THE RELATIONSHIP OF SOME POST-WEANING TRAITS TO STRAIN IN THE BOVINE

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ABSTRACT

THE RELATIONSHIP OF SOME POST-WEANING TRAITS TO STRAIN IN THE BOVINE

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The post-weaning performances of steer calves from four beef strains of cattle (Hereford, Highland, Highland X Hereford, Hereford X Highland) were compared during four successive winter feedlot periods (1957-1960 inclusive) at the Canada Department of Agriculture Experimental Farm, Manyberries, Alberta. Seven performance traits were measured: feedlot average daily gain (ADG), pounds of total digestible nutrients (TDN) consumed per pound of weight gained, weight per day of age to the end of the feedlot test, hair sample weight, hair fibre length, hair fibre thickness, and number of hair fibres per square inch. The following relationships were determined on a within-strain basis: hair traits to ADG and TDN consumed per pound of weight gained, hair traits to each other, ADG to TDN consumed per pound of weight gained.

In general, Hereford, Highland X Hereford, and Hereford X Highland calves significantly exceeded Highland calves in ADG and in weight per day of age to the end of the feedlot test, while consuming fewer pounds of TDN per pound of weight gained. Highland calves significantly surpassed calves of the other strains in hair fibre length, hair sample weight, and hair fibre thickness. Each of the reciprocal crosses significantly exceeded the Hereford in hair fibre length and hair sample weight. There were no significant mean differences among strains in number of hair fibres per square inch.

The significant correlations and regressions among hair characteristics showed that (1) both the number of hair fibres and hair fibre length affected hair sample weight, (2) there was a direct relationship between hair fibre thickness and hair fibre length, (3) there was an inverse relationship between hair fibre thickness and number of hair fibres per square inch.

A significant inverse relationship existed between ADG and TDN consumed per pound of weight gained.

No significant relationships were found between any of the hair characteristics and either ADG or TDN consumed per pound of weight gained.

There were no significant differences between the Highland X Hereford and Hereford X Highland in any of the performance traits.

Estimates of per cent heterosis in performance traits were: ADG, 3.2; TDN consumed per pound of weight gained, 3.7; weight per day of age to the end of the feedlot test, 8.2; hair fibre length, 1.5; hair fibre thickness, 0.7; hair sample weight, -3.0; number of hair fibres per square inch, -5.5.

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CHAPTER I

THE PROBLEM AND DEFINITION OF TERMS

I. THE PROBLEM

Introduction to the problem. The Western ranges, on which large herds of cattle are maintained, consist of vast tracts of grassland which offer relatively low carrying capacity and little protection from inclement weather. Range cattle receive minimum feed and care during the winter and often are subjected to poor summer grazing conditions as a result of overgrazing or drought. Outstanding rustling ability and winter hardiness, therefore, are required by an animal if it is to have a long and productive life in a range herd.

Project 51.01.03, entitled "A comparative study of Highland and Hereford cattle and their reciprocal crosses," was initiated at the Experimental Farm, Manyberries, Alberta, in 1956. The objective was to determine if Highland and Highland-Hereford cattle differed significantly from Herefords in hardiness and productivity under Alberta range conditions. The Hereford is noted for its rustling ability on the range and the Scotch Highland for its hardiness in the cold, damp, mountainous regions of Scotland. This study is based on some of the data collected for Project 51.01.03.

The problem stated. It was the purpose of this study (1) to compare the performance of four strains of beef cattle (Hereford, Highland, Highland X Hereford, and Hereford X Highland) in each of seven post-weaning traits (feedlot average daily gain, pounds of total digestible nutrients consumed per pound of weight gained, weight per day of age to the end of the feedlot test, hair sample weight, hair fibre length, hair fibre thickness, number of hair fibres per square inch); (2) to determine the within-strain association of each hair trait to feedlot average daily gain and pounds of total digestible nutrients consumed per pound of weight gained; (3) to determine the within-strain association of the hair characteristics to each other; (4) to determine the within-strain association of feedlot average daily gain to pounds of total digestible nutrients consumed per pound of weight gained.

Importance of the study. Basic information is lacking about the response in individual traits and also in overall performance of Highland, Highland X Hereford, and Hereford X Highland strains of cattle. An objective appraisal of each strain is achieved by comparing its performance to that of the predominant range breed--the Hereford.

A simple, effective measure of the hardiness of cattle is needed as an aid to the selection of breeding stock where climatic conditions are severe. It is important to know whether any of the hair coat characteristics under study is a possible indicator of winter hardiness. Winter hardiness will be measured in terms of the relationship between each of the hair traits and average daily feedlot gain or pounds of feed consumed per pound of weight gained.

Limitations of the study. Only a part of the overall performance of the various strains is being studied. Certain of the traits (feedlot average daily gain, pounds of total digestible nutrients consumed per pound of weight gained, weight per day of age to the end of the feedlot period) are of recognized economic importance. Strain comparisons of these traits will yield valuable information for breeders and feeders.

The study of the four hair characteristics must be termed basic research. However, the relationship of each hair characteristic to each of feedlot ADG and pounds of TDN consumed per pound of weight gained is an important consideration in the search for an indicator of winter hardiness.

This study is based on the performance of steer calves under feedlot conditions. No heifer calves were included in these tests. The longevity and lifetime production records, which would give a good estimate of the hardiness and rustling ability of cows, are not considered here.

II. DEFINITION OF TERMS USED

When strain crosses are indicated the breed of the sire is named first. For example, a Highland X Hereford animal is the offspring of a Highland sire and a Hereford dam.

The terms S_1, S_2, S_3, and S_4, hereinafter, will be used to designate the strains Hereford, Highland, Highland X Hereford, and Hereford X Highland, respectively.

The terms Y_1, Y_2, Y_3, and Y_4, hereinafter, will be used to designate the calf crops born in 1957, 1958, 1959, and 1960, respectively.

The term TDN, hereinafter, will be used to designate the three words--total digestible nutrients.

The term ADG, hereinafter, will be used to designate the three words--average daily gain.

CHAPTER II

REVIEW OF LITERATURE

The theories of heterosis and crossbreeding are discussed here only briefly, but their application to breeding programs is demonstrated in the results of several crossbreeding experiments. Although a history of the parental breeds is reported, little is known of the performance of the Highland or the reciprocal crosses involving the Highland, especially under Western range conditions. Reports on hair coat characteristics describe the physical properties of the hair coat and sometimes their relationship to heat or cold tolerance.

I. LITERATURE ON THEORIES OF HETEROSIS AND CROSSBREEDING

Shull (1952) described the heterosis concept as being:

> . . . the interpretation of increased vigor, size, fruitfulness, speed of development, resistance to disease and to insect pests, or to climatic rigors of any kind, manifested by crossbred organisms as compared with corresponding inbreds, as the specific results of unlikeness in the constitutions of the uniting parental gametes.

Lush (1949) interpreted crossbreeding to mean the mating of two animals which were both purebreds but belonged to different breeds, and suggested that the mating of a purebred sire of one breed to a high grade female of another breed could also be termed crossbreeding. Winters (1954) suggested that crossbreeding promotes the pairing of unlike genes and that the purpose of a single cross is to introduce new genes to a closed population. He observed that a closed population could be either a closebred family or a breed. Winters (1954) referred to a U.S.D.A. experiment by Rhoad and Black in 1943 in which Brahman were crossed with Angus, Shorthorn, and Hereford. The hybrids proved to be better suited to the Gulf Coast region than either parental breed because of their superiority to the Brahman in carcass quality and to the British breeds in ability to resist high humidity and temperature.

An appraisal of the section on the theories of heterosis and crossbreeding indicates that it is possible, through a crossbreeding program, to introduce new genes into a closed population and to produce animals with greater adaptability to a given environment than that enjoyed by either of the parental breeds.

II. LITERATURE ON HISTORY OF THE PARENTAL BREEDS

MacEwan (1941) described the Hereford as being an early developing breed, with cows weighing 1200 to 1600 pounds and bulls weighing 1700 to 2200 pounds at maturity. He claimed that the Hereford is unsurpassed as a range breed and noted that the Hereford dominates the Alberta range. Briggs (1951) credited the Hereford with the capacity to withstand heat, drought, and cold satisfactorily, and also with an unsurpassed rustling ability. Vaughan (1950) reported that although in some of the severe winters before the 1900's the Hereford suffered considerable losses, it was the consensus of opinion that it stood the test better than any other known type. He observed that, in the opinion of Charles Gudgell (a pioneer American Hereford breeder), the ability of the Hereford to withstand rigorous conditions was due mainly to its capacity and diligence in laying up stores of flesh on which it could draw when hardship presented itself.

MacEwan (1941), Vaughan (1950), and Briggs (1951) believed the West Highland or Kayloe to be descended from the Celtic black cattle. They reported that the West Highland was native to the cold, damp, mountainous regions of Scotland where it had gained a reputation for extreme hardiness. MacEwan, and also Vaughan, rated the Highland as being slow to medium in rate of growth, with mature weights in the range of 800 to 1100 pounds for cows and 1100 to 1500 pounds for bulls. Briggs reported that Highlands had been tried on the ranges of Kansas, Montana, and Wyoming in the early 1900's and were considered to be hardy but lacking the beef producing qualities of the more common breeds. MacEwan indicated that Highland bulls had been used on range herds during that same period and that the crossbred steers produced had fair size, valuable rustling qualities, and good fattening tendencies.

The above descriptions suggest that (1) the Hereford is outstanding in rustling ability, and is as winter hardy as any of the common range breeds; (2) the Highland has a reputation for outstanding hardiness in an environment of cold, damp climate and rough, mountainous terrain. This is in contrast to the dry, flat plains areas of the Western range where this study was initiated. Some observations about the adaptability of the Highland to the Western range were made, but were not supported by experimental evidence.

