ENVIRONMENTAL AND GENETIC INFLUENCES UPON HEPATIC AND PLASMA VITAMIN A AND CAROTENE LEVELS IN RANGE CATTLE

by

Richard H. Diven

A Dissertation Submitted to the Faculty of the

DEPARTMENT OF AGRICULTURAL BIOCHEMISTRY

In Partial Fulfillment of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

1959

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in The University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in their judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: 

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Carl Roubicek — Nov. 5 - 1959

C. B. ROUBICEK
Professor of Animal Science

Date

TABLE OF CONTENTS

Page

APPENDIX
TABLE

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENT

The author wishes to give sincere thanks to Dr. E. S. Erwin for his valuable advice and assistance in conducting the current study and in the writing of this dissertation.

The advice and invaluable criticisms by Drs. O. F. Pahnish and C. B. Roubicek concerning the genetic phase of this study and the presentation of the material are greatly appreciated.

The author also thanks Drs. B. R. Taylor and Henry Tucker for reviewing this dissertation. Special thanks is given to Dr. Henry Tucker for his assistance with the numerical analyses.

The help given by Mr. H. M. Page with the chemical analyses as well as the assistance by Dr. G. E. Nelms and Messrs. Al Lane, J. W. Blair, N. G. Elliston, and R. E. Taylor in sampling the animals is greatly appreciated.

Special thanks is given to my wife, Betty, for her encouragement and patience while this study was in progress and for typing this dissertation.

INTRODUCTION

There are two principal reasons why information is limited concerning the genetic and environmental factors that may influence hepatic and plasma vitamin A and carotene levels in cattle: a) only a limited number of studies with cattle have been conducted, necessitating the application of information from studies with other species to the bovine animal, and b) the few studies with cattle, have for the most part, involved small numbers of animals. Therefore, with a large number of purebred Hereford calves, it was the purpose of this investigation to consider the environmental and genetic influences upon liver and plasma levels of vitamin A and carotene. Because in widespread areas of semi-arid cattle ranges, in the southwestern United States, cattle may exist for several months at a time on dry plants largely devoid of carotene, the measurement of vitamin A and carotene in range cattle is important to the cattleman (47). Although cows have the capacity to maintain themselves for long periods on low carotene diets, their normally-born calves may suffer from vitamin A deficiency shortly after birth (6). Examples of the frequency of vitamin A deficiency relative to all beef cattle nutritional diseases and ailments has been reported from a survey by Washington workers (19). This group found that vitamin A deficiency accounted for 26.2 per cent of all nutritional diseases in the United States. A comparable figure for the "western" states was 42.2 per cent.

Vitamin A measurements in range cattle also supply basic information that may be useful in subsequent studies. In the past, the relatively few vitamin A studies with cattle on natural ranges have involved a limited number of animals. Because of species difference in the ability to utilize carotene for vitamin A, it is difficult to apply the results obtained from one species to another.

Results of previous studies with cattle have indicated considerable variation between individual animals, in blood and liver vitamin A and carotene contents. This variation resulted from either environmental or genetic influences or the sum total of both. The variation in vitamin A and carotene concentrations caused by the environment can be controlled, but the variation in inherited levels must be considered in the selection and allotment of the animals to experimental treatments.

LITERATURE REVIEW

In most of the studies so far made regarding hepatic vitamin A content in cattle, considerable variation between animals has been indicated. Consequently, large treatment differences are necessary to establish statistical significance.

Most studies of factors that affect vitamin A utilization have been conducted with laboratory animals and humans. Although all the results obtained from these species do not directly apply to cattle, it is necessary to include this information because of the lack of adequate data from studies involving the bovine animal. The among-animal variation in vitamin A storage may arise from several factors; but, in general, they have been categorized as environmental or genetic. Environmental factors that may contribute to the variation in vitamin A storage in cattle are climatic conditions, diet, age, age of dam (in the case of young calves), and initial hepatic vitamin A content. Previous work regarding the influence of the last three of these environmental factors as well as sex and other genetic influences upon vitamin A and carotene storage in cattle are discussed separately below.

Age of Animal: Results of studies with rats and humans have been conflicting with regard to the influence of age upon vitamin A reserves. Booth (8) reported that the efficiency of vitamin A storage

in rats was unaffected by age. Studies with human subjects of different age groups indicated that lowest vitamin A reserves occurred during childhood and old age (40); however, it was pointed out that this evidence was not conclusive and more work was necessary for confirmation.

Similar conflicting results have been observed with cattle. Riggs (49) found that the accumulation of vitamin A in the body of range cattle increased with age. Oklahoma workers (37) reported that age did not influence blood vitamin A levels of ten mature cows and five heifers. However, the validity of using blood values, per se, as indicators of body storage has been questioned. It is generally accepted that blood levels reflect body storage only when the hepatic content is low (9) (34) (45) (51).

Age of Dam: The possible age-of-dam influence could be mediated through total vitamin A intake via milk consumption by the suckling calf. Chanda (12) observed that milk from heifers contained a greater vitamin A concentration than milk from mature cows. However, total milk and milk fat production has been shown to increase until dairy cows were seven or eight years old (41). Also, it is conceivable that the cow may secrete more total vitamin A in her milk as she becomes older, since Riggs (49) reported that the accumulation of vitamin A in the body was linear with age. Consequently, the age-of-dam influence upon milk composition could be expressed in the stores of the preweanling calf.

In three separate studies, Oklahoma workers (6) (7) (45) observed that the liver storage of vitamin A in calves reflected the carotene intake of the dam. These studies were discontinued after the calves reached three months of age; consequently, these results can not be directly related to weaned beef calves (eight months).

Because of the rapid decline in the vitamin A content of milk following parturition (55) (29) (12), the influence of the dam upon vitamin A storage in the calf may not extend much beyond three months of age. The amount of vitamin A provided the beef calf by the dam's milk would be further masked as the calf approaches weaning age and begins to forage its own feed. This thesis has been supported by Wise et al. (55) who showed that calves reflected the vitamin A content of whole milk until they were six weeks old, at which time enough hay was consumed to raise blood levels of vitamin A.

However, weaning weights of beef calves are known to be related to the age of the dam (44) (48). Further, this influence is a direct reflection of the total milk produced by the cow (27). Therefore, there is some justification for assuming that weight and vitamin A storage may respond as parallels to age of dam.

Sex of the Animal: The influence of sex on vitamin A and carotene levels in animal tissues has been clearly shown with laboratory animals. Blood vitamin A tended to be higher in males than in females when depleted rats were dosed with vitamin A (10) (35). The opposite was true for the liver stores. Esh and Sutton (22) also observed that under comparable experimental conditions female rats stored more liver

vitamin A than males. After oral administration of high levels of vitamin A to the rat, Brenner et al. (10), Callison and Knowles (11), and Booth (8) found tha females had greater liver storage. It was also observed that the males continued to maintain less hepatic vitamin A than the females during rapid depletion on vitamin A-free diets.

Furthermore, as indicated by Moore (40), Poulson found a higher level of vitamin A in the body fat of cows than in the fat of bulls, and Ender reported a similar sex ratio of hepatic vitamin A in bovine animals.

The Influence of Initial Hepatic Vitamin A Levels Upon Subsequent Levels: Because of the sporadic rainfall in the semi-arid regions of the southwestern United States, hepatic vitamin A content of range cattle may increase or decrease. This change in vitamin A concentration during any season reflects not only available carotene but also the previous hepatic storage. With 16 Hereford heifers on vitamin A depletion diets, Arizona workers (43) reported that the different amounts of vitamin A lost from the liver could be numerically equalized by considering the expenditures as percentages of the initial levels. Further, Dolge et al. (17) observed that in increases in the logarithm of plasma vitamin A were influenced by initial stores in Holstein calves.

Heritability: Since early in history, the Guernsey breed has been selected for, among other factors, the yellow color of its milk. Since the yellow color was due to the carotene, breeders unknowingly selected cattle that were poor utilizers of carotene. In support of

these facts, Dolge et al. (16) observed that the Guernsey was less efficient in utilizing carotene than the Holstein. Holstein cows produce milk which contains less carotene, thus less yellow color, but more vitamin A than Guernsey milk (41). It appears that if selection procedures can ultimately produce a breed of cattle that are poor utilizers of carotene, then carotene utilization should be heritable. On the other hand, European breeds of beef cattle have not been selected for their ability to utilize carotene unless carotene utilization is associated with body conformation or color markings. The non-selection of beef cattle for carotene utilization was further shown by the work of Wise (55) in which serum vitamin A and carotene levels could not be distinguished between beef breeds because of large within-breed variation. However, Long et al. (37) with 15 cows reported that Shorthorn cattle had higher blood carotene levels than Hereford or Angus cattle. Also, Shorthorns appeared to have higher blood levels of vitamin A, although the within-breed variation was too large to establish a definite conclusion.

The heritability of blood vitamin A and carotene would probably reflect multiple gene influences upon several physiological phenomena. One such genetically-controlled phenomenon could be serum proteins (3) (4) (5) (32) (52) (53), which have been shown to be associated with vitamin A and carotene (21).

Blood vitamin A and carotene have not been shown to be directly associated with other blood constituents considered to be heritable, other than serum proteins. Nevertheless, vitamin A and carotene levels

may be construed to be heritable by the simple analogy that if "some are" others "may be." In a study with 16 pairs of identical twin calves, Claesson and Hansson (14) found that blood glucose was influenced by heredity, while no genetic relationship was found with blood cholesterol. Further, Evans (23) observed with 1933 sheep that the animals could be classified according to three types of hemoglobin as well as relative concentrations of blood cell potassium and sodium.

MATERIALS AND METHODS

The progeny of a nine-sire herd of purebred Hereford cows were made available for the current study through a cooperative agreement with the Apache Tribal Enterprises, the United States Department of Agriculture[1], and the Montana and Wyoming State Agricultural Experiment Stations. All animals were maintained year long on native range on the Apache Indian Reservation at San Carlos, Arizona. The elevation of this site is 4,705 feet above sea level. The mean temperature for January is about 45 degrees Fahrenheit, while the July average is 85 degrees. Yearly mean rainfall is 14 inches (47). The data used in this study were obtained from two calf crops (1957 and 1958). Samples were obtained from the 1957 progeny at four sampling periods and from the 1958 progeny at two sampling periods.

MANAGEMENT

The dams were randomly arranged within age groups to breeding units at the beginning of the calving season, early in February. Heifer replacements were distributed to all units in the same fashion for the 1957 breeding season. However, the heifer replacements for the 1956 breeding season were distributed into two breeding units and,

---

[1]This work is in cooperation with the Bureau of Animal Industry, United States Department of Agriculture, under Western Regional Project W-1 on beef cattle breeding research.

therefore, their progeny represent only two sires. Each year, the cows were recombined into a single herd at the end of the 70-day breeding season (about July 31).

During the calving and breeding seasons the sire complements were maintained in pastures of comparable forage composition, topography, and carrying capacity. With the exception of salt, the range forage was unsupplemented.

