficiency. This method of measuring efficiency does not take into consideration differences in composition of gain. However, if done at a relatively young age and with adjustments for differences in weight, variations in composition of gain may not be of serious consequence. Differences in efficiency seem to be relatively more important than differences in feed consumption in accounting for differences in rate of gain. The heritability of differences in efficiency of gain seems to be reasonably high (30-50%). Increased research is needed to evaluate the relative importance of differences in efficiency of gain that are associated with differences in feed consumption and differences in efficiency of metabolic processes. Some research is underway in this area, and more is being planned.

Preliminary results indicate that the genetic correlation between rate and efficiency of gain may be high enough so that the rate of genetic improvement in efficiency, when evaluated by differences in growth rate, may compare favorably with that obtained by measuring efficiency directly when selecting for total performance. However, it is emphasized that this should be considered as a preliminary observation.

Longevity

With a higher proportion of our beef cattle population being made up of breeding cows, longevity is an increasingly important trait from the standpoint of total industry efficiency. There is automatic selection
for this trait in that the animals that live longest tend to leave the greatest number of offspring for possible replacements. For mass selection to be effective, reliable indicators of longevity in young breeding cattle must be developed. Since very little research has been conducted in this area, little information is available in regard to such indicators. It is not known how feasible selection for longevity through indicators might be, nor is it known how effective pedigree selection is for this trait. It is doubtful if deliberate selection through indicators or by the use of 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, etc.), that may reduce length of productive life. However, structural soundness, which may affect length of productive life, seems to have rather high heritabilities.

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 reasonably high (30%). Research has also shown that the incidence of lid cancers is associated with lack of eyelid pigmentation and that the heritability of eyelid pigmentation is quite high.

**Carcass Desirability**

If mass selection for carcass desirability is to be effective, reliable indicators of desirable carcass traits must be developed for use in evaluating differences in live breeding cattle at the time replacements are

The use of ultrasonic equipment for estimating differences in fat and muscling in live cattle is being evaluated at the Missouri Station. Other stations in the region are also evaluating this technique.
added to the breeding herd. It has been estimated that under practical conditions the rate of genetic improvement in carcass traits would be only approximately one-fourth as rapid from using progeny test information as from mass selection. This assumes that differences in carcass characteristics can be evaluated rather accurately in live breeding cattle.

Present information indicates that the American public desires beef with a high percentage of lean relative to outside fat and bone and that the lean must be tender, flavorful, and juicy. Thickness of muscling and tenderness are traits with rather high heritabilities (50-70%). Methods are needed for measuring lean and fat in prospective breeding cattle if research is to provide the industry with techniques for making maximum genetic improvement in these traits. Results indicate that rib eye area is of limited value in evaluating differences in muscling in the entire carcass. The analyses of live animal scores and linear body measurement data indicate that they are of limited value for predicting differences in carcass characteristics. Results indicate that differences in outside fat cover are a very important source of variation affecting yield of edible meat from the carcass. Hence, the development of procedures for appraising differences in outside fat of live breeding cattle should be quite useful.

Mechanical and electrical conductivity methods of measuring fatness in live cattle are not very accurate for establishing small differences. An approach employing ultrasonic techniques is presently being

Measuring differences in tenderness of beef with a Warner-Bratzler Shear at the Nebraska Station.

The use of the Thermistor Thermometer for measuring differences in outside fat of live cattle is being evaluated at the Nebraska Station.
investigated, but research has not been extensive enough in this area to know the real potential of this technique. Other approaches that are being evaluated for predicting carcass characteristics in live cattle include the use of thermistor thermometer, isotopes, and biopsy techniques. One of the important research responsibilities is that of providing new tools for improved methods of evaluating conformation in beef cattle if appreciable genetic improvement is to be made in carcass desirability. Increased emphasis is being given to this area in NC-1 investigations.

**Inbreeding and Heterosis**

Research has shown that level of performance in most of the economically important traits declines with inbreeding. Fertility and mothering ability are the traits that seem to show the greatest decline with increased intensity of inbreeding.

Bulls from production selected inbred lines have consistently performed well relative to outbred bulls from breeders' herds in topcross tests on outbred stocks. It is not known what proportion of this improved performance, if any, is due to heterosis and what proportion is due to the selection practiced in these lines. Since this increased performance would seem to be due largely to additive gene effects, the most logical inference is that these results are largely the effects of selection in these lines.