III. LITERATURE ON RESULTS OF CROSSBREEDING EXPERIMENTS

Shaw and MacEwan (1938) used Galloway, Shorthorn, Angus, and Hereford cattle to produce all possible single crosses as well as the four pure breeds. They reported that crossbred steers had a definite advantage over those of the pure breeds in rate of gain on feed. Galloways were judged to be the hardiest because the cows of that breed required less special care in the winter and grazed in the open in weather in which the cows of the other breeds sought shelter. Galloway and Galloway crosses required longer to achieve a market finish on feed, however. Vaughan (1950) suggested that a close relationship existed between Galloway and West Highland cattle because they originated from neighbouring areas and were much alike in conformation, hair coat, and carcass characteristics.

Knapp and others (1949) discovered that Shorthorn - Hereford crossbred steers were heavier at weaning than identically raised purebreds, gained more in the feedlot, and were heavier in final feedlot weight--by a significant margin in each case. Slight, non-significant differences favored the crossbreds in birth weight, slaughter grade, and carcass grade. Gerlaugh et al. (1951) compared the feedlot performance of Hereford, Angus, and the steers of the reciprocal crosses and found that the Hereford and the two crossbred groups gained more rapidly on feed than the Angus steers. Holt (1955) summarized twenty-two published experiments in crossbreeding beef cattle in which British, other European, Zebu, and unimproved cattle were used. Crossbred beef cattle had an average of 4.35 per cent heterosis in weight and growth rate, 3.5 per cent in weaning weight, and 3.0 per cent in finished weight. Crosses between common beef breeds consistently displayed hybrid vigor in measured production traits and the wider crosses showed the greater heterosis. Damon et al. (1961) used six breeds of bulls (Brahman, B; Brangus, BA; Angus, A; Hereford, H; Charolaise, C; Shorthorn, S) on four breeds of cows (B, BA, A, H) and measured five traits on the crossbred and straightbred progeny. A significant or highly significant heterosis effect (percentage by which the average of the reciprocal crosses exceeded the average of the parental breeds) was found for 180 day weight, slaughter grade, rate of gain on feed, and weight per day of age, but none for slaughter calf grade. In rate of gain on feed B X H, A X B, and B X BA reciprocal crosses significantly exceeded straightbreds, while the heterosis effect of BA X H, A X BA, and A X H crosses was not significant. In weight per day of age B X H, A X B, BA X H, and B X BA crosses exhibited significant heterosis while the A X BA cross showed heterosis which was not significant and the A - H reciprocal crosses actually were significantly lower than the parental breeds. Damon and others (1959) suggested that the performance of the Angus and Hereford breeds and their reciprocal crosses showed that there was little or no advantage to be gained from crosses between these breeds in rate of gain, weight per day of age, and carcass grade. There were no significant differences among the weights per day of age of steers sired by Charolaise, Shorthorn, Brahman, or Hereford bulls. The weights per day of age of steers sired by Brangus and Angus bulls were significantly lower than those of the steers by the other four breeds of bulls. There were no significant differences among the weights per day of age of the steers raised by the four different breeds of cows. Steers sired by Shorthorn and Charolaise bulls averaged a greater rate of gain on feed than steers sired by Brahman and Brangus bulls. Steers sired by Hereford and Angus bulls had an average rate of gain that was intermediate between that of the other two groups.

In the crossbreeding experiments reviewed in this section, significant effects of heterosis were recorded for most of the traits studied. The wider crosses showed the greater heterosis. In situations where the basic genetic material of the parental breeds was apparently similar, the crossbreds showed non-significant heterosis and even an effect opposite to heterosis. It was suggested that the Galloway and Highland had a strong genetic similarity. Hardiness and vigor were attributed to the Galloway, although it required a longer feeding period in order to reach a market finish. If the suggested Highland and Galloway similarity is correct, the same performance may be expected of the Highland. The genetic diversity between Hereford and Highland, however, may well permit the expression of heterosis in the reciprocal crosses.

IV. LITERATURE ON HAIR COAT CHARACTERISTICS

Shrode and Cartwright (1950) obtained correlation coefficients between respiration rate and number of hair fibres per unit of skin area of -0.68 and -0.72 for Brahman and Jersey cattle, respectively, and concluded that the density of the hair coat may be a useful indication of heat tolerance. Peters (1962) recorded hair sample weight and density of the hair coat and observed that the cattle with the best performance did not necessarily have the thickest hair coats. Logan and Sylvestre (1950) reported on the reduction in feedlot gain during cold periods in three groups of calves. The group which suffered the least reduction in gain had the heaviest coat and the finest hair. There was no significant difference between the other two groups in coat density and fineness of hair although there was a significant difference in reduction of gain during the cold spells.

Lee (1953) stated that the tolerance of many animals to cold is closely associated with the depth of the coat. He listed several mechanical considerations which would help to determine the value of a coat, including the ease with which the coat is disturbed, its resistance to separation, its matting tendency, and its resistance to compression. He suggested that density of fibres, fibre curvature, fibre thickness, and fibre length were important hair characters. Additional records which he recommended be taken to complete the overall appraisal were: body temperature, respiration rate, work capacity, reproductive capacity, free behavior (loose or confined), age, sex, breed, health and condition of the animal, location and date of any tests, and the management practises involved throughout. Hafez et al. (1955) suggested that in both temperate and tropical zones the thermal equilibrium of animals is controlled by the density, length, and color of the hair coat, and that the amount of heat loss from the surface of the coat is inversely related to the hair length. Schleger and Turner (1960) believed that of the characters contributing to coat type, the most important were depth of coat, hair diameter, per cent medullated hairs, and maximum length of fine hairs. They obtained a correlation of 0.71 between growth rate and coat type.

The foregoing indicates that several workers have studied the physical properties of a hair coat. Three of the characteristics being examined in this study (hair fibre length, hair fibre thickness, number of hair fibres per square inch) were considered by many to be among the most important. Others have studied the effect of coat color and medullation of fibres. A classification of coat type, involving several characters, was considered necessary by some researchers, while others recommended a complete appraisal involving the study of a number of physical and mechanical properties along with a detailed history of the environment of the tested animals. A simple effective test of winter hardiness is still required.

CHAPTER III

SOURCE OF DATA, EXPERIMENTAL TECHNIQUE

I. SOURCE OF DATA

Project 51.01.03, "A comparative study of Highland and Hereford cattle and their reciprocal crosses," was initiated in 1956 at the Experimental Farm, Manyberries, Alberta. In this project, registered Hereford and Highland bulls were bred to both high grade Hereford and registered Highland cows. A total of 115 heifer calves and 101 bull calves were produced in the calf crops born in 1957, 1958, 1959, and 1960. The heifer calves were retained for breeding on the project. All of the male calves were castrated and, following weaning, were placed on a feedlot and carcass test. Weight gains, feed consumption, hair coat characteristics, and carcass data were recorded. Part of the data collected on the test forms the basis for this study. The number of steer calves of each strain and year, used in this study, is shown below:

	S_1	S_2	S_3	S_4	Total
Y_1	11	6	6	5	28
Y_2	6	2	8	4	20
Y_3	7	6	3	3	19
Y_4	8	7	11	8	34
Total	32	21	28	20	101

The foundation grade Hereford cows and some of the Hereford and Highland bulls were raised at the Experimental Farm, Manyberries. Hereford bulls were purchased from Oregon State College; S. C. Williams, Claresholm, Alberta; A. A. Mitchell, Lloydminster, Saskatchewan. The first and largest group of Highland cows was obtained from C. Shoop, Browning, Montana. Later purchases were made from B. Berry, Belvidere, South Dakota; G. Holmes, Decker, Montana; Mary Lindsay, Greenstreet, Saskatchewan. Highland bulls were purchased from C. Shoop; Mary Lindsay; C. S. Pettit, Credit Forks, Ontario; A. Besler, Wetaskawin, Alberta.

II. EXPERIMENTAL TECHNIQUE

Management. Each year different bulls were used for breeding. Cows were culled only if they failed to calve in each of two successive years, or if they sustained an injury which interfered with normal reproduction. At no time were calves culled from this study.

Each year the calves were born between April 1 and May 15. Male calves were castrated in June, and were weaned on November 1. Calves were allowed a preliminary feeding period in which to become accustomed to grain. They were started on the feedlot test January 6, 1958; January 2, 1959; November 13, 1959; November 11, 1960.

Twice daily, from 8 to 10 A.M. and 3 to 5 P.M., the calves were fed in individual stalls inside a steel shed. When not feeding, the calves had access to a small pen within the shed and also, through a large open doorway, to an outdoor pen surrounded by a high board fence. While partially sheltered from the wind, the calves were exposed to the cold weather even while feeding.

At the beginning of the feedlot period, each calf received a daily allowance of two pounds of whole oats. This was increased gradually until the calves were leaving oats in their feeders. Then the ration was changed to 2 parts rolled oats to 1 part rolled barley, by weight. After eight weeks the ratio was changed to equal parts oats and barley, while after twelve weeks the ratio was changed to 2 parts barley to 1 part oats. The grain portion of the ration remained at that ratio until the completion of the test. The hay portion consisted of 2 parts grass hay to 1 part alfalfa hay, by weight, throughout the feedlot period. Feed consumption records were kept for each calf.

All the steer calves were held in the feedlot until the Herefords were judged to have reached a market finish, at which time all the calves were shipped for slaughter. The duration of the feeding period in days was 203, 224, 254, and 241 in 1958, 1959, 1959-60, and 1960-61, respectively.