Six of the nine sires that were distributed among the breeding units in 1956 were from the U. S. Range Livestock Experiment Station, Miles City, Montana. Two sires were selected from the Apache Indian Tribal herd according to common selection procedures, while the ninth sire was from a mid-western purebred herd. The two bulls that sired the offspring of first calf heifers in 1957 were from the U. S. Range Livestock Experiment Station. They also sired calves of other damage groups in 1957. The 1958 progeny represented five of the six original Miles City bulls and four bulls (none of which were represented in 1957) from the Apache Indian Tribal herd.

During the calving season all cows were observed daily. At birth, the calves were tattooed for individual identification and their birth dates were recorded. Since the cows were numbered and placed into specific sire groups, the identity of the dam and sire of each calf was known.

The first progeny used in the current study were weaned November 6 and 7, 1957, and the second group were weaned on November 13 and 14 of the following year. The weaning age range in both groups was

approximately 5½ to 8½ months. From the time the calves were weaned in November until green forage was available--some time in March--they received, in addition to the natural forage, an ad libidum supplement of cottonseed meal mixed with 33 per cent salt. No supplement was made available to these animals subsequently.

All animals used in the study were essentially unselected. The only exceptions to this were a few animals with unacceptable color markings and any animals with obvious physical deformities.

SAMPLING AND CHEMICAL ANALYSES

Venous blood and liver samples (20) were withdrawn from each animal according to the following schedule:

Sampling Period	1957 Progeny				1958 Progeny			
	Mean Age[1]	Date	Plasma	Liver	Mean Age[1]	Date	Plasma	Liver
Period I	213	11-6-57		X	234	11-13-58	X	X
Period II	372	4-13-58	X	X	337	2-25-59	X	X
Period III	583	11-11-58	X	X				
Period IV	689	2-24-59	X	X				

[1]Age in days.

Promptly prepared plasma and saline-washed liver samples, were immediately frozen in plastic tubes with dry ice. Five mls. of each plasma sample and approximately one-half gram of each liver sample were later analyzed for carotene and vitamin A according to procedures described by Kimble (34) and Gallup and Hoefer (25) respectively. All

resulting vitamin A and carotene values as well as the calf's age at time of sampling, age and identity of respective dam, identification of respective sire, sex of the calf, weight of the calf at each sampling period, and the day and year that the observations were made were recorded in punch cards for numerical analyses.

NUMERICAL ANALYSES

Heritability of Absolute Values

Prior to estimating the heritability of each of the dependent variables (hepatic vitamin A and carotene and plasma vitamin A and carotene), it was necessary to account for the variation contributed by age-of-animal and age-of-dam influences.

Age of Animal: Means and standard deviations for each of the four dependent variables (hepatic vitamin A and carotene and plasma vitamin A and carotene) were computed for different age-of-calf classes in Period I. Each class represented approximately one-third of the age range as follows: A, 166-197 days; B, 198-229 days; and C, 230-262 days. The means of the dependent variables were plotted against the mean ages of the three classes to estimate the nature of age effect on the dependent variables.

Assuming a linear relationship between the dependent variables and age of the calf, correlation and regression coefficients were computed. These computations were made by sex within year of birth and sampling period. When the sex within-year subclass coefficients were observed to be homogeneous (30--p. 253-259), an average regression

coefficient was computed for the variable and sampling period involved for each sex. The proportion of the variation in each dependent variable attributable to age effect was estimated by the square of the correlation coefficients (coefficient of determination). As only a small amount of the variation in dependent variables could be attributed to age of the calf, no corrections were applied.

Age of Dam: In a manner similar to that just described, the nature of the relationship and the degree of variation attributable to age of dam was estimated. A graph of the dependent variable means plotted against age of dam displayed no obvious relationship. Therefore, the application of correction factors for age-of-dam influence was not warranted.

Analysis of Variance and Estimation of Heritability: The data were subjected to an analysis of variance procedure for "nested sampling" described by Anderson and Bancroft (2--p. 327-330). The computational procedure was repeated for each dependent variable within sex and sampling period. In addition to the sire variation the analysis estimated the variation due to years (for those sampling periods in which both the 1957 and 1957 progenies were present) and the sire-by-year interaction. The sire-by-year interaction (53--p. 382) was computed only from the progeny of those five sires that produced calves both in 1957 and 1958.

The variance components, necessary for heritability estimates (38) (39), were also determined by the procedure described by Anderson and Bancroft (2--p. 327-330). The standard error of the heritability

estimate was computed in the manner presented by Hazel and Terrill (46). The resulting value was multiplied by 1.96 to establish 95 per cent confidence intervals.

Heritability of Hepatic Vitamin A Differences Between Sampling Periods.

The heritability of hepatic vitamin A differences could not be accurately estimated without first adjusting the data for variation due to environmental influences. Thus, the influences of initial hepatic vitamin A content and age of animal as well as the heritability of hepatic vitamin A differences were accounted for as described below.

Influence of Initial Value: Differences in hepatic vitamin A values in adjacent periods were computed and the physiological influence of initial levels on subsequent differences (i.e., the influence that Period I levels had upon the differences between Periods I and II, etc.) was determined. The influence of initial level was estimated in each case by computation of correlation and regression coefficients from a covariance analysis, for which the data were first sorted by sex within year. When the variances of sex-within-year subclasses were found to be homogeneous (30--p. 253-259), average coefficients were computed.

Correction factors, computed as described in the preceding paragraph, were established for the hepatic vitamin A differences according to the following schedule.

Sampling Period	Subclass	Equations Used to Adjust Data
Period I	57 M&F	$Y' = Y - 0.8311 (X - 97.00$ ug./gm.)
	58 M&F	No adjustment.
Period II	57 M&F	$Y' = Y + 2.1213 (X - 51.00$ ug./gm.)
Period III	57 M	$Y' = Y - 0.6902 (X - 235.00$ ug./gm.)
	57 F	No adjustment.

Age of Animal: The differences, adjusted for initial levels, were correlated with the age of the animal in a manner previously described for "Age of Animal" under "Heritability of Absolute Values."

Analysis of Variance and Estimation of Heritability: The hepatic vitamin A differences as adjusted for initial levels were analyzed by analysis of variance for each sex and sampling period as described for "Analysis of Variance and Heritability" under "Heritability of Absolute Values."

Sex and Age

Since the age-of-animal influences that have been considered thus far are simply the differences in calving dates within each progeny, it was desirable to estimate age differences in animals from both progenies sampled at the same time. In the latter case, differences in age are approximately one year. In so doing, means and standard deviations were computed (28) for each dependent variable within sex, year, and sampling period at Periods I and II for the 1958 progeny and at Periods III and IV for the 1957 progeny.

RESULTS AND DISCUSSION

Heritability of Hepatic and Plasma Vitamin A and Carotene Levels.

Influence of Animal Age: The 1957 and 1958 progenies used in this study were born within a period of 83 and 76 days respectively. When the means of the dependent variables (hepatic and plasma vitamin A and carotene) were computed for three age classes within year of birth and sampling period, the plotting of these means against the means of the age classes suggested linear relationships. Therefore, linear correlation and regressions of the dependent variables on age were computed for each sex within year (when 1957 and 1958 progenies were involved) and within sampling period. Through tests of homogeneity (30), it was found that sex and year differences could be ignored. Thus, the data were pooled and average correlation and regression coefficients for each dependent variable were computed within sampling period (Table 1).

Each of the dependent variables was found to be significantly ($P < .05$) related to age of animal at least once out of the four sampling periods. However, these relationships were not consistently positive or negative from one period to the next, which suggests that the mutual relationship may vary with dietary regime, age at different sampling periods or season.

Table 1. Regression and Correlation Coefficients for Dependent Variables on Age of Animal For Various Subclass Groupings[a]

Sampling Period	Variable	Subclass Involved[b]	Size of Subclass	Mean Age (Days)	Variable Mean[c]	Correlation Coefficient	r^2	Regression Coefficient[d]
I	Hepatic A	57 & 58	309	224	115.3	+.2076**	.0431	+ .382 ± .197**
	Hepatic Caro.	57 &58	308	224	5.8	+.0431	.0091	+ .004
	Plasma A	58	177	231	46.3	-.0587	.0034	- .037
	Plasma Caro.	58	184	232	509.0	-.1938**	.0376	-1.605 ±1.182**
II	Hepatic A	57 & 58	257	351	126.0	-.0651	.0065	- .388
	Hepatic Caro.	57 & 58	256	351	9.3	-.1549*	.0155	- .019
	Plasma A	57 & 58	288	350	48.7	-.1297*	.0130	- .011
	Plasma Caro.	57 & 58	297	351	656.8	+.0159	.0016	+ .190
III	Hepatic A	57	106	583	209.5	+.0385	.0015	+ .143
	Hepatic Caro.	57	106	583	12.6	+.0849	.0072	+ .016
	Plasma A	57	105	584	55.4	+.1191	.0142	+ .075
	Plasma Caro.	57	108	584	619.3	+.0005	.0000	+ .005
IV	Hepatic A	57	90	689	237.7	-.0079	.0001	- .023
	Hepatic Caro.	57	90	689	8.2	-.1112	.0124	- .013
	Plasma A	57	102	688	65.1	-.2120*	.0449	- .105
	Plasma Caro.	57	102	688	537.9	-.2287*	.0523	- .173 ± .096*

[a]All sublcasses incorporated into respective groups were homogeneous ($P > .01$).

[b]Each subclass involves both bulls and heifers.

[c]Hepatic vitamin A and carotene reported as ug./gm, plasma vitamin A and carotene reported as ug.%.

[d]When the hypothesis $\beta = 0$ was rejected the standard deviation of the regression coefficient was computed.

* $P < .05$.

** $P < .01$.

Although the dependent variables were, at times, influenced by age of animal, the coefficients of determination indicated that less than 10 per cent of the variation could be attributed to age. The dependent variables were not adjusted for animal age since 10 per cent had been established as the minimum amount of accountable variation necessary to justify data adjustment. Therefore, it appears that when animals vary in age by only three months the age influence would be of little concern in any type of study that involves the measurement of hepatic and plasma vitamin A and carotene in cattle.

Influence of Age of Dam: The animals used in this study were from dams that ranged in age from three to eleven years. Each of the dependent variables (hepatic and plasma vitamin A and carotene) for each sex-within-year subclass was plotted against age of dam in Period I (Figure 1, 2, 3, 4). A consistent age-of-dam influence upon any of the dependent variables was not apparent. Further, it was assumed that a relationship would not be present at subsequent sampling periods.

However, results of previous studies have shown that vitamin A content of the calf was reflected by the diet of the dam until the calf was three months of age. Assuming that carotene intake was random among the age-of-dam subclasses, then the total vitamin A contained in the milk could conceivably depend upon total milk production. Total milk production, discussed previously, varies with the age of the cow. Therefore, in order to establish the presence and duration of age-of-dam influence, hepatic vitamin A concentration should be measured in calves that are between three and eight months of age.