The use of inbreeding would seem to be dependent largely on the amount of heterosis or hybrid vigor that can be obtained from the

Steers from crossbreeding experiment at the Fort Robinson Station. Straightbreds of the Angus, Hereford, and Shorthorn breeds and the reciprocal crosses among them are included in this experiment. These steers are being used to evaluate heterosis effects on growth rate and carcass characteristics.
systematic crossing of inbred lines through a rotational sires program. The rather high heritabilities (additive genetic variance) for most economically important traits indicate that heterosis (non-additive genetic variance) may not be as important in beef cattle as has been shown in some of the other species. However, the marked inbreeding decline, particularly in fertility, would suggest that heterosis may have an important effect on this trait. This seems reasonable in view of the seemingly low heritability of fertility. The results are far from conclusive, but preliminary information does not indicate that heterosis (non-additive genetic variance) is of great importance for growth and carcass traits.

Research in this area is being given increased emphasis. A rather extensive crossbreeding study, involving the three major British breeds, has been initiated to determine the importance of heterosis on all major performance traits in crosses of these breeds. A crossbreeding study is also being initiated between the Charolais and one of the British breeds to determine the importance of heterosis in this cross.

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

**Genetic Environmental Interactions**

Very little research has been done to evaluate the importance of genetic-environmental interactions on performance traits of beef cattle. Little is known about the range in adaptability of the different kinds, types, etc., to the different climatic conditions and environmental regimes in which beef cattle are produced. Some research is underway in this area that should yield information on the adaptability of different types of cattle to different systems of production.

Beef cattle provide a means of utilizing the 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 climatic conditions. An evaluation of the importance of genetic-environmental interactions and the effectiveness of selection for adaptability to specific climatic conditions and production programs are important 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

Even though the heritabilities for most of the economically important traits seem high enough for selection to be reasonably effective (fertility being an exception) and no important genetic antagonisms have been demonstrated between the important performance traits, the effectiveness of mass selection for these traits remains to be demonstrated experimentally.

Research has not been underway in NC-1 for a sufficient length of time to experimentally evaluate the effectiveness of selection for economically important traits. Because of the relatively large sampling errors that are involved, sufficient data have not been accumulated in NC-1 investigations to provide the most reliable estimates of the genetic correlations among the different performance traits. Additional selection experiments for specific traits with measurement of correlated responses in other traits are being initiated. These are controlled experiments so that genetic change in all traits can be evaluated. Obtaining reliable estimates of heritabilities and genetic correlations involving all economically important traits represents an important part of the research effort in NC-1.

Identical and fraternal twins are being used at the Wisconsin Station to obtain estimates of heritabilities and genetic correlations.
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 genetic-environmental interactions) are fundamental to planning and conducting effective research programs to experimentally evaluate selection and breeding procedures. As basic knowledge is accumulated on methods of measurement and genetic parameters, research to evaluate different breeding and selection procedures will receive increased emphasis. 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 desirability. This information is essential if beef cattle breeding is to be exploited to its full potential in the development of the most efficient agriculture.

Hereditary Dwarfism and Other Deleterious Genes

The Iowa Station has developed the radiographic technique for the determination of “carriers” of “snorter” dwarfism. The Oklahoma, Nebraska, Michigan, and South Dakota stations have cooperated in the evaluation of this technique.

Research results indicate that this technique can be used to predict “clean” and “carrier” genotypes with approximately 80-85 percent accuracy. This is considered sufficient accuracy to be used for early screening for dwarfism in problem herds, but it is not recommended as a basis for the guarantee of dwarf-free breeding stock.

Studies have revealed a difference between the means of “clean” and “carrier” groups in length of cannon bone and head width-length ratio; however, there has been considerable overlap between the two genotypes in these measurements. Other procedures for the detection of “carriers” of “snorter” dwarfism have been investigated at the Missouri, Iowa, Oklahoma, North Dakota, and South Dakota stations. These include differential physiological responses (blood constituents, etc.) with and without the use of stress agents. While these studies have revealed a difference between the means of “clean” and “carrier” groups in several of the constituents, in general, the overlap has been so great that individual genotypes cannot be predicted with sufficient accuracy to warrant their use. The investigations for developing methods of identifying carriers of dwarfism are tending to be concentrated at fewer stations, resulting in a reduction in the total research effort in this area.