Calves were weighed at the beginning, at two week intervals throughout, and at the end of the feedlot period.

Description of traits. Feedlot ADG was determined by dividing the total gain in weight during the feedlot period, by the duration of the feedlot period in days.

The weight per day of age to the end of the feedlot period was determined by dividing the total live weight at the end of the feedlot period, by the total age in days.

The daily consumption of grass hay (predominantly crested wheat), alfalfa hay, barley, and oats was recorded for each animal. Coefficients used to determine the percentage of TDN available to ruminants from each type of feed were taken from Tables of Feed Composition (1959). The coefficients were 0.60 for oats (U.S., all analyses), 0.71 for barley (U.S., all analyses), 0.50 for alfalfa hay (all analyses), and 0.50 for wheatgrass hay (all analyses). The number of pounds of TDN consumed was then divided by the number of pounds of weight gained throughout the feedlot period, to establish the trait labelled pounds of TDN consumed per pound of weight gained.

In mid-February, in each of the four years of the study, hair samples were clipped from the mid-rib area on the left side of each animal. A section of teeth, one-half inch in length, was removed from each clipper blade. One vertical and one horizontal sweep with these clippers isolated a hair sample one-quarter of a square inch in size. This was clipped off and placed in an envelope. All the hair samples were forwarded to the Wool Laboratory at the Research Station, Lethbridge, where the various measurements were made.

The weight of each sample was calculated in terms of the milligrams of sample per square inch.

The number of hair fibres was recorded on a per square inch basis.

The average hair fibre length for each animal was recorded in millimeters.

The average hair fibre thickness for each animal was recorded in microns.

CHAPTER IV

METHODS OF ANALYSES, RESULTS

A separate section for each of the post-weaning traits under study is included in this chapter. Another section is devoted to the discussion of simple correlation and regression coefficients.

Each of the four hair traits, feedlot ADG, and pounds of TDN consumed per pound of weight gained were analyzed on an intra-strain and intra-year basis.

Weight per day of age to the end of the feedlot test was analyzed on an intra-strain, intra-year, and intra-age-of-dam basis. Dams were classified into groups which were 2, 3, 4, 5-7, and 8+ years of age.

Except in the analysis of weight per day of age to the end of the feedlot test, the regression of each trait on initial feedlot weight was the first analysis conducted within each section. The subsequent analyses in each section resulted in estimates of the strain mean differences and their significance.

The mean of S_1 was determined for each trait using the formula SX/n. The strain mean difference between S_1, and each of S_2, S_3, and S_4 was calculated on an intra-year basis for each of the hair traits, feedlot ADG, and pounds of TDN consumed per pound of weight gained, and on an intra-year and intra-age-of-dam basis for weight per day of age. To establish the adjusted strain means, the estimated strain mean difference between S_1, and each of S_2, S_3, and S_4 was added to or subtracted from the mean of S_1, as indicated.

All methods of analyses used were taken from Snedecor (1946). Detailed examples of all analyses mentioned in Chapter IV (except the method of fitting of constants to a two factor table with interaction negligible) are found in the Appendix. The List of Examples is found on page x. Some of the data for hair fibre length are used to show the method of weighted squares of means with interaction present (Example XII). For all other examples, the data for pounds of TDN consumed per pound of weight gained are used.

I. FEEDLOT ADG

A covariance analysis was performed to determine the regression of feedlot ADG on initial feedlot weight. There was a non-significant regression of 0.0003 pounds of feedlot ADG per pound of increase in initial feedlot weight. Heterogeneity of regression was non-significant. The yearly strain means for feedlot ADG (Table I, page 22) were subjected to an analysis of variance which indicated that interaction was non-significant and that significant ($P < 0.01$) differences existed for each of strains and years. The method of fitting of constants to a two factor table, interaction negligible, was then followed and interaction proved to be non-significant, while both year and strain effects were significant ($P < 0.01$). All possible strain comparisons were made, using the method described for disproportionate subclass numbers in an R X 2 table with interaction negligible. The estimated strain mean differences in feedlot ADG are shown in Table II. The adjusted strain averages for feedlot ADG were: S_1, 1.86 pounds; S_3, 1.85 pounds; S_4, 1.71 pounds; S_2, 1.59 pounds. Each of S_1, S_3, and S_4 significantly ($P < 0.01$) exceeded S_2, and S_1 significantly ($P < 0.05$) exceeded S_4 in feedlot ADG. There were no significant differences between S_1 and S_3 or S_3 and S_4 in feedlot ADG.

II. POUNDS OF TDN CONSUMED PER POUND OF WEIGHT GAINED

A covariance analysis was performed to determine the regression of pounds of TDN consumed per pound of weight gained on initial feedlot weight. There was a significant ($P < 0.01$) regression of 0.0042 pounds of TDN consumed per pound of weight gained for each increase of one pound in initial feedlot weight. Heterogeneity of regression among subclasses was non-significant. The curvilinearity of the regression was tested using X^2 as the second independent variate. Curvilinearity was non-significant. Because the regression proved to be significant, homogeneous, and

TABLE I

YEARLY STRAIN MEANS OF FEEDLOT ADG (POUNDS)

	S_1	S_2	S_3	S_4	Total
Y_1	1.61	1.56	1.83	1.64	6.64
Y_2	2.11	1.86	1.96	2.01	7.94
Y_3	1.93	1.57	1.86	1.65	7.01
Y_4	1.94	1.52	1.89	1.82	7.17
Total	7.59	6.51	7.54	7.12	28.76

TABLE II

ESTIMATED STRAIN MEAN DIFFERENCES IN FEEDLOT ADG (POUNDS)

	S_1	S_3	S_4	S_2
S_1		.003	.101*	.270**
S_3			.089	.288**
S_4				.173**
S_2				

* $P< 0.05$

** $P< 0.01$

linear, the average regression coefficient of 0.0042 and the average initial feedlot weight of 396 pounds were used as the bases for the adjustment of all values of pounds of TDN consumed per pound of weight gained. New SX, SX^2, $(SX)^2/n$, and Sx^2 values were calculated for pounds of TDN consumed per pound of weight gained. Table III shows the adjusted yearly strain means for pounds of TDN consumed per pound of weight gained. The adjusted yearly strain means were subjected to an analysis of variance. Interaction effects were non-significant, but significant strain ($P < 0.05$) and year ($P < 0.01$) effects were indicated. The method of fitting constants to a two factor table with interaction negligible showed that interaction effects were non-significant while strain and year effects were significant ($P < 0.01$). An analysis utilizing disproportionate subclass numbers in an R x 2 table with interaction negligible was used to determine the significance of the strain mean differences. All possible strain comparisons were made. The results are shown in Table IV. The adjusted strain averages of pounds of TDN consumed per pound of weight gained were: S_3, 5.11 pounds; S_1, 5.23 pounds; S_4, 5.28 pounds; S_2, 5.55 pounds. S_2 significantly exceeded S_1 ($P < 0.05$) and S_3 ($P < 0.01$) in pounds of TDN consumed per pound of weight gained. No significant differences were found between S_2 and S_4, S_4 and S_1, S_1 and S_3, S_3 and S_4 in pounds of TDN consumed per pound of

TABLE III

YEARLY STRAIN MEANS OF POUNDS OF TDN CONSUMED PER POUND OF WEIGHT GAINED (BASED ON TDN VALUES ADJUSTED FOR DIFFERENCES IN INITIAL FEEDLOT WEIGHT)

	S_1	S_2	S_3	S_4	Total
Y_1	5.99	6.20	5.49	5.73	23.41
Y_2	4.88	4.92	5.02	5.03	19.85
Y_3	5.00	5.51	4.99	5.46	20.96
Y_4	4.66	5.03	4.62	4.71	19.02
Total	20.53	21.66	20.12	20.93	83.24

TABLE IV

ESTIMATED STRAIN MEAN DIFFERENCES IN POUNDS OF TDN CONSUMED PER POUND OF WEIGHT GAINED (BASED ON TDN VALUES ADJUSTED FOR DIFFERENCES IN INITIAL FEEDLOT WEIGHT)

	S_2	S_4	S_1	S_3
S_2		.25	.32*	.44**
S_4			.05	.16
S_1				.12
S_3				

* $P < 0.05$

** $P < 0.01$

weight gained.

All strains of calves were taken off feed and slaughtered when S_1 was judged to have reached a market finish. The resulting carcass grades were converted to numerical values, and an analysis of variance was performed on the yearly strain means. Only S_4 did not differ significantly from S_1 in carcass grade. On the average, S_1 and S_4 reached a good to choice grade while S_3 and S_2 were inferior by about 0.5 and 1.5 grades, respectively. If it is assumed that beef cattle become less efficient in feed utilization as the degree of their fatness increases, then it must be assumed also that the adjusted strain averages for pounds of TDN consumed per pound of weight gained are underestimated for S_3 and S_2 because they passed through only part of their fattening period.

III. WEIGHT PER DAY OF AGE TO THE END OF THE FEEDLOT TEST

Weight per day of age is commonly used to assess growth in beef calves, especially when birth weights are unavailable. Unless the calves being compared have been raised in a common environment and are of uniform age, however, the comparison may be meaningless. Accordingly, the first step in the determination of weight per day of age figures was to perform an analysis of variance of the yearly strain means of age in days at the end of the feedlot test. The yearly strain means are shown below:

	S_1	S_2	S_3	S_4	Total
Y_1	465.0	467.0	460.5	464.4	1,856.9
Y_2	481.5	460.5	471.4	487.8	1,901.2
Y_3	463.7	468.8	459.3	467.7	1,859.5
Y_4	451.6	449.3	442.0	446.1	1,789.0
Total	1,861.8	1,845.6	1,833.2	1,866.0	7,406.6

There were no significant strain or interaction effects, although year effects were significant ($P < 0.01$). When no strain differences were indicated in age in days at the end of the feedlot test, weight per day of age figures were calculated using the method previously described.