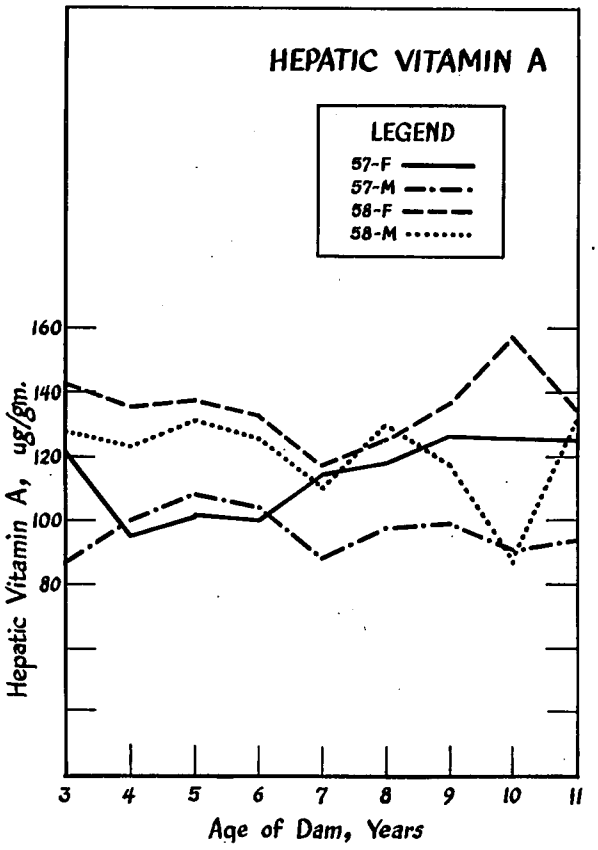

Figure 1. The influence of age of dam upon hepatic vitamin A in weanling calves.

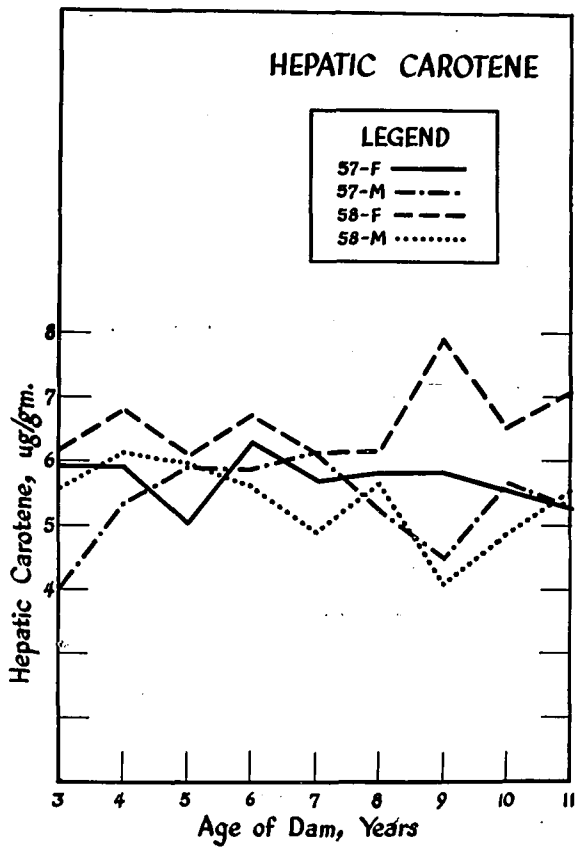

Figure 2. The influence of age of dam upon hepatic carotene in weanling calves.

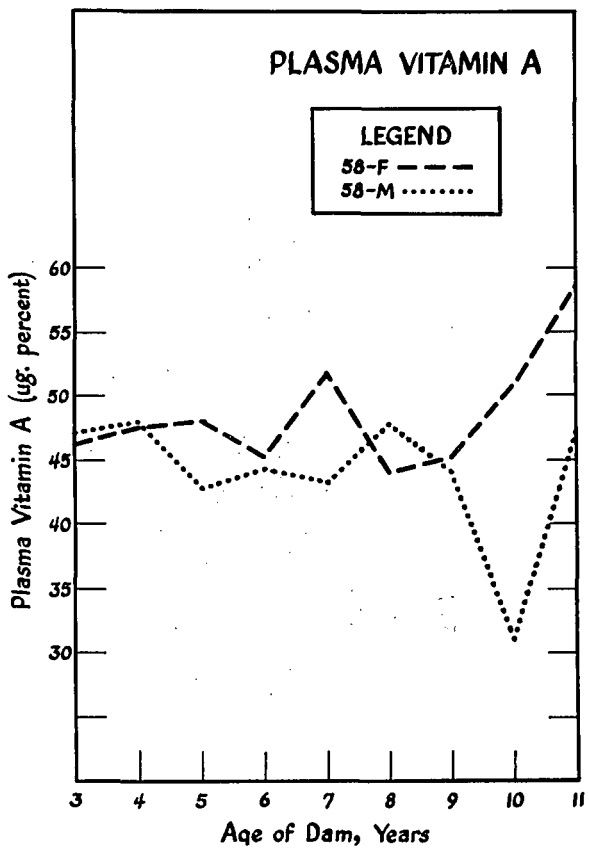

Figure 3. The influence of age of dam upon plasma vitamin A in weanling calves.

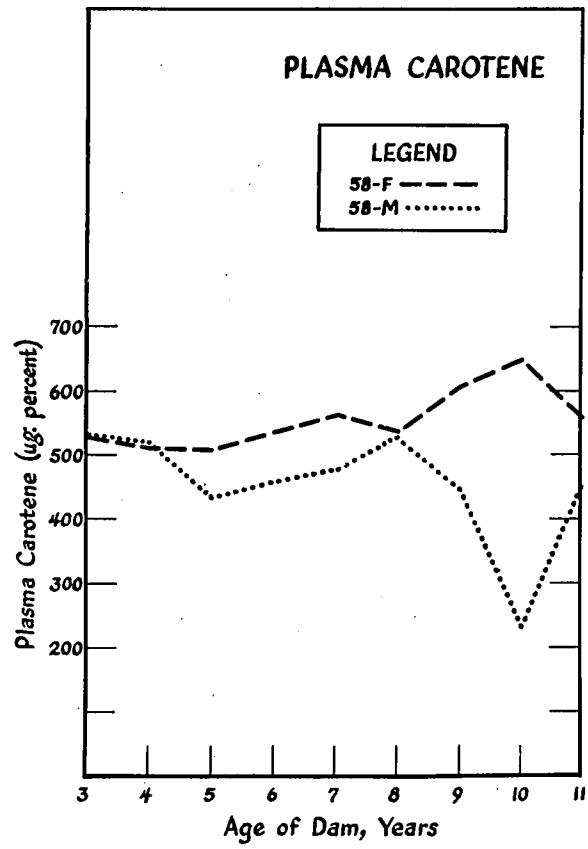

Figure 4. The influence of age of dam upon plasma carotene in weanling calves.

Heritability: Results of most studies that have involved the measurement of hepatic vitamin A have revealed considerable among-animal variation (37) (49) (55). Conceivably, part of this variation could be attributable to genetic influence. In the present study, the heritability of hepatic vitamin A content was 72 per cent and 44 per cent for heifers and bulls respectively at the time the animals were weaned (Period I). The heritability coefficients (Table 2) were of sufficient magnitude to suggest the use of selection on the basis of individual animal merit to increase hepatic vitamin A content. However, the 95 per cent confidence limits for these estimates were large, suggesting the need for further study in order to obtain greater confidence. The heritability coefficients were of sufficient magnitude to indicate that if cattle were selected and bred for their high hepatic vitamin A content, animal loss or disorder associated with vitamin A deficiency (19) on dry ranges could be reduced. Furthermore, the heritability of hepatic vitamin A content suggests that initial vitamin A storage should be considered when selecting and allotting animals in vitamin A studies.

The heritability of hepatic vitamin A in both sexes at Period II (Twelve months) was approximately 20 per cent. The confidence limits set on the coefficients were of approximately the same magnitude in both Periods I and II. In addition to the different number of observations from one period to the next, these lower heritability coefficients may also indicate that factors which contributed to the overall variation in hepatic vitamin A were different and/or more pronounced

Table 2. Heritability Estimates with 95 Per Cent Confidence Interval and Sire and Error Variance Components

Sex	Sampling Period	N	Heritability Coefficients	95 Per Cent Confidence Intervals	Variance Components σ_s^2	Variance Components σ_e^2
Hepatic Vitamin A						
Bulls	I	165	.4414	.4853	105.17	848.80
	II	135	.2044	.4792	1110.12	20617.93
	III	56	1.0370	1.1550	2312.87	6603.92
	IV	53	1.1400	1.1900	1090.15	2734.54
Heifers	I	165	.7223	.6221	252.83	1147.34
	II	122	.2137	.5253	125.69	2227.08
	III	50	.7570	1.1339	272.79	1168.62
	IV	37	[a]		0.00	3177.87
Hepatic Carotene						
Bulls	I	164	[a]		0.0000	1.85
	II	134	.1412	.4541	.2477	6.77
	III	56	.3207	.5580	1.0320	11.84
	IV	53	.2174	.8396	.3046	5.30
Heifers	I	144	.3527	.5220	.2911	3.01
	II	122	1.3236	.8187	2.0277	4.10
	III	49	.0454	.7964	.1704	14.83
	IV	37	2.0833	1.4401	2.2174	4.04
Plasma Vitamin A						
Bulls	I	95	[a]		0.000	122.48
	II	146	[a]		0.000	295.34
	III	60	[a]		0.000	209.12
	IV	52	1.0530	1.1750	30.473	85.28
Heifers	I	82	.2458	.6026	8.933	136.43
	II	142	.0645	.3858	4.144	252.74
	III	45	[a]		0.000	109.02
	IV	50	[a]		0.000	87.70
Plasma Carotene						
Bulls	I	98	.1269	.4561	617.07	18832.55
	II	150	.5213	.5748	6296.72	42018.70
	III	62	.1572	.6968	2196.52	53709.77
	IV	52	.3471	.0924	2669.99	28103.16
Heifers	I	86	.2824	1.2403	1927.61	25377.48
	II	147	.2618	4.2659	3388.03	48369.28
	III	46	.2917	1.0129	1816.28	23089.32
	IV	50	.3768	.9938	1458.00	14018.01

[a]A negative estimate for sire variance, thus heritabilities were not computed.

from one age or season to the next. Although the coefficient of 75 per cent observed at Period III for the heifers appears reasonable, the confidence intervals were extremely wide, which is, in part, a reflection of the limited number (fifty) of observations. The high hepatic vitamin A heritability coefficients reported for the males at the last two periods were considered unreliable because of the few available observations--they still suggest a probable gene influence. The lack of a sufficient number of observations was also reflected in the zero coefficient for heifers in Period IV.

Since high carotene storage in animals could indicate that carotene was inefficiently utilized for vitamin A, it would appear to be desirable to produce animals with low carotene content. However, hepatic carotene and hepatic vitamin A were found to be directly related (this relationship will be discussed in detail in another section). These two variables may have been in agreement because they both reflected carotene consumption or because they were under common gene influence. The latter case was not obvious from the available data although hepatic carotene content appeared to be heritable as did the vitamin A.