Even though the research to develop a technique approaching 100 percent accuracy for the detection of “carriers” of “snorter” dwarfism has not been completely successful, research efforts in this area have had a major impact on the industry in regard to this problem. Research has established the inheritance of this most serious kind of dwarfism
The radiographic technique for detection of carriers of "snorter" dwarfism was developed by the Iowa Station.

as a simple autosomal recessive. This knowledge has made it possible for research workers to counsel with the industry on slower, yet effective ways of combating this problem. This has led to a better understanding of the problem by breeders, and pedigree selection accompanied by progeny testing has been effective in reducing the frequency of the dwarf gene in our seed stock herds. The "snorter" type of dwarfism has been identified in both the Angus and Hereford breeds.

Other types of dwarfism have been investigated in this project. Research results indicate that "long-headed" dwarfism is also inherited as a simple autosomal recessive. This type of dwarfism has been identified in the Angus breed, and results indicate that the gene responsible for it is not the same as the gene causing "snorter" dwarfism. Preliminary research results indicate that the "compact" condition in Short-horns and the "comprest" condition in Herefords are probably the result of the action of a gene with incomplete dominance. It is not known whether or not the same gene is responsible for these conditions ("compact" and "comprest") in the Shorthorn and Hereford breeds. A rather extreme type of dwarf segregates from inter se matings among "comprest" and among "compact" individuals. This rather extreme dwarf seems to differ from both the "long-headed" and "snorter" dwarfs, and it is presumed to be the result of the presence of "comprest" or "compact" genes in the homozygous condition.
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 some concern to individual breeders and producers. Research workers are counseling with breeders and producers on ways of reducing the frequency of this gene in individual herds.

APPLICATION OF RESULTS AND PERSPECTIVE

Approximately 200 scientific, technical, and popular reports have been published from the research conducted in NC-1. These publications have contributed greatly to our knowledge of methods and procedures for measuring economically important traits and have provided some 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.

Record of Performance Programs applying the results of this research under the leadership and guidance of State Agricultural Extension Services are underway in most of the states cooperating in NC-1. Information provided by Record of Performance Programs is making it possible for breeders to increase the accuracy of their selections, thus giving them greater control over their operations. The entire beef cattle industry has indicated a real interest in the research program being conducted in this project. The immediate application of the results evolving from this effort is indicative of the need for increased knowledge on beef cattle breeding. While the results obtained from this project have had a marked influence in the breeding programs in many of our seed stock herds, much remains to be done if research is to provide the basic information necessary to guide the beef cattle industry in attaining maximum efficiency in producing the most desirable beef.

One of the real accomplishments of NC-1 to date 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 can come only from well organized and properly conducted research. It is emphasized that much remains to be done in the development of improved procedures for measuring some of the economically important traits, obtaining reliable estimates of their genetic parameters, and in evaluating selection methods and procedures and breeding systems and procedures.

It is not realistic to expect short-term results of a sensational nature from research in this area. Increased knowledge in this field accumulates relatively slowly, but it is evident that this project has already made significant contributions to increased knowledge and that this knowledge has had a real impact on the beef cattle industry.
The basic approach in NC-1 is to obtain reliable answers to the more pertinent questions, thus doing well whatever is done. The predominant thinking by the research personnel is that one good answer is, in general, worth several partial answers. An effective job has been done in adapting contributing projects to the need and to the available resources, with effective and efficient experimental designs that will yield interpretable results.

Even though the accomplishments during the first 12 years are considered quite significant, the progress that is being made toward answering some of the major fundamental questions indicates that the most important contributions to increased knowledge by this project will be in the future.

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163. SMITH, CHARLES.

164. SMITH, R. O.

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189. TEMPLE, R. S.

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191. TURMAN, E. J.


194. WHITEMAN, JOE V., LOGGINS, P. F., CHAMBERS, D., POPE, L. S. AND STEPHENS, D. F.

195. WILDER, C. P.

196. WILLIAMS, DAVID C.

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