The averages of weight per day of age within-strain, within-year, and within-age-of-dam, and the number of steers within each class are shown in Table V. The number of pairs of age-of-dam groups, and the number of steer calves on which each strain comparison is based, are shown in Table VI, page 28. The method of disproportionate subclass numbers in an R X 2 table with interaction negligible was used, and all possible strain comparisons made. The estimated strain mean differences are given in Table VII, page 28. The adjusted strain averages of weight per day of age to the end of the feedlot test were: S_3, 1.82 pounds; S_1, 1.74 pounds; S_4, 1.73 pounds; S_2, 1.54 pounds. Each of S_1, S_3, and S_4 significantly ($P < 0.01$) exceeded S_2 in weight per day of age

TABLE V

AVERAGES OF WEIGHT PER DAY OF AGE TO THE END OF THE FEEDLOT TEST, WITHIN STRAIN, YEAR, AND AGE-OF-DAM

	Dam age	S_1	S_2	S_3	S_4
Y_1	2	1.50 (3)	1.10 (1)		
	3	1.47 (1)			1.43 (1)
	4		1.41 (1)	1.64 (1)	
	5-7	1.53 (2)	1.43 (1)	1.79 (4)	1.53 (3)
	8+	1.60 (5)	1.63 (3)	1.64 (1)	1.61 (1)
Y_2	2	1.95 (1)			1.77 (1)
	3			1.98 (1)	1.79 (1)
	4		1.71 (2)		2.00 (1)
	5-7	1.92 (1)		2.02 (1)	1.94 (1)
	8+	1.70 (4)		1.79 (6)	
Y_3	2	1.67 (2)	1.44 (1)	1.73 (1)	
	3				
	4				
	5-7	1.67 (1)	1.83 (3)		1.94 (3)
	8+	1.91 (4)	1.71 (2)	1.95 (2)	
Y_4	2	1.91 (2)	1.46 (3)	1.95 (3)	1.72 (1)
	3	1.84 (3)		2.13 (1)	1.89 (2)
	4	1.97 (2)		2.08 (1)	
	5-7		1.72 (1)	1.95 (1)	1.93 (3)
	8+	2.09 (1)	1.55 (3)	1.79 (5)	1.96 (2)

TABLE VI

NUMBER OF PAIRS OF AGE-OF-DAM GROUPS AND NUMBER OF STEERS, ON WHICH ARE BASED STRAIN COMPARISONS FOR WEIGHT PER DAY OF AGE TO THE END OF THE FEEDLOT TEST

	Pairs of age-of-dam groups	Number of steers
S_1 versus S_2	8	37
S_1 versus S_3	10	51
S_1 versus S_4	9	32
S_2 versus S_3	8	33
S_2 versus S_4	7	31
S_3 versus S_4	8	31

TABLE VII

ESTIMATED STRAIN MEAN DIFFERENCES IN WEIGHT PER DAY OF AGE TO THE END OF THE FEEDLOT TEST

	S_3	S_1	S_4	S_2
S_3		.079	.103	.282**
S_1			.006	.195**
S_4				.232**
S_2				

** $P < 0.01$

to the end of the feedlot test. No significant differences were found among the other strain means. No strain X year interaction effects were apparent in these comparisons.

IV. HAIR FIBRE LENGTH

A covariance analysis was performed to determine the regression of hair fibre length on initial feedlot weight. There was a non-significant regression of -0.0101 millimeters of hair fibre length per pound increase in initial feedlot weight. Heterogeneity of regression was non-significant. The yearly strain means for hair fibre length (Table VIII) were subjected to an analysis of variance which indicated significant ($P < 0.01$) strain, year, and interaction effects. All possible strain comparisons were made. The method of disproportionate subclass numbers in an R X 2 table with interaction negligible was used to determine the strain mean differences between S_1 and S_2 and also between S_3 and S_4. With all other determinations of the strain mean differences, the method of weighted squares of means was used because interaction was present. The estimated strain mean differences are shown in Table IX. The adjusted strain means for hair fibre length were: S_2, 61.5 millimeters; S_4, 51.1 millimeters; S_3, 49.5 millimeters; S_1, 37.6 millimeters. S_2 significantly ($P < 0.01$) exceeded each of S_1, S_3, and S_4, while each of S_3 and S_4 significantly ($P < 0.01$) exceeded S_1. There

TABLE VIII

YEARLY STRAIN MEANS OF HAIR FIBRE LENGTH (MILLIMETERS)

	S_1	S_2	S_3	S_4	Total
Y_1	37.1	56.2	43.0	54.4	190.7
Y_2	34.2	53.5	46.3	41.1	175.1
Y_3	35.8	62.4	56.5	58.8	213.5
Y_4	42.2	70.6	51.3	49.3	213.4
Total	149.3	242.7	197.1	203.6	792.7

TABLE IX

ESTIMATED STRAIN MEAN DIFFERENCES IN HAIR FIBRE LENGTH (MILLIMETERS)

	S_2	S_4	S_3	S_1
S_2		9.78**	11.40**	23.90**
S_4			.99	13.58**
S_3				11.95**
S_1				

** $P < 0.01$

was no significant strain mean difference in hair fibre length between S_3 and S_4.

V. HAIR FIBRE THICKNESS

A covariance analysis was performed to determine the regression of hair fibre thickness on initial feedlot weight. There was a non-significant regression of -0.0057 microns of hair fibre thickness per pound of increase in initial feedlot weight. The yearly strain means for hair fibre thickness (Table X) were subjected to an analysis of variance which indicated that interaction was non-significant although both strain and year effects were significant ($P < 0.01$). The method of fitting constants to a two factor table with interaction negligible, showed interaction to be non-significant, while both strain and year effects were significant ($P < 0.01$). An analysis involving the use of disproportionate subclass numbers in an R X 2 table with interaction negligible was used to determine the significance of the strain mean differences. All possible strain comparisons were made. The estimated strain mean differences are shown in Table XI. The adjusted strain means for hair fibre thickness were: S_2, 36.0 microns; S_3, 35.0 microns; S_4, 34.3 microns; S_1, 32.8 microns. S_2 had significantly greater hair fibre thickness than S_4 ($P < 0.05$) and S_1 ($P < 0.01$), while S_3 also exceeded S_1 significantly ($P < 0.01$). Strain mean differences between S_2 and S_3,

TABLE X

YEARLY STRAIN MEANS OF HAIR FIBRE THICKNESS (MICRONS)

	S_1	S_2	S_3	S_4	Total
Y_1	30.9	32.1	32.4	33.4	128.8
Y_2	33.2	37.3	37.0	34.6	142.1
Y_3	32.9	38.5	35.9	34.1	141.4
Y_4	34.9	37.7	36.1	35.7	144.4
Total	131.9	145.6	141.4	137.8	556.7

TABLE XI

ESTIMATED STRAIN MEAN DIFFERENCES IN HAIR FIBRE THICKNESS (MICRONS)

	S_2	S_3	S_4	S_1
S_2		1.07	1.67*	3.19**
S_3			.71	2.19**
S_4				1.48
S_1				

* $P < 0.05$

** $P < 0.01$

S_4 and S_1, S_3 and S_4 were non-significant.

VI. NUMBER OF HAIR FIBRES PER SQUARE INCH

A covariance analysis was conducted to determine the regression of number of hair fibres per square inch on initial feedlot weight. There was a non-significant regression of 2.1785 hair fibres (per square inch) per pound increase in initial feedlot weight. The heterogeneity of regression was non-significant. The yearly strain means for number of hair fibres per square inch (Table XII) were subjected to an analysis of variance which indicated that interaction, strain, and year effects were all non-significant. The F value for interaction, however, closely approached significance at the 5% level. Although strain mean differences were not significant, each of the other strains was compared to S_1 to determine the adjusted strain averages in number of hair fibres per square inch. As strain X year interaction was significant in each comparison, estimates of strain mean differences (Table XIII) were made by determining the differences between the averages of yearly strain means. Each of the strain mean differences was then added to the strain average (SX/n) determined for S_1. The adjusted strain averages for number of hair fibres per square inch were: S_1, 5274 hair fibres; S_3, 5093 hair fibres; S_2, 5064 hair fibres; S_4, 4678 hair fibres.

TABLE XII

YEARLY STRAIN MEANS OF NUMBER OF HAIR FIBRES PER SQUARE INCH

	S_1	S_2	S_3	S_4	Total
Y_1	5,482	5,547	5,297	5,007	21,333
Y_2	5,203	5,376	5,317	5,067	20,963
Y_3	6,749	4,406	4,639	3,997	19,791
Y_4	3,750	5,017	5,207	4,729	18,703
Total	21,184	20,346	20,460	18,800	80,790

TABLE XIII

ESTIMATED STRAIN MEAN DIFFERENCES IN NUMBER OF HAIR FIBRES PER SQUARE INCH

	S_1	S_3	S_2	S_4
S_1		181.0	209.5	596.0
S_3				
S_2				
S_4				

VII. HAIR SAMPLE WEIGHT

A covariance analysis was performed to determine the regression of hair sample weight on initial feedlot weight. There was a non-significant regression of 0.1238 milligrams of hair sample weight (per square inch) per pound increase in initial feedlot weight. The heterogeneity of regression was non-significant. The yearly strain means for hair sample weight (Table XIV) were subjected to an analysis of variance which indicated non-significant interaction and year effects and significant ($P < 0.01$) strain differences. The method of fitting constants to a two factor table, interaction negligible, confirmed that interaction and year effects were non-significant and strain effects significant ($P < 0.01$). All possible strain comparisons were made using either the method of disproportionate subclass numbers in an R X 2 table with interaction negligible, or the method of weighted squares of means with interaction present. The estimated strain mean differences are shown in Table XV. The adjusted strain averages for hair sample weight were: S_2, 559.3 milligrams; S_4, 389.4 milligrams; S_3, 385.7 milligrams; S_1, 239.5 milligrams. S_2 significantly ($P < 0.01$) exceeded each of S_1, S_3, and S_4, while each of S_3 and S_4 significantly ($P < 0.01$) exceeded S_1. There was no significant strain mean difference between S_3 and S_4 in hair sample weight.