Except for two coefficients which were larger than 100 per cent, the heritability coefficients for hepatic carotene were lower than the hepatic vitamin A coefficients (Table 2). In fact, changing the inherent capacity to store hepatic carotene would probably be slow if individual animal merit was the basis for selection. However, the confidence limits on the hepatic carotene heritability coefficients

were extremely wide and further study is necessary before appropriate breeding programs could be recommended. The heritability of hepatic carotene was not necessarily the highest at those periods when hepatic vitamin A heritability was highest. Also, the differences in the heritability coefficients between the sexes at the first two periods was greater for hepatic carotene than for hepatic vitamin A. Since hepatic carotene probably reflects dietary carotene levels more directly than does hepatic vitamin A, the possibility of a common gene influence upon hepatic vitamin A and carotene could be masked.

The heritability coefficients computed for plasma vitamin A did not suggest a strong genetic influence. Although more than 140 observations were made for each sex at Period II, the coefficients were essentially zero for both sexes. Also, zero heritabilities were found at Periods I and III for the bulls and at Periods III and IV for the heifers. The only heritability of plasma vitamin A in heifers was a reasonable value of 24 per cent. However, the 95 per cent confidence limits showed a range from -35 per cent to +84 per cent. One major source of variation which may mask a possible heritability could be the normal blood-diurnal variation (15) (42). Despite the presence of diurnal variation, blood vitamin A levels were considered to be relatively constant within each animal (16) (36) (45) (51), with more variation among animals. The results reported herein, do not indicate that the among-animal variation in plasma vitamin A is due appreciably to genetic influence.

The heritability coefficients of plasma carotene were relatively consistant between sexes and among sampling periods. Further, the magnitudes of the heritability coefficients were sufficient to suggest a genetic influence, but not large enough to permit the alteration of plasma carotene levels by selection on the basis of individual animal merit. While diurnal variation or some other factor or factors appeared to mask the heritability of plasma vitamin A, plasma carotene was not similarly affected. Thus, it appeared that the capacity for blood to carry vitamin A and carotene may be controlled, at least in part, by separate gene action.

Differences Between Hepatic Vitamin A Contents at Various Sampling Periods.

Influence of Initial Value: Hepatic Vitamin A content of the 1957 progeny at Period II (twelve months) subtracted from the values observed at Period I (weaning) showed that hepatic storage declined during this five month period. Further, significant ($P < .01$) correlations of this loss in hepatic vitamin A with the observed values at Period I (Table 3), indicated that there was a physiological influence of the initial value on the subsequent loss. The positive relationship observed implies that those animals with the greatest hepatic vitamin A content at Period I also lost the most vitamin A by the time the next sample was taken. A positive relationship was also observed by Arizona workers (42); on this basis, hepatic vitamin A expenditure was adjusted for the influence of the initial content by the use of "per cent retention."

Table 3. Regression and Correlation Coefficients for the Differences Between Hepatic Vitamin A Contents at Succeeding Sampling Periods on Initial Content Within Sex and Year

Subclass	Size of Subclass	Correlation Coefficient	Regression Coefficient[a]		$\bar{X}$	$\bar{Y}$
Difference (Period I - Period II Hepatic Vitamin A) (Y) on Hepatic Vitamin A at Period I (X)						
57 M	59	.8998**	.8416		90.4	38.0
57 F	45	.9640**	.8182		103.8	53.6
57 M&F	104	.9262**	.8311	± .2099**	97.1	45.8
58 M	71	.0891	.5709		126.1	-66.8
58 F	63	.1867	.2383		137.3	-30.3
Difference (Period II - Period III Hepatic Vitamin A) (Y) on Hepatic Vitamin A at Period II (X)						
57 M	48	-.3126*	-2.5922		52.8	-175.2
57 F	33	-.2873	-1.0953		49.8	-135.2
57 M&F	81	-.2950**	-2.1213	±1.5303**	51.3	-155.2
Difference (Period III - Period IV Hepatic Vitamin A) (Y) on Hepatic Vitamin A at Period IV (X)						
57 M	45	.8062**	.6902	± .2126**	235.8	-23.9
57 F	32	.1356	.1657		175.6	-30.9

[a]When the hypothesis $\beta = 0$ was rejected the standard deviation of the regression coefficient was computed.

*$P < .05$.

**$P < .01$.

A test of homogeneity revealed that an average regression coefficient could be used to adjust hepatic vitamin A contents of calves of both sexes for initial differences. Because of the significant relationship between the initial value and the subsequent loss, the amount expended from the liver was adjusted for the initial level by the formula described in the numerical analyses procedure. The 1958 progeny, on the other hand, increased in hepatic vitamin A content and was not related to the initial content measured at Period I. Also, hepatic storages increased for the 1957 progeny between Periods II and III and again between Periods III and IV. The increases observed between Periods II and III were found to be significantly ($P < .01$) correlated with the content at Period II when the sexes were pooled. However, when the heifers were considered separately the hepatic differences were not related to the initial value.

The increases in hepatic vitamin A between Periods III and IV showed a definite sex difference. The content increased by the same amount in both sexes, but the initial mean content ($P_{\text{eriod III}}$) varied considerably between sexes. The differences in hepatic vitamin A content between these two periods were adjusted for the initial level only in the case of the males.

Age of Animal: The differences in hepatic vitamin A content between Periods I and II (adjusted as described in the procedure) were correlated with the age of the animal at Period I. None of the correlations were significant at the 1 per cent level. Consequently, the differences in hepatic vitamin A contents between Periods I and II were

not adjusted for animal age. Similar nonsignificant age correlations were found for the differences between the remaining sampling periods.

Age of Dam: Since age of dam did not appear to influence the actual content of hepatic vitamin A, there was no reason to believe that it would influence the changes in hepatic content. Furthermore, by adjusting the differences in hepatic vitamin A content for the initial content, any age-of-dam influence would be taken into account. Therefore, no consideration was given age-of-dam influence upon hepatic vitamin A losses or increases in the statistical analyses.

Heritability: The ability of range cattle to retain their body stores of vitamin A when consuming carotene-free forage may be more important than the amount that was originally stored. Conceivably, a genetic influence upon the ability to retain vitamin A could be separate from the genetic influence controlling vitamin A storage. However, the mean squares computed for sire variation (Table 4) were significant only for the increase in hepatic vitamin A content for heifers between Periods II and III. Since there was a total of only thirty-one observations distributed among eight sire subclasses, the significant sire variation was perhaps mostly due to chance. Moreover, there was no significant sire variation in the vitamin A differences between any of the remaining periods. The absence of significant sire differences in all but one instance indicated that, under the conditions of this study, increases or decreases in hepatic vitamin A storage were not heritable. However, it should be recalled that the hepatic vitamin A differences observed between sampling periods were, in most instances, adjusted for the

Table 4. Analysis of Variance for Differences in Hepatic Vitamin A Content Between Various Sampling Periods

	Degrees of Freedom	Mean Square	Degrees of Freedom	Mean Square
Period I - Period II				
Years	1	395,927.60**	1	160,851.05**
Sires Within Years	16	28,526.46	16	2,374.30
Individuals Within Sires	111	21,738.53	90	1,702.50
Period II - Period III				
Sires	7	12,358.27	7	2,783.73**
Individuals Within Sires	40	7,203.34	25	809.68
Period III - Period IV				
Sires	7	2,540.58	7	1,495.91
Individuals Within Sires	37	2,608.78	24	1,970.85

*$P < .05$.

**$P < .01$.

physiological influence of the initial value. Since the sire variation was found to influence this initial or observed content, the sire variation could have been eliminated by making this adjustment.

Age and Sex Influences

The means of the dependent variables (hepatic and plasma vitamin A and carotene) reported in Table 5 were arranged in such a manner that age comparisons for each sex were made between the two progenies (1957 and 1958) when the observations for both progenies were made at the same time. For instance, at the time the Period I (weaning) observations were made for the 1958 progeny, the Period III (eighteen month) observations were made for the 1957 progeny. The mean hepatic vitamin A concentration in cattle of both sexes increased between weaning and eighteen months of age and between twelve months and two years of age. It has been previously pointed out that Riggs (49) observed a similar relationship between age and body storage of vitamin A. Also, hepatic carotene content was found to vary directly with increasing age in both sexes from weaning to eighteen months of age, but no difference could be found between yearling and two years of age. Probably, the initial storage between weaning and eighteen months occurred prior to twelve months of age. However, it was possible that carotene content declined after eighteen months of age.

Both plasma vitamin A and carotene levels increased as the animals became older. This association between age and the dependent variables suggests that in studies of this type the various age groups must be considered separately.

Table 5. Means and Standard Deviations of Hepatic and Plasma Vitamin A and Carotene Levels for Each Sex at Different Ages

	Bulls		Heifers	
	Period I (Weaning)	Period III (18 months)	Period I (Weaning)	Period III (18 months)
Hepatic Vitamin A[b]				
N[a]	90	56	76	50
Mean	124.95 ±31.85	234.28 ±92.79	138.13 ±41.31	181.80 ±23.75
Hepatic Carotene[b]				
N	90	56	76	50
Mean	5.63 ± 1.27	10.91 ± 3.57	6.50 ± 1.77	14.48 ± 2.38
Plasma Vitamin A[c]				
N	95	60	82	45
Mean	45.03 ±10.98	56.73 ±13.95	47.81 ±12.01	53.64 ± 9.83
Plasma Carotene[c]				
N	98	62	86	46
Mean	479.91 ±44.03	562.77 ±436.04	542.26 ±164.60	695.52 ±157.04

	Bulls		Heifers	
	Period II (Yearling)	Period IV (2 years)	Period II (Yearling)	Period IV (2 years)
Hepatic Vitamin A[b]				
N	74	53	75	37
Mean	170.12 ± 49.34	257.07 ± 60.81	168.08 ±30.62	210.13 ± 53.83
Hepatic Carotene[b]				
N	74	53	75	37
Mean	8.84 ± 2.43	8.39 ± 2.43	8.82 ± 2.47	8.01 ± 2.42
Plasma Vitamin A[c]				
N	87	52	86	50
Mean	56.29 ± 16.10	64.73 ± 10.60	48.50 ±12.99	65.68 ± 9.33
Plasma Carotene[c]				
N	89	52	86	50
Mean	556.93 ±191.32	631.13 ±174.55	381.73 ±93.60	441.00 ±123.55

[a] N = Number of observations.

[b] ug./gm. fresh liver.

[c] ug. per cent of plasma.

The differences in the dependent variables between sexes were not as consistent as between the different age groups (Table 6). These data suggested that sex differences may be dependent upon age and season. Hepatic vitamin A values were higher for weanling heifers than for bulls in both 1957 and 1958. The values for yearling bulls and heifers were approximately the same within each year, while eighteen-month and two-year-old bulls had higher hepatic vitamin A than heifers of respective age groups. Also, hepatic carotene was found in greater concentrations in heifers at Period I for both the 1957 and 1958 progenies and at Periods II and III for the 1957 progeny, whereas the bulls had higher hepatic vitamin A and carotene contents at Periods II and IV for the 1958 and 1957 progenies respectively.

The differences in Plasma vitamin A levels between the sexes (Table 6) suggested that seasonal variation influenced sex differences more than did age. Conversely, the sex variation in plasma carotene appeared to be more consistant with season than age.

For the most part, the sex influence upon the dependent variables agreed with the results of previous studies only at certain ages and/or seasons.