TABLE XIV

YEARLY STRAIN MEANS OF HAIR SAMPLE WEIGHT (MILLIGRAMS)

	S_1	S_2	S_3	S_4	Total
Y_1	266.0	566.8	334.4	522.0	1,689.2
Y_2	222.3	542.6	384.0	329.8	1,478.7
Y_3	256.4	566.1	432.3	392.5	1,647.3
Y_4	201.2	549.1	387.6	292.4	1,430.3
Total	945.9	2,224.6	1,538.3	1,536.7	6,245.5

TABLE XV

ESTIMATED STRAIN MEAN DIFFERENCES IN HAIR SAMPLE WEIGHT (MILLIGRAMS)

	S_2	S_3	S_4	S_1
S_2		175.53**	174.75**	319.74**
S_3			.40	146.18**
S_4				149.84**
S_1				

** $P < 0.01$

VIII. REGRESSION AND CORRELATION COEFFICIENTS

With the exception of weight per day of age to the end of the feedlot test, each trait was related to each of the other traits and initial feedlot weight by means of regression and correlation coefficients.

Regression coefficients. Among the more important considerations involved in this study were the effects which each of the other traits had on pounds of TDN consumed per pound of weight gained and on feedlot ADG.

As shown in Table XVI, there was a significant ($P < 0.01$) regression of -1.6539 pounds of TDN consumed per pound of weight gained for each increase of one pound in feedlot ADG. Also, there was a significant ($P < 0.01$) regression of 0.0042 pounds of TDN consumed per pound of weight gained for each increase of one pound in initial feedlot weight. The regression of pounds of TDN consumed per pound of weight gained on each of hair sample weight, number of hair fibres, hair fibre thickness, and hair fibre length was non-significant.

The regression of feedlot ADG on each of hair sample weight, number of hair fibres, hair fibre thickness, hair fibre length, and initial feedlot weight was non-significant.

There was a significant ($P < 0.01$) regression of 0.0466 milligrams of hair sample weight for each increase of one

TABLE XVI

REGRESSION COEFFICIENTS. TRAITS: A, TDN CONSUMED PER POUND OF WEIGHT GAINED (POUNDS); B, FEEDLOT ADG (POUNDS); C, HAIR SAMPLE WEIGHT (MILLIGRAMS); D, NUMBER OF HAIR FIBRES (PER SQUARE INCH); E, HAIR FIBRE THICKNESS (MICRONS); F, HAIR FIBRE LENGTH (MILLIMETERS); G, INITIAL FEEDLOT WEIGHT (POUNDS)

Regression	A	B	C	D	E	F	G
of A on		-1.6539**	0.00003	-0.00002	-0.0027	-0.0097	0.0042**
of B on			-0.0003	0.000006	-0.0089	-0.0015	0.0003
of C on				0.0466**	6.8039	5.5927**	0.1238
of D on					-143.7800**	-33.8034	2.1785
of E on						0.1127**	-0.0057
of F on							-0.0101

** $P < 0.01$

hair fibre per square inch. Also, there was a significant ($P < 0.01$) regression of 5.5927 milligrams of hair sample weight for each increase of one millimeter in hair fibre length. The regression of hair sample weight on each of hair fibre thickness and initial feedlot weight was non-significant.

There was a significant ($P < 0.01$) regression of -143.7800 hair fibres per square inch for each increase of one micron in hair fibre thickness. The regression of number of hair fibres on each of hair fibre length and initial feedlot weight was non-significant.

There was a significant ($P < 0.01$) regression of 0.1127 microns of fibre thickness for each increase of one millimeter in hair fibre length. The regression of hair fibre thickness on initial feedlot weight was non-significant.

The regression of hair fibre length on initial feedlot weight was non-significant.

All of the regressions were homogeneous except the regression of pounds of TDN consumed per pound of weight gained on feedlot ADG; hair sample weight on number of hair fibres; hair sample weight on hair fibre thickness; number of hair fibres on hair fibre thickness.

Correlation coefficients. All possible simple correlation coefficients were computed using each of the four hair traits, feedlot ADG, pounds of TDN consumed per pound of weight gained, and initial feedlot weight. As shown in Table XVII, significant ($P < 0.01$) correlation coefficients existed between pounds of TDN consumed per pound of weight gained and feedlot ADG (-0.7171); pounds of TDN consumed per pound of weight gained and initial feedlot weight (0.5512); hair sample weight and number of hair fibres (0.6057); hair sample weight and hair fibre length (0.3998); number of hair fibres and hair fibre thickness (-0.2985); hair fibre thickness and hair fibre length (0.2985). None of the other correlation coefficients were significant.

IX. HETEROSIS

In this study, the heterosis effect is measured in terms of the percentage by which the average of the adjusted strain means of the reciprocal crosses exceeds the average of the adjusted strain means of the parental breeds. The heterosis effect (in per cent) for each trait is: feedlot ADG, 3.2; pounds of TDN consumed per pound of weight gained, 3.7; weight per day of age to the end of the feedlot test, 8.2; hair fibre length, 1.5; hair fibre thickness, 0.7. The reciprocal crosses were below the average of the parental breeds by 3.0 and 5.5 per cent for hair sample weight and number of fibres per square inch, respectively.

TABLE XVII

CORRELATION COEFFICIENTS. TRAITS: A, TDN CONSUMED PER POUND OF WEIGHT GAINED (POUNDS); B, FEEDLOT ADG (POUNDS); C, HAIR SAMPLE WEIGHT (MILLIGRAMS); D, NUMBER OF HAIR FIBRES (PER SQUARE INCH); E, HAIR FIBRE THICKNESS (MICRONS); F, HAIR FIBRE LENGTH (MILLIMETERS); G, INITIAL FEEDLOT WEIGHT (POUNDS)

Correlation	A	B	C	D	E	F	G
between A and		-0.7171**	0.0707	-0.0637	-0.0163	-0.1551	0.5512**
between B and			-0.1415	0.0445	-0.1244	-0.0552	0.1150
between C and				0.6057**	0.1837	0.3998**	0.0803
between D and					-0.2985**	-0.1858	0.1086
between E and						0.2985**	-0.1380
between F and							-0.0915

** $P < 0.01$

CHAPTER V

SUMMARY, DISCUSSION, AND CONCLUSIONS

I. SUMMARY AND DISCUSSION

Thirty-two Hereford, 21 Highland, 28 Highland X Hereford, and 20 Hereford X Highland steer calves were used in the study of seven performance traits.

The purpose of the study was to compare the performance of the four strains of cattle for each of the seven traits and to determine the within-strain relationship of six of the traits to each other.

Table XVIII, page 44, which summarizes the results of the analyses of variance of the yearly strain means, shows that estimated strain mean differences were significant for feedlot ADG, pounds of TDN consumed per pound of weight gained, hair sample weight, hair fibre length, and hair fibre thickness, while there were no significant strain mean differences in number of hair fibres per square inch. Year effects were shown to be significant for feedlot ADG, pounds of TDN consumed per pound of weight gained, hair fibre length, and hair fibre thickness, but not for hair sample weight or number of hair fibres per square inch. The only strain X year interaction was found in the analysis of the trait hair fibre length.

Table XIX, which summarizes the results of the fitting of constants to a two factor table with interaction negligible, confirms the results in Table XVIII.

Sire and climate effects are probably two of the most important factors involved in the year variation. No attempt was made to separate these components of variation in this study.

Table XX, page 45, summarizes the adjusted strain means, and indicates the results of the tests of significance of the estimated strain mean differences for each trait studied.

Growth characteristics. There was no relationship between feedlot ADG and initial feedlot weight, although there was a significant, homogeneous, and linear regression of 0.0042 pounds of TDN consumed per pound of weight gained for each increase of one pound in initial feedlot weight. The coefficient of correlation between pounds of TDN consumed per pound of weight gained and initial feedlot weight was 0.5512, an indication that animals which were the heaviest at the beginning of the feedlot test tended to be the least efficient in feed utilization on the feedlot test.