Interrelationships

Several attempts have been previously made to determine the nature of the relationship between blood and hepatic levels of vitamin A and carotene in various animal species (1) (9) (17) (18) (24) (26) (28) (33) (35) (46) (50). However, the results from such studies involving cattle under natural range conditions are limited.

Table 6. Means and Standard Deviations for Each Sex Within Year and Sampling Period

	1957		1958	
	Bulls	Heifers	Bulls	Heifers
Hepatic Vitamin A				
Period I	91.75 ± 28.80	103.19 ± 31.52	124.95 ± 31.85	138.13 ± 41.31
Period II	52.45 ± 12.48	50.06 ± 9.05	170.12 ± 49.34	168.08 ± 30.62
Period III	234.28 ± 92.79	181.80 ± 23.75		
Period IV	257.07 ± 60.81	210.13 ± 53.83		
Hepatic Carotene				
Period I	5.34 ± 1.45	5.79 ± 1.85	5.63 ± 1.27	6.50 ± 1.77
Period II	9.79 ± 2.88	10.32 ± 2.33	8.84 ± 2.43	8.82 ± 2.47
Period III	10.91 ± 3.57	14.48 ± 2.38		
Period IV	8.39 ± 2.43	8.01 ± 2.42		
Plasma Vitamin A				
Period I			45.03 ± 10.98	47.81 ± 12.01
Period II	39.29 ± 17.81	47.29 ± 19.81	56.29 ± 16.10	48.50 ± 12.99
Period III	56.73 ± 13.95	53.64 ± 9.83		
Period IV	64.73 ± 10.60	65.68 ± 9.33		
Plasma Carotene				
Period I			479.91 ± 44.03	542.26 ±164.60
Period II	851.29 ±255.79	995.92 ±334.34	556.93 ±191.32	381.73 ± 93.60
Period III	562.77 ±436.04	695.52 ±157.04		
Period IV	631.13 ±174.55	441.00 ±123.55		

Because of the abundance of data available from this study, it appeared worthwhile to determine the presence and nature of any relationships which may have existed between the dependent variables.

The four variables--hepatic vitamin A and carotene expressed in ug./gm. and plasma vitamin A and carotene expressed in ug./100 ml.--were correlated in all possible combinations using arithmetic, semi-log, and log-log functions (Tables 7, 8, 9, 10). Because of the lack of mutual relationships, the correlations between hepatic vitamin A and plasma vitamin A and between hepatic carotene and plasma vitamin A are not presented in tabular form. The remaining correlations were established for each sex within year and sampling period. The subclasses were combined when homogeneity of variances was obvious ($P > .05$) (30).

Of the 40 grouped correlation coefficients for plasma vitamin A on hepatic vitamin A only three were sufficiently large ($P < .01$) to indicate an existing relationship. The relationships existed for the 1957 females when the correlations were computed from log plasma vitamin A on log hepatic vitamin A at Period IV and log plasma vitamin A on hepatic vitamin A at Periods III and IV. A positive relationship was present for the significant correlation at Period III. Because of this inconsistency and the infrequency of a significant relationship, prediction equations were not computed.

On the other hand, the hepatic carotene on plasma carotene relationship (Table 7) was significant in enough instances to indicate that a positive relationship existed. All average regressions were highly significant for linear relationships of the arithmetic values;

Table 7. Correlation and Regression Coefficients for Hepatic Carotene on Plasma Carotene With Respective Means

Sampling Period	Subclass	Size of Subclass	Correlation Coefficient	Regression Coefficient	Standard Deviation of The Regression	Means: Hepatic Carotene	Means: Plasma Carotene
			Hepatic Carotene[a] on Plasma Carotene[b]				
I	58 M&F	155	.360**	36.29	15.05**	6.051	510.61
II	57 M&F	96	.564**	58.88	17.71**	9.900	869.26
	58 M&F	146	.399**	23.76	8.99**	8.849	479.78
III	57 M&F	96	.291**	15.98	2.95**	12.383	617.53
IV	57 M&F	84	.510**	33.01	12.24**	8.211	562.96
			Log Hepatic Carotene on Log Plasma Carotene				
I	58 M&F	155	.377**	.4873	.1918	.7678	2.6872
II	57 M	54	.968**	2.5843	.3134**	.9478	2.7951
	57 F	42	.267	.5843	.6742	.9959	2.9296
	58 M&F	146	.430**	.5138	.1786**	.9332	2.6539
III	57 M&F	96	.273**	.3605	.2612**	1.0709	2.7592
IV	57 M&F	84	.551**	.5192	.1799**	.8966	2.7286
			Log Hepatic Carotene on Plasma Carotene				
I	58 M&F	155	.381**	560.96	217.60**	.7678	510.61
II	57-58 M&F	242	.529**	864.27	175.73**	.9526	674.52
III	57 M&F	96	.297**	466.44	307.66**	1.0708	617.33
IV	57 M&F	84	.526**	674.49	239.16**	.8966	562.96
			Hepatic Carotene on Log Plasma Carotene				
I	58 M&F	155	.359**	.0318	.0133*	6.051	2.687
II	57 M	54	.900*	2.3281	3.1660	.9478	2.7951
	57 F	42	.267	.5843	.5913	.9959	2.9296
	58 M	73	.444**	.5738	.2704**	.9328	2.7404
	58 F	73	.417**	.4558	.2330**	.9336	2.5674
III	57 M&F	96	.263**	.0122	.00915**	12.383	2.759
IV	57 M&F	84	.525**	.0250	.0089**	8.211	2.7286

[a] ug./gm.

[b] ug./100 ml.

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

Table 8. Correlation and Regression Coefficients for Hepatic Carotene on Hepatic Vitamin A with Respective Means

Sampling Period	Subclass	Size of Subclass	Correlation Coefficient	Regression Coefficient	Standard Deviation of the Regression	Means: Hepatic Carotene	Means: Hepatic Vitamin A
			Hepatic Carotene[a] on Hepatic Vitamin A[a]				
I	57 M&F	142	.290**	2.600	2.9868	5.57	97.33
	58 M&F	166	.408**	9.850	1.4386**	6.07	131.54
II	57-58 M&F	256	.170*	7.483	5.330*	9.44	115.77
III	57 M&F	106	.222*	4.328	3.645*	12.70	208.04
IV	57 M&F	90	.449**	10.916	4.586**	8.20	233.61
			Log Hepatic Carotene on Log Hepatic Vitamin A				
I	57-58 M&F	308	.2863**	.3229	.3826	.7479	2.0340
II	57-58 M&F	256	.258**	.3941	.1811**	.9603	1.9523
III	57 M&F	106	.302**	.2741	.1677*	1.0813	2.2995
IV	57 M&F	90	.516**	.5150	.1785**	.8965	2.3510
			Log Hepatic Carotene on Hepatic Vitamin A				
I	57 M&F	142	.173*	40.93	38.72*	.7267	97.33
	58 M&F	166	.232**	146.52	48.45**	.7690	131.54
II	57-58 M&F	256	.181**	187.27	127.12*	.9603	220.82
III	57 M&F	106	.260**	147.21	105.19	1.0812	208.05
IV	57 M&F	90	.500	240.56	87.85**	.8965	233.61
			Hepatic Carotene on Log Hepatic Vitamin A				
I	57-58 M&F	308	.268**	.0222	.0087**	5.57	2.0339
II	57-58 M&F	256	.251**	.0163	.0077**	9.44	1.9523
III	57 M&F	106	.264**	.0082	.0057*	12.70	2.2987
IV	57 M&F	90	.448**	.0226	.0097**	8.20	2.3510

[a] ug./gm.

*P < .05.

**P < .01.

Table 9. Correlation and Regression Coefficients for Plasma Carotene on Plasma Vitamin A with Respective Means

Sampling Period	Subclass	Size of Subclass	Correlation Coefficient	Regression Coefficient	Standard Deviation of the Regression	Means: Plasma Carotene	Means: Plasma Vitamin A
			Plasma Carotene[a] on Plasma Vitamin A[a]				
I	58 M&F	176	.540**	.0404	.0060**	512.74	46.51
II	57 M&F	115	-.205*	-.0136	.0121*	913.93	43.28
	58 M&F	173	.600**	.0601	91.7×10^{-5}**	465.87	52.40
III	57 M&F	105	.199	.0119	.0115*	632.57	55.19
IV	57 M&F	102	.485**	.0319	.0114**	536.07	65.21
			Log Plasma Carotene on Log Plasma Vitamin A				
I	58 M&F	176	.578**	.4482	.0593**	2.6894	1.6551
II	57 M&F	115	.169	.2807	.3026	2.9344	1.5735
	58 M&F	173	.568**	.5752	.1249**	2.6423	1.6997
III	57 M	60	.090	.0525	.1510	2.7139	1.7394
	58 F	45	.491**	.3585	.1958**	2.8296	1.7227
IV	57 M&F	102	.494**	.2920	.1019**	2.7074	1.7310
			Log Plasma Carotene on Plasma Vitamin A				
I	58 M&F	176	.546**	46.869	10.679**	2.6894	46.51
II	57 M&F	115	.184	15.8913	21.032	2.9344	51.78
	58 M&F	173	.605**	67.788	13.355	2.6423	52.40
III	57 M&F	105	.211*	15.3088	13.8735*	2.7718	55.19
IV	57 M&F	102	.496**	43.790	15.1947	2.7074	65.21
			Plasma Carotene on Log Plasma Vitamin A				
I	58 M&F	176	.561**	38.0×10^{-5}	7.8×10^{-5}**	512.74	1.6551
II	57 M&F	115	-.218**	-21.1×10^{-5}	17.6×10^{-5}*	913.93	1.5735
	58 M&F	173	.541**	49.0×10^{-5}	11.4×10^{-5}**	465.87	1.6997
III	57 M	60	.032	1.6×10^{-5}	13.8×10^{-5}	570.70	1.7394
	57 F	45	.499**	24.5×10^{-5}	12.0×10^{-5}**	694.44	1.7227
IV	57 M&F	102	.484**	21.1×10^{-5}	7.6×10^{-5}**	536.08	1.8093

[a] ug.;100 ml.