Each of S_1, S_3, and S_4 significantly exceeded S_2 in feedlot ADG and weight per day of age to the end of the feedlot test, while S_1 and S_3 also consumed significantly

TABLE XVIII

F VALUES FOR INTERACTION, STRAIN, AND YEAR EFFECTS RESULTING FROM SIMPLE ANALYSIS OF VARIANCE OF YEARLY STRAIN MEANS. TRAITS: A, FEEDLOT ADG (POUNDS); B, TDN CONSUMED PER POUND OF WEIGHT GAINED (POUNDS); C, HAIR SAMPLE WEIGHT (MILLIGRAMS); D, HAIR FIBRE LENGTH (MILLIMETERS); E, HAIR FIBRE THICKNESS (MICRONS); F, NUMBER OF HAIR FIBRES PER SQUARE INCH

	Interaction	Strains	Years
A	1.35	9.47**	11.33**
B	1.19	3.54*	29.90**
C	1.67	38.84**	2.26
D	2.76**	40.80**	9.78**
E	.99	6.58**	9.66**
F	1.97	.85	1.20

TABLE XIX

F VALUES FOR INTERACTION, STRAIN, AND YEAR EFFECTS RESULTING FROM FITTING OF CONSTANTS TO A TWO FACTOR TABLE WITH INTERACTION NEGLIGIBLE. A, B, C, AND E (SAME AS IN TABLE XVIII)

	Interaction	Strains	Years
A	1.19	12.64**	13.67**
B	1.21	4.72**	43.25**
C	1.92	48.05**	2.33
E	1.18	7.67**	12.77**

For Table XVIII and Table XIX
Strains and years $F_{.01}(3,85) = 4.02$ $F_{.05}(3,85) = 2.71$
Interaction $F_{.01}(9,85) = 2.63$ $F_{.05}(9,85) = 1.98$

TABLE XX

SUMMARY OF ADJUSTED STRAIN MEANS. GROUPS OF MEANS, WITHIN WHICH IT IS NOT POSSIBLE TO DEMONSTRATE SIGNIFICANT DIFFERENCES, ARE UNDERLINED

Feedlot ADG	S_1 1.86	S_3 1.85	S_4 1.71	S_2 1.59
Pounds of TDN consumed/ pound of weight gained	S_2 5.55	S_4 5.28	S_1 5.23	S_3 5.11
Weight per day of age	S_3 1.82	S_1 1.74	S_4 1.73	S_2 1.54
Hair sample weight	S_2 559.3	S_4 389.4	S_3 385.7	S_1 239.5
Hair fibre length	S_2 61.5	S_4 51.1	S_3 49.5	S_1 37.6
Hair fibre thickness	S_2 36.0	S_3 35.0	S_4 34.3	S_1 32.8
Number of hair fibres	S_1 5274	S_3 5093	S_2 5064	S_4 4678

fewer pounds of TDN per pound of weight gained than did S_2. S_1 significantly exceeded S_4 in feedlot ADG. No significant differences were found among the other strain means for any of the three traits. It already has been shown that S_2 has a much slower rate of growth and is less efficient in feed utilization than the other strains. However, the adjusted strain means of pounds of TDN consumed per pound of weight gained probably were underestimated for S_2 and S_3 because they passed through only part of their fattening period.

There was a significant regression of -1.6539 pounds of TDN consumed per pound of weight gained for each increase of one pound in feedlot ADG. The corresponding correlation coefficient was -0.7171, indicating that the animals with the highest rate of gain on test tended to be the most efficient in feed utilization.

The heterosis effect was 3.2, 3.7, and 8.2 per cent for feedlot ADG, pounds of TDN consumed per pound of weight gained, and weight per day of age to the end of the feedlot test, respectively.

Although there was no significant difference between the reciprocal crosses in any of the growth characteristics, S_3 exceeded S_4 in each of them. This may be attributed partially to differences in the foundation strains. If the Highland bulls or the Hereford cows, or both, were genetically superior to their counterparts in the other strains,

S_3 could be expected to have an advantage in performance over S_4.

<u>Hair characteristics</u>. There was no significant relationship between initial feedlot weight and any of the hair characteristics.

S_2 significantly exceeded each of S_1, S_3, and S_4, while each of S_3 and S_4 significantly surpassed S_1 in hair fibre length and hair sample weight. S_2 had significantly greater hair fibre thickness than S_4 and S_1, while S_3 also exceeded S_1 significantly. No significant strain mean differences were found among the other strain means for any of these three traits, or for the trait number of hair fibres per square inch.

Each hair characteristic was related to each of the others by regression and correlation coefficients. The regression coefficients (correlation coefficients in brackets) which were significant were: regression of 0.0466 milligrams of hair sample weight for each increase of one hair fibre per square inch (0.6057), regression of 5.5927 milligrams of hair sample weight for each increase of one millimeter in hair fibre length (0.3998), regression of -143.7800 hair fibres per square inch for each increase of one micron in hair fibre thickness (-0.2985), regression of 0.1127 microns of hair fibre thickness for each increase of one millimeter in hair fibre length (0.2985). It is not surprising that both the number of hair fibres and hair fibre length directly affected the weight of the hair sample, or that hair fibres tended to become thicker as they attained greater length. The tendency of animals with fewer hair fibres to have hair fibres of greater thickness presumably is an attempt by nature to maintain a relatively dense protective hair coat. A similar but non-significant relationship existed between the number of hair fibres per square inch and hair fibre length.

The heterosis effect was 1.5 and 0.7 per cent for each of hair fibre length and hair fibre thickness, respectively, while the average of the reciprocal crosses was below the average of the parental breeds by 3.0 and 5.5 per cent for each of hair sample weight and number of hair fibres per square inch, respectively.

The adjusted strain means of the reciprocal crosses were intermediate between those of the parental breeds for hair sample weight, hair fibre length, and hair fibre thickness, but they had a lower average than the parental breeds in number of hair fibres per square inch.

Association between growth and hair characteristics. Each of the hair characteristics was related to each of feedlot ADG and pounds of TDN consumed per pound of weight gained by means of regression and correlation coefficients. No significant relationships were found. This indicated that no single hair trait had influenced an increase in feedlot ADG or an improvement in efficiency of feed utilization. Possible explanations for this result are (1) climatic conditions during the test may not have been severe enough to demonstrate the importance of superior hair characteristics, (2) other individual traits or a combination of traits may influence hardiness more than do the hair characteristics measured, (3) it may be that benefits of increased hardiness can be demonstrated only in an appraisal of overall performance.

II. CONCLUSIONS

Hereford, Highland X Hereford, and Hereford X Highland calves significantly exceeded Highland calves in feedlot ADG and weight per day of age to the end of the feedlot test. Hereford and Highland X Hereford calves consumed significantly fewer pounds of TDN per pound of weight gained than did Highland calves.

Highland calves significantly surpassed calves of the other strains in hair fibre length and hair sample weight. Hereford calves were exceeded significantly by Highland X Hereford and Hereford X Highland calves in these traits also. The hair fibre thickness of Highland calves significantly exceeded that of the Hereford X Highland and Hereford calves. There were no significant strain mean differences in number of hair fibres per square inch.

The significant relationships among hair characteristics showed that (1) both the number of hair fibres and hair fibre length directly affected hair sample weight, (2) there was a direct relationship between hair fibre thickness and hair fibre length, (3) there was an inverse relationship between hair fibre thickness and number of hair fibres per square inch.

There was a direct relationship between initial feedlot weight and pounds of TDN consumed per pound of weight gained on the feedlot test.

There was an inverse relationship between feedlot ADG and pounds of TDN consumed per pound of weight gained on the feedlot test.

No significant relationships were found between any of the hair characteristics and either feedlot ADG or pounds of TDN consumed per pound of weight gained. It is possible that the climatic conditions experienced during this study were not severe enough to indicate adequately the contribution which outstanding hair characteristics could make to hardiness. It is possible that other individual traits, or combination of traits, might be a better test of hardiness than were the traits recorded in this study.

There was no significant difference between the Highland X Hereford and Hereford X Highland strains in any of the performance traits. The Highland X Hereford strain had a slight, but consistent, advantage over the Hereford X Highland in each of the growth characteristics, however. If the Highland bulls or the Hereford cows, or both, from the foundation herd, were genetically superior to their counterparts in the other strains, the Highland X Hereford calves could be expected to have an advantage in performance over Hereford X Highland calves.

The averages of the adjusted strain means of the reciprocal crosses were intermediate between those of the parental strains in feedlot ADG, hair sample weight, hair fibre length, and hair fibre thickness; slightly lower in pounds of TDN consumed per pound of weight gained and number of hair fibres per square inch; and slightly higher in weight per day of age to the end of the feedlot test.

The greatest heterosis effect was found in the growth traits, where the average of the reciprocal crosses exceeded that of the parental strains by 3.2, 3.7, and 8.2 per cent for feedlot ADG, pounds of TDN consumed per pound of weight gained, and weight per day of age to the end of the feedlot test, respectively.

The reciprocal crosses exhibited no real advantage in heterosis in the hair traits, the percentage in their favor being only 1.5 and 0.7 for hair fibre length and hair fibre thickness, respectively, while the average of the reciprocal crosses was below that of the parental strains by 3.0 and 5.5 per cent for hair sample weight and number of hair fibres per square inch, respectively.