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

Table 10. Correlation and Regression Coefficients for Hepatic Vitamin A on Plasma Carotene with Respective Means

Sampling Period	Subclass	Size of Subclass	Correlation Coefficient	Regression Coefficient	Standard Deviation of the Regression	Means: Hepatic Vitamin A	Means: Plasma Carotene
			Hepatic Vitamin A[a] on Plasma Carotene[b]				
I	58 M&F	155	.269**	1.1168	.6337**	131.85	512.52
II	57 M&F	97	.386**	9.9964	4.8542**	51.17	888.75
	58 M&F	146	.272**	.2705	.1564**	179.91	479.77
III	57 M&F	96	.115	.3120	.5489	207.47	623.68
IV	57 M&F	84	.291**	.7853	.5637**	234.41	551.91
			Log Hepatic Vitamin A on Log Plasma Carotene				
I	58 M&F	155	.323**	.3660	.1700**	2.1030	2.6888
II	57 M&F	97	.378**	.6191	.3083**	1.6975	2.9181
	58 M&F	146	.297**	.1900	.0998**	2.2035	2.6539
III	57 M&F	96	.045	.0647	.2944	2.2966	2.7653
IV	57 M&F	84	.331**	.3143	.1960*	2.3519	2.7198
			Log Hepatic Vitamin A on Plasma Carotene				
I	58 M&F	155	.293**	377.81	195.41**	2.1030	512.52
II	57 M&F	97	.371**	991.51	504.22**	1.6975	888.75
	58 M&F	146	.296**	219.24	115.44**	2.2035	479.77
III	58 M&F	96	.060	101.77	349.34	2.2966	623.68
IV	57 M&F	84	.298**	385.76	269.74*	2.3519	551.91
			Hepatic Vitamin A on Log Plasma Carotene				
I	58 M&F	155	.291**	.0011	.00055*	131.85	2.6888
II	57 M&F	97	.385**	.0061	.0030**	51.17	2.9181
	58 M&F	146	.233**	2.0×10^{-4}	9.4×10^{-5}**	179.91	2.6539
III	57 M	53	.119	2.3×10^{-4}	6.1×10^{-4}	235.74	2.7072
	57 F	43	.001	.0000		179.21	2.8234
IV	57 M&F	84	.319**	6.3×10^{-4}	4.2×10^{-4}*	234.41	2.7198

[a] ug./gm.

[b] ug./100 ml.

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

whereas, the linearity of the logarithmic values, for the most part, was not as consistant. In all of the different forms of the data (arithmetic and logarithmic functions), the regression coefficients showed considerable variation. This variation suggested that although a liver carotene on plasma carotene relationship generally existed, the prediction equation varied with sampling period.

A similar situation existed with the relationships between hepatic carotene and hepatic vitamin A (Table 8), hepatic vitamin A and plasma carotene (Table 10). The parallel association between these variables was probably not a direct physiological dependence of one upon another. Curch et al. (13) observed that normally circulating carotene was not utilized for vitamin A in Hereford calves. If plasma and liver carotene levels are indicative of dietary intake of carotene and if hepatic and plasma vitamin A concentrations indirectly reflect dietary carotene levels, then a physiological relationship between plasma vitamin A and plasma carotene, hepatic vitamin A and hepatic carotene, and between plasma carotene and hepatic vitamin A would be expected. Although the correlations computed were gross correlations, there exists the possibility that all of the positively related variables were influenced to an undetermined degree by common gene action. Genetic correlations of the dependent variables would be necessary in order to speak definitely about a common genetic influence.

All of the regression coefficients involving either arithmetic or logarithmic values were not homogeneous. Considering both the degree of significance and the variation between the regression coefficients,

hepatic carotene and vitamin A were best related when log hepatic carotne was used. These regression coefficients varied from 0.0226 to 0.0082. The best equations for relating plasma carotene and vitamin A were perhaps the ones that involved simple arithmetic functions of the observed variables. In this case, the regression coefficients varied from -0.0136 to 0.0601. The linear relationship between hepatic vitamin A and plasma carotene was shown equally well in arithmetic values or logarithms of the observed values.

Correlation coefficients of the actual observations and various logarithmic values for hepatic carotene and plasma vitamin A were of insufficient magnitude ($P < .05$) to indicate any relationship.

Although significant relationships existed between several of the above variables, the variation made impossible accurate predictions of vitamin A and carotene levels for randomly selected range cattle. In general, the logarithmic relationships that have been suggested as well as the arithmetic relationships were in agreement with observations made with range cattle in Washington (46). Predictions might be feasible in a situation where the genetic background, stage of animal maturity, and dietary regime of the test animals could be controlled.

SUMMARY AND CONCLUSIONS

The vitamin A and carotene concentrations of liver and blood were determined for a large number of purebred Hereford calves at four periods for two years. The resulting values were subjected to statistical analyses in order to estimate the presence and magnitude of genetic and various environmental influences.

Hepatic vitamin A content and plasma levels of vitamin A and carotene appeared to increase in cattle from weaning to two years of age, while hepatic carotene content increased with age only until the cattle reached one year of age. Age variation (approximately three months) among calves born in the same herd in a single year did not influence the amounts of vitamin A and carotene in the liver or blood of cattle from the time they were weaned until they were two years of age. Similarly, the age of dam, which has been found to be associated with weanling weights in calves, did not appear to affect vitamin A and carotene concentrations in liver or blood in calves of approximately eight months of age.

The hepatic vitamin A and carotene contents and plasma carotene levels were found to be heritable, but the magnitude of the heritability coefficients varied considerably with age, sex, and season. The heritability of plasma vitamin A levels was not conclusive. While relative levels of the four variables did not favor either sex from

one age group or season to the next, nearly all of the heritability coefficients that appeared to be accurate estimates were higher for heifers than bulls.

For the most part, the amount of vitamin A that was either lost or gained from the liver between any two sampling periods was related to the initial hepatic storage. After the differences in hepatic vitamin A content were adjusted for the initial content, no age and only a slight genetic influence was evident.

Finally, an attempt was made to measure the degree of association between hepatic vitamin A, hepatic carotene, plasma vitamin A, and plasma carotene with the following results:

1. In only a limited number of sex, year, and seasonal subclasses was hepatic vitamin A related to plasma vitamin A, and the relationship was not consistantly direct or inverse. However, hepatic vitamin A was directly associated with hepatic carotene and plasma carotene.

2. Hepatic carotene was directly related to plasma carotene but was not related to plasma vitamin A.

3. A relationship between plasma vitamin A and plasma carotene was observed.

The regression coefficients computed for the above relationships were extremely variable in magnitude, making the formulation of prediction equations impractical. Furthermore, there was no apparent advantage in using exponential functions for any of the variables except when relating log hepatic carotene to hepatic vitamin A.

Appendix

Table 1. Means and Standard Deviations of Hepatic Vitamin A Levels for Each Sex and Year Within Sire Subclasses at Period I

	1957		1958	
	Bulls	Heifers	Bulls	Heifers
Sire #1				
N[a]	12	9		
Mean[b]	79.83 ±26.98	90.22 ±16.59		
Sire #2				
N	14	6	8	12
Mean	87.78 ±27.80	93.00 ±16.75	105.25 ±22.95	119.25 ±20.46
Sire #3				
N	5	7	13	8
Mean	86.60 ±29.30	87.71 ±29.41	136.07 ±29.07	155.75 ±22.38
Sire #4				
N	8	8	14	9
Mean	96.87 ±24.79	132.87 ±20.19	136.50 ±31.98	147.44 ±42.79
Sire #5				
N	7	16	11	8
Mean	81.71 ±29.63	94.75 ±30.99	111.09 ±15.09	134.00 ±44.61
Sire #6				
N	10	12	8	5
Mean	108.00 ±34.36	125.66 ±37.21	150.62 ±29.54	172.40 ±91.32
Sire #7				
N	7	4		
Mean	78.14 ±19.33	81.75 ±13.74		
Sire #8				
N	3	4		
Mean	91.33 ±10.98	86.00 ±12.36		
Sire #9				
N	9	2		
Mean	112.66 ±28.18	137.50 ±29.00		
Sire #10				
N			12	6
Mean			113.50 ±28.76	123.33 ±40.37
Sire #11				
N			4	10
Mean			101.75 ±40.84	162.40 ±49.47
Sire #12				
N			10	8
Mean			129.50 ±38.98	113.12 ±25.57
Sire #13				
N			10	10
Mean			123.30 ±37.36	128.89 ±20.54

[a]N = Number of observations
[b]Mean = Mean and standard deviation

Appendix

Table 2. Means and Standard Deviations of Hepatic Carotene for Each Sex and Year Within Sire Subclasses at Period I

	1957		1958	
	Bulls	Heifers	Bulls	Heifers
Sire #1				
N[a]	12	9		
Mean[b]	6.00 ±1.78	6.50 ±2.42		
Sire #2				
N	14	6	8	12
Mean	5.39 ±1.26	5.85 ±1.19	5.10 ±0.71	5.74 ±1.26
Sire #3				
N	5	7	13	8
Mean	4.82 ±1.71	5.60 ±1.77	5.56 ±1.21	6.78 ±2.60
Sire #4				
N	7	8	14	9
Mean	5.21 ±1.92	6.68 ±2.23	5.70 ±1.18	7.27 ±2.14
Sire #5				
N	7	16	11	8
Mean	4.80 ±0.92	4.55 ±0.88	5.22 ±1.14	7.07 ±1.50
Sire #6				
N	10	12	8	5
Mean	5.51 ±1.73	6.42 ±1.44	6.55 ±1.12	7.28 ±1.31
Sire #7				
N	7	4		
Mean	5.55 ±1.37	7.15 ±2.04		
Sire #8				
N	3	4		
Mean	5.00 ±0.46	5.30 ±2.44		
Sire #9				
N	9	2		
Mean	4.92 ±1.17	3.95 ±0.36		
Sire #10				
N			12	6
Mean			5.18 ±0.99	5.55 ±1.13
Sire #11				
N			4	10
Mean			5.32 ±0.97	6.70 ±2.05
Sire #12				
N			10	8
Mean			5.95 ±1.75	5.75 ±2.06
Sire #13				
N			10	10
Mean			6.12 ±1.63	6.61 ±0.84

[a]N = Number of observations
[b]Mean = Mean and standard deviation

Appendix

Table 3. Means and Standard Deviations of Plasma Vitamin A and Carotene Levels for Each Sex Within Sire Subclasses at Period I

	1958			
	Plasma Vitamin A		Plasma Carotene	
	Bulls	Heifers	Bulls	Heifers
Sire #2				
N[a]	7	13	7	13
Mean[b]	40.85 ± 3.60	42.61 ± 6.28	433.42 ±116.55	506.07 ±120.18
Sire #3				
N	10	7	11	9
Mean	42.00 ± 8.98	56.85 ±13.07	514.90 ±142.92	548.66 ±182.56
Sire #4				
N	14	10	14	10
Mean	46.21 ± 8.46	49.40 ±17.10	475.42 ±162.26	534.90 ±141.94
Sire #5				
N	13	9	14	9
Mean	46.07 ±12.87	46.44 ±13.49	460.42 ±130.92	639.22 ±213.32
Sire #6				
N	10	6	11	6
Mean	45.60 ±12.56	48.50 ±11.00	564.36 ±164.15	690.16 ±194.71
Sire #10				
N	14	6	14	7
Mean	45.57 ± 9.65	54.37 ± 9.37	427.57 ±102.28	545.87 ±143.60
Sire #11				
N	4	12	4	12
Mean	52.50 ±19.50	47.00 ± 7.37	450.50 ±103.20	468.25 ±122.09
Sire #12				
N	12	5	12	6
Mean	48.01 ± 9.68	38.00 ± 7.07	531.75 ±139.41	452.83 ± 59.40
Sire #13				
N	11	14	11	14
Mean	40.54 ±10.08	49.00 ±13.71	440.45 ±123.81	551.28 ±190.92

[a]N = Number of observations
[b]Mean = Mean and standard deviation

Appendix

Table 4. Means and Standard Deviations of Hepatic Vitamin A Levels for Each Sex and Year Within Sire Subclasses at Period II