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APPENDIX

EXAMPLE I. CALCULATION OF REGRESSION OF (Y) ON (X), WITHIN STRAIN AND YEAR

TABLE XXI

COVARIANCE. REGRESSION OF POUNDS OF TDN CONSUMED PER POUND OF WEIGHT GAINED (Y) ON INITIAL FEEDLOT WEIGHT (X)

1 Year	2 Strain	3 n	4 SX	5 SX^2	6 SY	7 SY^2	8 SXY	9 $(SX)^2/n$
Y_1	S_1	11	4,308	1,718,880	65.66	396.8996	25,952.54	1,687,169.45
	S_2	6	2,222	844,108	36.57	224.4671	13,580.18	822,880.67
	S_3	6	2,580	1,120,640	33.78	191.4558	14,487.26	1,109,400.00
	S_4	5	1,888	716,696	28.28	160.3450	10,689.58	712,908.80
Y_2	S_1	6	2,360	953,832	29.19	142.7311	11,604.02	928,266.67
	S_2	2	738	272,564	9.60	46.0800	3,542.40	272,322.00
	S_3	8	3,482	1,536,476	41.49	215.7713	18,124.66	1,515,540.50
	S_4	4	1,854	863,452	21.25	113.3143	9,883.64	859,329.00
Y_3	S_1	7	2,430	910,668	33.56	162.2490	11,911.74	843,557.14
	S_2	6	2,456	1,031,560	33.41	186.9473	13,740.54	1,005,322.67
	S_3	3	1,166	474,708	14.87	74.5881	5,909.24	453,185.33
	S_4	3	1,462	715,636	17.54	103.3598	8,528.50	712,481.33
Y_4	S_1	8	3,216	1,311,832	37.46	175.9628	15,130.14	1,292,832.00
	S_2	7	2,266	758,852	33.08	159.1328	10,905.28	733,536.57
	S_3	11	4,252	1,667,512	50.34	231.4904	19,571.80	1,643,591.27
	S_4	8	3,280	1,361,128	38.17	182.7227	15,722.64	1,344,800.00
Total		101	39,960	16,258,544	524.25	2,767.5171	209,284.16	15,937,123.40

TABLE XXI (continued)

10 $(SY)^2/n$	11 (SX)(SY)/n	12 Sx^2 (5-9)	13 Sxy (8-11)	14 Sy^2 (7-10)	15 b (13/12)	16 SS 14-(13x15)
391.9305	25,714.84	31,710.55	237.70	4.9691	0.0075	3.1863
222.8942	13,543.09	21,227.33	37.09	1.5729	.0017	1.5098
190.1814	14,525.40	11,240.00	- 38.14	1.2744	- .0034	1.1447
159.9517	10,678.53	3,787.20	11.05	.3933	.0029	.3613
142.0094	11,481.40	25,565.33	122.62	.7217	.0048	.1331
46.0800	3,542.40	242.00	0.00	.0000	.0000	.0000
215.1775	18,058.52	20,935.50	66.14	.5938	.0032	.3822
112.8906	9,849.38	4,123.00	34.26	.4237	.0083	.1393
160.8962	11,650.11	67,110.86	261.63	1.3528	.0039	.3324
186.0380	13,675.83	26,237.33	64.71	.9093	.0025	.7475
73.7056	5,779.47	21,522.67	129.77	.8825	.0060	.1039
102.5505	8,547.83	3,154.67	- 19.33	.8093	- .0061	.6914
175.4065	15,058.92	19,000.00	71.22	.5563	.0037	.2928
156.3266	10,708.47	25,315.43	196.81	2.8062	.0078	1.2711
230.3741	19,458.70	23,920.73	113.10	1.1163	.0047	.5847
182.1186	15,649.70	16,328.00	72.94	.6041	.0045	.2759
2,748.5314	207,922.59	321,420.60	1,361.57	18.9857	0.0042#	11.1564

S15= S13/S12

EXAMPLE II. ANALYSIS OF COVARIANCE AND TEST OF SIGNIFICANCE OF ADJUSTED LOT MEANS

$$CX = \frac{(SSX)^2}{Sn} = \frac{(39{,}960)^2}{101} = 15{,}809{,}916.83$$

$$CY = \frac{(SSY)^2}{Sn} = \frac{(524.25)^2}{101} = 2{,}721.1689$$

$$CXY = \frac{(SSX)(SSY)}{Sn} = \frac{(39{,}960)(524.25)}{101} = 207{,}416.14$$

Total $Sx^2 = SSX^2 - CX = 16{,}258{,}544 - 15{,}809{,}916.83 = 448{,}627.17$
$Sy^2 = SSY^2 - CY = 2{,}767.5171 - 2{,}721.1689 = 46.3482$
$Sxy = SSXY - CXY = 209{,}284.16 - 207{,}416.14 = 1{,}868.02$

Lots $Sx^2 = S9 - CX = 15{,}937{,}123.40 - 15{,}809{,}916.83 = 127{,}206.57$
$Sy^2 = S10 - CY = 2{,}748.5314 - 2{,}721.1689 = 27.3625$
$Sxy = S11 - CXY = 207{,}922.59 - 207{,}416.14 = 506.45$

TABLE XXII

ANALYSIS OF COVARIANCE AND TEST OF SIGNIFICANCE OF ADJUSTED LOT MEANS (ADJUSTED FOR DIFFERENCES IN INITIAL FEEDLOT WEIGHT) SNEDECOR (1946), PAGE 320

	D.f.	Sx^2	Sxy	Sy^2	SS	D.f.	MS
T	100	448,627.17	1,868.02	46.3482	38.5700	99	
L	15	127,206.57	506.45	27.3625			
E	85	321,420.60	1,361.57	18.9857	13.2180	84	.1574
					25.3520	15	1.6901

$$TSS = TSy^2 - \frac{(TSxy)^2}{TSx^2} = 46.3482 - \frac{(1{,}868.02)^2}{448{,}627.17} = 38.5700$$

$$ESS = ESy^2 - \frac{(ESxy)^2}{ESx^2} = 18.9857 - \frac{(1{,}361.57)^2}{321{,}420.60} = 13.2180$$

$$F = \frac{LMS}{EMS} = \frac{1.6901}{.1574} = 10.74^{**}$$

EXAMPLE III. CALCULATION OF SIMPLE CORRELATION COEFFICIENT

Correlation coefficient $r_{xy} = \frac{S13}{\sqrt{(S12)(S14)}} = \frac{1,361.57}{\sqrt{6,102,395.0854}}$

$= \frac{1,361.57}{2,470.3027} = 0.5512$

EXAMPLE IV. TEST OF SIGNIFICANCE OF REGRESSION

TABLE XXIII

ANALYSIS OF ERROR VARIANCE FOR TEST OF SIGNIFICANCE OF REGRESSION. SNEDECOR (1946), PAGE 323

Source of variation	D.f.	SS	MS	F
W/in lots, unadjusted TDN, Sy^2	85	18.9857		
Reduction due to regression	1	5.7677	5.7677	36.64**
Error for adjusted TDN	84	13.2180	.1574	

EXAMPLE V. TEST OF SIGNIFICANCE OF HETEROGENEITY OF REGRESSION

TABLE XXIV

ANALYSIS OF ERRORS OF ESTIMATE FROM AVERAGE REGRESSION WITHIN LOTS. SNEDECOR (1946), PAGE 327

Source of variation	D.f.	SS	MS	F
Dev. from ave. (error) reg. W/in lots	84	13.2180		
Dev. from ind. lot reg.	69	11.1564	.1617	
Differences among lot regressions	15	2.0616	.1374	.85

EXAMPLE VI. INCORPORATION OF X^2 AS SECOND INDEPENDENT VARIATE

TABLE XXV

INCORPORATION OF X^2 AS SECOND INDEPENDENT VARIATE. EXTENSION OF DATA FROM TABLE XXI, PAGE 57. SNEDECOR (1946), PAGE 379

Year	Strain	n	$S(X^2)^2$	SXX^2	SX^2Y
Y_1	S_1	11	289,133,461,824	698,647,680	10,446,434.84
	S_2	6	129,481,093,936	327,634,904	5,173,295.56
	S_3	6	218,523,753,536	492,048,672	6,273,855.80
	S_4	5	104,854,748,960	273,458,800	4,061,591.48
Y_2	S_1	6	165,036,044,064	393,634,016	4,727,524.60
	S_2	2	37,277,370,896	100,754,712	1,308,307.20
	S_3	8	308,040,211,760	685,194,584	8,021,938.84
	S_4	4	189,923,249,968	404,026,056	4,618,095.52
Y_3	S_1	7	153,612,304,176	364,291,800	4,542,683.16
	S_2	6	193,993,265,440	443,082,656	5,788,751.32
	S_3	3	86,921,468,688	200,412,296	2,451,032.72
	S_4	3	173,634,005,008	351,788,968	4,164,586.36
Y_4	S_1	8	226,901,625,376	542,292,144	6,198,068.60
	S_2	7	93,217,373,264	262,257,592	3,711,684.32
	S_3	11	265,065,151,072	661,683,664	7,711,249.92
	S_4	8	241,759,188,832	570,941,008	6,551,683.76
Total			2,877,374,316,800	6,772,149,552	85,750,784.00

EXAMPLE VII. CALCULATION OF SUMS OF SQUARES AND PRODUCTS, AND CORRELATION COEFFICIENTS, FOLLOWING THE INCORPORATION OF X^2

TABLE XXVI

CALCULATION OF SUMS OF SQUARES AND PRODUCTS, AND CORRELATION COEFFICIENTS, FOLLOWING THE INCORPORATION OF X^2. SNEDECOR (1946), PAGE 379

N= 101	X	X^2	Y
Sum	39,960.	16,258,544.	524.25
Mean	395.6436	160,975.6832	5.1906
X. SX^2, SXX^2, SXY	16,258,544.00	6,772,149,552.00	209,284.16
CT	15,809,916.83	6,432,588,299.41	207,416.14
Sx^2, Sxx^2, Sxy	448,627.17	339,561,252.59	1,868.02
$\sqrt{Sx^2}$, $\sqrt{[Sx^2][S(x^2)^2]}$, $\sqrt{(Sx^2)(Sy^2)}$	669.7964	341,625,096.40	4,560.00
r_{xx^2}, r_{xy}		.9940	.4097
X^2. $S(X^2)^2$, SX^2Y		2,877,374,316,800.00	85,750,784.00
CT		2,617,230,227,722.14	84,391,501.90
$S(x^2)^2$, Sx^2y		260,144,089,077.86	1,359,282.10
$\sqrt{S(x^2)^2}$, $\sqrt{[S(x^2)^2][Sy^2]}$		510,043.2227	3,472,349.3870
r_{x^2y}			.3915
Y. SY^2			2,767.5171
CT			2,721.1689
Sy^2			46.3482