	1957		1958	
	Bulls	Heifers	Bulls	Heifers
Sire #1				
N[a]	11	9		
Mean[b]	42.63 ± 8.89	47.56 ± 7.38		
Sire #2				
N	13	4	7	10
Mean	47.84 ± 9.08	50.00 ± 8.21	148.85 ±18.27	137.80 ±60.19
Sire #3				
N	5	7	10	7
Mean	55.80 ± 8.11	55.57 ±10.47	176.70 ±52.14	202.71 ±26.40
Sire #4				
N	7	3	12	9
Mean	56.42 ± 8.46	56.00 ± 2.65	168.58 ±63.29	215.55 ±76.11
Sire #5				
N	3	7	9	6
Mean	41.00 ±24.58	46.42 ± 9.78	186.88 ±44.39	183.16 ±37.37
Sire #6				
N	6	10	8	5
Mean	63.66 ± 5.76	52.80 ± 6.30	198.87 ±38.48	176.80 ±85.37
Sire #7				
N	8	3		
Mean	93.12 ±16.03	43.33 ± 1.12		
Sire #8				
N	1	3		
Mean	55.00	38.33 ± 4.16		
Sire #9				
N	7	1		
Mean	58.85 ± 7.26	70.00		
Sire #10				
N			7	8
Mean			161.14 ±68.76	143.75 ±47.59
Sire #11				
N			4	11
Mean			112.25 ±75.32	159.54 ±46.62
Sire #12				
N			11	9
Mean			168.27 ±24.36	157.33 ±45.86
Sire #13				
N			6	10
Mean			449.00 ±67.21	156.50 ±42.46

[a]N = Number of observations
[b]Mean = Mean and standard deviation

Appendix

Table 5. Means and Standard Deviations of Hepatic Carotene Levels for Each Sex and Year Within Sire Subclasses At Period II

	1957		1958	
	Bulls	Heifers	Bulls	Heifers
Sire #1				
N[a]	11	9		
Mean[b]	9.11 ±2.58	10.47 ±2.04		
Sire #2				
N	12	4	7	10
Mean	8.51 ±1.97	10.67 ±3.28	7.71 ±1.38	7.62 ±0.99
Sire #3				
N	5	7	10	7
Mean	10.88 ±3.84	11.67 ±2.04	9.05 ±1.90	10.08 ±3.21
Sire #4				
N	7	3	12	9
Mean	11.01 ±5.02	10.10 ±3.30	8.00 ±1.69	8.64 ±1.07
Sire #5				
N	3	7	9	6
Mean	11.50 ±0.85	9.02 ±1.16	9.28 ±4.85	8.05 ±1.37
Sire #6				
N	6	10	8	5
Mean	12.18 ±1.99	11.73 ±2.16	9.78 ±1.49	13.26 ±3.46
Sire #7				
N	8	3		
Mean	9.31 ±2.34	8.33 ±1.33		
Sire #8				
N	1	3		
Mean	5.50	3.83 ±0.67		
Sire #9				
N	7	1		
Mean	9.04 ±1.76	9.30		
Sire #10				
N			7	8
Mean			7.68 ±1.73	8.47 ±1.23
Sire #11				
N			4	11
Mean			8.87 ±7.52	7.70 ±1.40
Sire #12				
N			11	9
Mean			9.52 ±2.38	7.27 ±0.95
Sire #13				
N			6	10
Mean			9.60 ±2.24	10.49 ±3.07

[a] N = Number of observations
[b] Mean = Mean and standard deviation

Appendix

Table 6. Means and Standard Deviations of Plasma Vitamin A Levels for Each Sex and Year Within Sire Subclasses at Period II

	1957		1958	
	Bulls	Heifers	Bulls	Heifers
Sire #1				
N[a]	8	8		
Mean[b]	38.12 ±18.70	56.75 ±27.18		
Sire #2				
N	13	6	7	12
Mean	35.46 ±20.29	52.00 ±21.33	58.85 ± 7.61	46.00 ± 9.22
Sire #3				
N	6	7	12	8
Mean	39.00 ±15.57	52.85 ±21.11	63.66 ±11.41	59.50 ±31.05
Sire #4				
N	7	4	13	9
Mean	45.14 ±24.00	51.00 ±10.68	54.53 ±16.68	49.55 ±15.13
Sire #5				
N	3	13	11	9
Mean	37.00 ±15.62	42.84 ±17.58	52.00 ±15.11	46.22 ±10.88
Sire #6				
N	6	11	9	6
Mean	34.06 ±20.25	43.09 ±18.59	57.55 ±21.92	51.16 ±10.72
Sire #7				
N	6	3		
Mean	45.00 ±14.51	30.66 ±24.58		
Sire #8				
N	2	3		
Mean	38.00 ±24.04	52.33 ± 3.79		
Sire #9				
N	8	1		
Mean	42.62 ±13.37	27.00		
Sire #10				
N			10	8
Mean			50.30 ±18.15	53.12 ±19.50
Sire #11				
N			5	11
Mean			50.60 ±19.86	45.00 ±10.97
Sire #12				
N			11	8
Mean			62.45 ±17.84	43.75 ±17.17
Sire #13				
N			9	15
Mean			53.33 ±13.89	46.93 ±10.00

[a]N = Number of observations
[b]Mean = Mean and standard deviation

Appendix

Table 7. Means and Standard Deviations of Plasma Carotene Levels for Each Sex and Year Within Sire Subclasses at Period II

	1957		1958	
	Bulls	Heifers	Bulls	Heifers
Sire #1				
N[a]	9	8		
Mean[b]	788.00 ±317.46	881.37 ±193.28		
Sire #2				
N	13	6	7	12
Mean	753.30 ±169.16	790.16 ±149.49	548.28 ±148.06	317.16 ± 88.85
Sire #3				
N	6	7	12	8
Mean	849.33 ±225.62	1033.71 ±205.39	584.16 ±127.21	420.37 ± 84.76
Sire #4				
N	8	5	13	9
Mean	993.87 ±237.93	1084.40 ±386.62	548.07 ±167.54	406.66 ±138.92
Sire #5				
N	3	15	12	9
Mean	1049.00 ±393.28	1142.06 ±429.61	540.41 ±193.03	355.22 ± 82.19
Sire #6				
N	6	12	10	6
Mean	1054.66 ±173.80	1029.83 ±237.06	636.50 ±200.54	435.66 ± 84.42
Sire #7				
N	6	3		
Mean	806.33 ±314.67	1039.00 ±356.22		
Sire #8				
N	2	3		
Mean	705.50 ± 20.51	703.00 ±144.39		
Sire #9				
N	8	2		
Mean	759.12 ±224.23	793.00 ± 67.88		
Sire #10				
N			10	8
Mean			423.60 ±143.63	408.75 ± 61.47
Sire #11				
N			5	11
Mean			389.60 ± 94.76	352.09 ± 77.02
Sire #12				
N			11	8
Mean			715.27 ±228.40	368.00 ± 98.60
Sire #13				
N			9	15
Mean			521.33 ±186.00	406.80 ± 84.56

[a] N = Number of observations
[b] Mean = Mean and standard deviation

Appendix

Table 8. Means and Standard Deviations of Hepatic Vitamin A and Carotene levels for Each Sex Within Sire Subclasses at Period III

	Vitamin A 1957		Carotene 1957	
	Bulls	Heifers	Bulls	Heifers
Sire #1				
N[a]	9	6	9	6
Mean[b]	164.22 ± 36.71	154.33 ±20.41	10.15 ±4.20	12.98 ±2.27
Sire #2				
N	12	6	12	6
Mean	195.16 ± 29.96	160.16 ±29.96	9.44 ±2.28	15.55 ±2.45
Sire #3				
N	8	7	8	7
Mean	250.37 ± 26.72	190.00 ±23.98	10.81 ±3.85	15.28 ±5.23
Sire #4				
N	6	5	6	5
Mean	268.16 ± 80.74	203.80 ±41.80	11.00 ±3.00	14.66 ±4.58
Sire #5				
N	2	13	2	13
Mean	236.00 ± 26.87	172.15 ±42.71	16.65 ±7.85	13.69 ±3.20
Sire #6				
N	5	5	5	5
Mean	266.00 ± 41.74	215.00 ±38.75	13.52 ±2.35	17.56 ±5.50
Sire #7				
N	7	4	7	4
Mean	215.28 ±42.58	191.75 ±12.55	11.24 ±4.26	15.45 ±3.73
Sire #8				
N	0	2	0	2
Mean		165.50 ±37.48		11.65 ±4.31
Sire #9				
N	7	2	7	2
Mean	339.85 ±200.00	110.50 ±58.69	10.64 ±2.17	10.90 ±0.14

[a]N = Number of observations.
[b]Mean = Mean and standard deviation.

Appendix

Table 9. Means and Standard Deviations of Plasma Vitamin A and Carotene Levels for Each Sex Within Sire Subclasses at Period III

	Vitamin A 1957		Carotene 1957	
	Bulls	Heifers	Bulls	Heifers
Sire #1				
N[a]	9	6	9	6
Mean[b]	55.66 ±18.11	53.00 ± 8.27	665.44 ±254.60	609.16 ±137.58
Sire #2				
N	11	5	12	5
Mean	52.27 ±12.72	54.40 ± 3.78	443.58 ±194.47	612.40 ± 41.38
Sire #3				
N	8	5	8	6
Mean	59.12 ±10.28	53.60 ±14.79	401.37 ± 20.00	704.83 ±189.56
Sire #4				
N	6	4	7	4
Mean	58.83 ± 4.62	50.25 ±14.46	638.57 ±213.48	701.00 ±215.86
Sire #5				
N	3	13	3	13
Mean	55.66 ± 3.21	55.07 ±28.79	485.00 ±167.42	740.30 ±128.65
Sire #6				
N	6	4	6	4
Mean	53.50 ±20.77	59.00 ±22.38	671.50 ±256.81	789.25 ±258.92
Sire #7				
N	8	4	8	4
Mean	56.87 ± 8.08	52.75 ± 5.50	584.87 ±225.22	753.00 ±139.39
Sire #8				
N	2	2	2	2
Mean	53.50 ± 2.12	48.00 ± 2.83	426.50 ± 13.44	477.00 ±190.92
Sire #9				
N	7	2	7	2
Mean	64.57 ±22.16	48.00 ± 2.83	629.00 ±371.55	748.50 ±149.20

[a] N = Number of observations
[b] Mean = Mean and standard deviation

Appendix

Table 10. Means and Standard Deviations of Hepatic Vitamin A and Carotene Levels for Each Sex Within Sire Subclasses at Period IV

	Vitamin A 1957		Carotene 1957	
	Bulls	Heifers	Bulls	Heifers
Sire #1				
N[a]	9	6	9	6
Mean[b]	192.11 ±43.41	177.16 ±69.28	7.75 ±2.11	5.53 ±1.66
Sire #2				
N	10	6	10	6
Mean	258.10 ±48.86	195.66 ±74.58	6.91 ±1.26	7.63 ±1.91
Sire #3				
N	6	3	6	3
Mean	265.66 ±66.95	224.00 ±45.92	8.43 ±2.76	11.23 ±2.20
Sire #4				
N	7	4	7	4
Mean	264.00 ±54.04	234.00 ±56.44	8.52 ±1.35	8.98 ±1.92
Sire #5				
N	4	10	4	10
Mean	230.75 ±31.74	211.20 ±42.30	8.95 ±1.24	7.70 ±1.90
Sire #6				
N	4	3	4	3
Mean	319.00 ±52.12	199.00 ±45.92	9.72 ±1.87	7.06 ±1.61
Sire #7				
N	7	3	7	3
Mean	266.00 ±68.85	247.33 ±39.21	9.94 ±4.17	10.53 ±3.37
Sire #8				
N	1	1	1	1
Mean	257.00	241.00	6.50	10.40
Sire #9				
N	5	1	5	1
Mean	311.00 ±32.44	238.00	9.00 ±1.93	7.40