EXAMPLE VIII. TEST OF SIGNIFICANCE OF DEPARTURE FROM LINEAR REGRESSION

$R^2Y(XX^2) = (.4097)^2 + (.3915)^2 - 2(.4097)(.3915)(.9940)/1-(.9940)^2$

$= .3211 - .3188/.0120 = .0023/.0120 = .1917$

Remainder after linear b= $(1-.4097^2)(46.3482) = 38.5685$

Remainder after curved b= $(1-.1917)(46.3482) = 37.4633$

TABLE XXVII

TEST OF SIGNIFICANCE OF DEPARTURE FROM LINEAR REGRESSION

Source of variation	D.f.	SS	MS	F
Deviation from linear b	99	38.5685		
Deviation from curved b	98	37.4633	.3823	
Curvilinearity	1	1.1052	1.1052	2.89

EXAMPLE IX. NEW SX, SX^2, $(SX)^2/n$, Sx^2 VALUES CALCULATED FOLLOWING SIGNIFICANT LINEAR REGRESSION

TABLE XXVIII

SX, SX^2, $(SX)^2/n$, Sx^2 VALUES (BASED ON TDN VALUES ADJUSTED FOR DIFFERENCES IN INITIAL FEEDLOT WEIGHT)

Year	Strain	SX	SX^2	$(SX)^2/n$	Sx^2
Y_1	S_1	65.88	398.1054	394.5613	3.5441
	S_2	37.22	232.5276	230.8881	1.6395
	S_3	32.92	182.4234	180.6211	1.8023
	S_4	28.67	164.7549	164.3938	.3611
Y_2	S_1	29.26	142.8308	142.6913	.1395
	S_2	9.83	48.3185	48.3145	.0040
	S_3	40.17	202.1127	201.7036	.4091
	S_4	20.12	101.4110	101.2036	.2074
Y_3	S_1	34.99	175.2309	174.9000	.3309
	S_2	33.07	183.0989	182.2708	.8281
	S_3	14.96	74.7690	74.6005	.1685
	S_4	16.39	90.5733	89.5440	1.0293
Y_4	S_1	37.26	173.8294	173.5385	.2909
	S_2	35.21	178.7017	177.1063	1.5954
	S_3	50.77	234.9167	234.3266	.5901
	S_4	37.69	177.8489	177.5670	.2819
Total		524.41	2,761.4531	2,748.2310	13.2221

EXAMPLE X. TEST FOR INTERACTION, USING ANALYSIS OF VARIANCE OF YEARLY STRAIN MEANS

TABLE XXIX

YEARLY STRAIN MEANS (BASED ON TDN VALUES ADJUSTED FOR DIFFERENCES IN INITIAL FEEDLOT WEIGHT)

SNEDECOR (1946), PAGE 294

	S_1	S_2	S_3	S_4	Total
Y_1	5.99	6.20	5.49	5.73	23.41
Y_2	4.88	4.92	5.02	5.03	19.85
Y_3	5.00	5.51	4.99	5.46	20.96
Y_4	4.66	5.03	4.62	4.71	19.02
Total	20.53	21.66	20.12	20.93	83.24

Total SS= SX^2-CF= 436.4320-433.0561= 3.3759

Strain SS= $(20.53)^2+(21.66)^2+(20.12)^2+(20.93)^2/4-CF=$ 0.3229

Years SS= $(23.41)^2+(19.85)^2+(20.96)^2+(19.02)^2/4-CF=$ 2.7271

Within subclasses MS= $SSx^2/D.f.=$ 13.2221/85= 0.1556

Harmonic mean of subclass numbers= $\frac{1}{16}\left(\frac{1}{11}+\frac{1}{6}+\ldots\frac{1}{11}+\frac{1}{8}\right)=$ 0.1954

EMS for comparisons with MS calculated from means

= (0.1556)(0.1954)= 0.0304

COMPLETED ANALYSIS OF VARIANCE

Source of variation	D.f.	SS	MS	F
Strains	3	.3229	.1076	3.54*
Years	3	2.7271	.9090	29.90**
Interaction	9	.3259	.0362	1.19
Error	85		.0304	

$*P < 0.05$

$**P < 0.01$

EXAMPLE XI. INTERACTION NEGLIGIBLE IN AN R X 2 TABLE WITH DISPROPORTIONATE SUBCLASS NUMBERS

TABLE XXX

NUMBER AND YEARLY MEANS OF POUNDS OF TDN CONSUMED PER POUND OF WEIGHT GAINED OF TWO STRAINS OF CALVES (INTERACTION NEGLIGIBLE). SNEDECOR (1946), PAGE 289

	S_2		S_1				
	k_1	$\bar{x}_1$	k_2	$\bar{x}_2$	$\frac{k_1k_2}{k_1+k_2}$ =W	$\bar{x}_1-\bar{x}_2$ =D	WD
Y_1	6	6.20	11	5.99	3.8824	.21	.8153
Y_2	2	4.92	6	4.88	1.5000	.04	.0600
Y_3	6	5.51	7	5.00	3.2308	.51	1.6477
Y_4	7	5.03	8	4.66	3.7333	.37	1.3813
Total					12.3465		3.9043

Total SS= $SSX^2-(SSX)^2/Sn$= $1532.643-(282.72)^2/53$

= 1532.643-1508.124= 24.519

Subclasses SS= $S\left[(SX)^2/n\right]-(SSX)^2/Sn$

= 1522.271-1508.124= 14.147

Within subclasses SS= 24.519-14.147= 10.372

D.f.= 45 MS= 10.372/45= .230

Interaction SS= $SWD^2-(SWD)^2/SW$= $1.525-(3.904)^2/12.346$

= 1.525-1.235= .290

D.f.= 3 MS= .290/3= .097 F= .097/.230= .42

Adjusted strain SS= MS= 1.235 F= 1.235/.230= 5.37*

Estimated strain mean difference=SWD/SW= 3.9043/12.3465= .316

EXAMPLE XII. WEIGHTED SQUARES OF MEANS WITH INTERACTION PRESENT

TABLE XXXI

NUMBER AND YEARLY MEANS OF HAIR FIBRE LENGTH (MILLIMETERS) OF TWO STRAINS OF CALVES (INTERACTION PRESENT)

SNEDECOR (1946), PAGE 291

	S_4		S_1		$\frac{k_1k_2}{k_1+k_2}$	$\bar{x}_1-\bar{x}_2$	
	k_1	$\bar{x}_1$	k_2	$\bar{x}_2$	=W	=D	WD
Y_1	5	54.4	11	37.1	3.4375	17.3	59.4688
Y_2	4	41.1	6	34.2	2.4000	6.9	16.5600
Y_3	3	58.8	7	35.8	2.1000	23.0	48.3000
Y_4	8	49.3	8	42.2	4.0000	7.1	28.4000
Total					11.9375		152.7288

Total SS= $SSX^2-(SSX)^2/Sn$= $99,102.11-(2208.70)^2/52$

= 99,102.11-93,814.53= 5,287.58

Subclasses SS= $S\left[(SX)^2/n\right]-(SSX)^2/Sn$

= 96,747.42-93,814.53= 2,932.89

Within subclasses SS= 5,287.58-2,932.89= 2,354.69

D.f.= 44 MS= 2,354.69/44= 53.5157

Interaction SS=$SWD^2-(SWD)^2/SW$= $2,455.6142-(152.7288)^2/11.9375$

= 2,455.6142-1,954.0177= 501.5965

D.f.= 3 MS= 501.5965/3= 167.1988

F= 167.1988/53.5157= 3.12*

TABLE XXXII

ANALYSIS OF VARIANCE IN R X 2 TABLE, INTERACTION PRESENT

		S_1	S_2	Sum of reciprocals	Weights W	$\bar{x}$ unweighted	$W\bar{x}$
Y_1	k	11	5				
	1/k	.09091	.20000	.29091	3.4375		
	$\bar{x}$	37.1	54.4			45.75	157.2656
Y_2	k	6	4				
	1/k	.16667	.25000	.41667	2.4000		
	$\bar{x}$	34.2	41.1			37.65	90.3600
Y_3	k	7	3				
	1/k	.14286	.33333	.47619	2.1000		
	$\bar{x}$	35.8	58.8			47.30	99.3300
Y_4	k	8	8				
	1/k	.12500	.12500	.25000	4.0000		
	$\bar{x}$	42.2	49.3			45.75	183.0000
					11.9375		529.9556

S reciprocals	.52544	+	.90833	=	1.43377
Weights W	1.90316	+	1.10092	=	3.00408
Unweighted $\bar{x}$	37.3250	+	50.9000	=	44.1125
$W\bar{x}$	71.0354	+	56.0368	=	127.0722

Weighted sums of squares

Strains= $16\left[SW\bar{x}^2-(SW\bar{x})^2/SW\right] = 16\left[5503.6694-5375.1378\right]$

$= 16\left[128.5316\right] = 2056.5056$

Years= $4\left[SW\bar{x}^2-(SW\bar{x})^2/SW\right] = 4\left[23{,}667.5142-23{,}526.9477\right]$

$= 4\left[140.5665\right] = 562.2660$

COMPLETED ANALYSIS OF VARIANCE

Source of variation	D.f.	SS	MS	F
Strains	1	2056.5056	2056.5056	38.43**
Years	3	562.2660	187.4220	3.50*
Interaction	3	501.5965	167.1988	3.12*
Individuals	44		53.5157	