[a]N = Number of observations
[b]Mean = Mean and standard deviation

Appendix

Table 11. Means and Standard Deviations of Plasma Vitamin A and Carotene Levels for Each Sex Within Sire Subclasses at Period IV

	Vitamin A 1957		Carotene 1957	
	Bulls	Heifers	Bulls	Heifers
Sire #1				
N[a]	9	7	9	7
Mean[b]	58.00 ±13.00	60.00 ± 8.02	577.33 ±207.89	363.14 ±196.93
Sire #2				
N	10	6	10	6
Mean	68.80 ± 9.11	61.66 ± 8.62	595.20 ±147.54	488.50 ±248.10
Sire #3				
N	5	5	5	5
Mean	66.60 ± 7.89	65.20 ± 3.49	653.60 ±150.91	400.60 ±145.27
Sire #4				
N	5	6	5	6
Mean	60.60 ± 5.41	69.00 ± 5.90	630.00 ±189.91	465.16 ± 81.07
Sire #5				
N	3	14	3	14
Mean	78.33 ± 8.62	67.14 ± 7.46	923.00 ±266.01	473.57 ±174.33
Sire #6				
N	6	7	6	7
Mean	67.00 ± 6.45	68.42 ± 8.54	676.00 ±151.69	404.00 ± 71.14
Sire #7				
N	7	3	7	3
Mean	68.71 ± 8.18	72.00 ±26.96	643.57 ±148.87	597.33 ±164.23
Sire #8				
N	2	1	2	1
Mean	68.00 ± 5.66	61.00	550.00 ± 86.84	492.00
Sire #9				
N	5	1	5	1
Mean	53.20 ± 8.93	58.00	564.60 ± 92.93	545.00

[a]N = Number of observations.
[b]Mean = Mean and standard deviation.

LITERATURE CITED

1. Almquist, H. J. 1952. Relation of vitamin A intake to plasma and liver vitamin A content. Arch. Biochem. and Biophysiol. 39: 243.

2. Anderson, R. L. and T. A. Bancroft. 1952. Statistical Theory in Research. McGraw Hill, New York. 399 pages.

3. Ashton, B. C. 1957. Serum protein differences in cattle by starch gel electrophoresis. Nature 180:917.

4. Ashton, G. C. 1958. Lack of "slow alpha" proteins in some guernsey cattle. Nature 182:193.

5. Ashton, G. C. 1958. Polymorphism in the β-globulins of sheep. 181:849.

6. Baker, F. H., R. MacVicar, L. S. Pope, C. K. Whitehair and W. D. Campbell. 1953. Vitamin A studies with beef cows and their calves. Okla. Agr. Exp. Sta. Misc. Pub. MP-31:59.

7. Baker, F. H., L. S. Pope, and R. MacVicar. 1954. The effect of vitamin A stores and carotene intake of beef cows on the vitamin A content of the liver and plasma of their calves. J. Anim. Sci. 13:802.

8. Booth, V. H. 1952. Liver storage of vitamin A by male and female rats. J. Nutr. 48:13.

9. Braun, W. 1945. Studies on the carotenoid and vitamin A levels in cattle. II. Carotenoids and vitamin A in the liver, their ratio and their relationship to blood levels. J. Nutr. 29:73.

10. Brenner, S., M. C. H. Brookes, and L. J. Roberts. 1942. The relation of liver stores to the occurrence of early signs of vitamin A deficiency in the white rat. J. Nutr. 23:459.

11. Callison, E. G., and V. H. Knowles 1945. Liver reserves of vitamin A and their relation to the signs of vitamin A deficiency in the albino rat. Am. J. Physiol. 143:444.

12. Chanda, R. 1953. The partition of carotenoids and vitamin A in the colostrum and milk of the cow and goat. J. Agr. Sci. 43:54.

13. Church, D. C., R. MacVicar, J. G. Bieri, F. H. Baker, and L. S. Pope. 1954. Utilization of intravenously-administered carotene by sheep and cattle. J. Anim. Sci. 13:677.

14. Claesson, O. and A. Hansson. 1956. Studies on monozygous cattle twins. XV. Variation of erythrocytes, leucocytes, hemoglobin, glucose and cholesterol in blood. Acta. Agric. Scand. 6:383.

15. Diven, R. H., H. M. Page, E. S. Erwin and C. B. Roubicek. 1958. Effect of environmental temperature on diurnal variation of blood constituents in the bovine. Am. J. Physiol. 195:88.

16. Dolge, K. L., H. D. Eaton, J. E. Avampato, R. D. Mochrie, F. I. Elliott, and G. Beall. 1952. Effect of feeding various percentages of artifically dehydrated alfalfa meal on the growth and carotene intake of dairy calves. J. Dairy Sci. 35:424.

17. Dolge, K. L., J. E. Rousseau, Jr., R. Teichman, H. D. Eaton, and G. Beall. 1956. Interrelationships between carotene from artificially dehydrated alfalfa and vitamin A from a dry carrier when fed simultaneously to holstein calves. J. Dairy Sci. 39:1660.

18. Eaton, H. D., J. E. Rousseau Jr., M. W. Dicks, R. Teichman and A. P. Grifo, Jr., 1958. Association between plasma and liver concentrations of vitamin A or of tocopherol in holstein male calves fed fixed intakes of these vitamins. J. Dairy Sci. 41: 1456.

19. Ensminger, M. E., M. W. Galgan, and W. L. Slocum. 1955. Problems and prictices of American cattlemen. Wash. Agr. Exp. Sta. Bul. 562.

20. Erwin, E. S., I. A. Dyer, T. O. Meyer, and K. W. Scott. 1956. Uses of aspiration biopsy technique. J. Anim. Sci. 15:428.

21. Erwin E. S., T. R. Varnell and H. M. Page. 1959. Relationship of Vit. A and carotene to bovine serum proteins. Soc. Exp. Biol. and Med. 100:373.

22. Esh, G. C. and T. S. Sutton. 1943. The effects of soya lecithin on the absorption, utilization, and storage of vitamin A and carotene in the white rat. J. Nutr. 26:549.

23. Evans, J. V., J. W. B. King, B. L. Cohen, H. Harri and F. L. Warren. 1956. Genetics of hemoglobin and blood potassium differences in sheep. Nature 178:849.

24. Frey, P. R., R. Jensen and W. E. Connell. 1947. Vitamin A intake in relation to hepatic stores and blood levels. J. Nutr. 34: 421.

25. Gallup, W. D. and J. A. Hoefer. 1946. Determination of vitamin A in liver. Ind. Eng. Chem. Ana. Ed. 18:288.

26. Ganguly, J. and N. H. Krinsky. 1953. Absence of a relationship between vitamin A alcohol levels in plasma and liver of rats. Biochem. J. 54:177.

27. Gifford, W. 1953. Record-of-performance tests for beef cattle in breeding herds. Ark. Agr. Exp. Sta. Bul. 531.

28. Glover, H., T. W. Goodwin and R. A. Morton. 1947. Studies in vitamin A. 2. The relationship between blood vitamin A levels and liver stores in rats. Biochem. J. 41:97.

29. Goodwin, T. W. and A. A. Wilson 1951. Studies in vitamin A. 15. the variations in the serum β-carotene and vitamin A levels of cows near parturation. Biochem. J. 49:499.

30. Goulden, C. H. 1952. Methods of Statistical Analysis, (2nd ed.). John Wiley and Sons, Inc., New York. 467 pages.

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

32. Hickman, C. G., and S. O. Smithies. 1957. Evidence for inherited differences in the serum proteins of cattle. Proc. Genet. Soc. Can. 2:39.

33. Hoefer, J. A. and W. D. Gallup. 1947. The comparative value of a carotene concentrate, alfalfa meal, and a fish liver oil in maintaining the vitamin A content of the blood and liver of fattening lambs. J. Anim. Sci. 6:325.

34. Kimble, M. S. 1939. The photocalorimetric determination of vitamin A and carotene in human plasma. J. Lab. and Clin. Med. 24:1055.

35. Krause, R. F. 1949. A paradoxical relationship between serum level and liver content of vitamin A. J. Nutr. 38:535.

36. Lewis, J. M., O. Bodansky, K. G. Falk and G. McGuire. 1942. Vitamin A requirements in the rat. The relation of vitamin A intake to growth and concentration of vitamin A in the blood plasma, liver and retinae. J. Nutr. 23:351.

37. Long, R. A., W. A. VanArsdell, R. MacVicar and O. B. Ross. 1952. Blood composition of normal beef cattle. Okla. Agr. Exp. Sta. Bul T-43

38. Lush, J. L. 1940. Intra-sire correlations or regressions of offspring on dam as a method of estimating heritability of characteristics. Proc. Am. Soc. Anim. Prod. (33rd annual meeting).

39. Lush J. L. 1949. Heritability of quantitative characters in farm animals. Hereditas (supplemental volume) 356.

40. Moore, T. 1957. Vitamin A. Elsevier Publishing Company, New York. 645 pages.

41. Olsen, T. M. 1950. Elements of Dairying. The Macmillan Company, New York. 708 pages.

42. Page, H. M., Jr. 1959. The effect of ambient temperatures and solar radiation on vitamin A metabolism and certain blood constituents in the bovine animal. M. S. Thesis. Uni. of Arizona.

43. Page, H. M., E. S. Erwin, T. R. Varnel and C. B. Roubicek. 1958. Effect of hepatic vitamin A and carotene concentration on the biological value of carotene in the bovine. Am. J. Physiol. 194:313.

44. Pahnish, O. F. 1958. Some genetic and environmental factors influencing the weaning weights of southwestern range cattle. Ph. D. Thesis. Oregon State College.

45. Pope, L. S., J. L. Pitts and C. Waller. 1958. Effect of three levels of carotene intake during lactation on the performance of beef cows and their calves. Okla. Agr. Exp. Sta. Misc. Pub. MP-51:42.

46. Ralston, A. T. and I. A. Dyer. 1959. Relationship of liver and plasma carotenoid and vitamin A content in cattle as affected by location and season. J. Anim. Sci. 18:874.

47. Repp, W. W. and W. E. Watkins. 1958. Carotene, vitamin A and inorganic phosphorus in the blood plasma of range cows. New Mex. Agr. Exp. Sta. Bul. 420.

48. Rice, F. J. 1956. Factors influencing performance in range hereford cattle. Ph.D. Dissertation. Univ of Missouri.

49. Riggs, J. K. 1940. The length of time required for depletion of vitamin A reserves in range cattle. J. Nutr. 20:491.

50. Rousseau, J. E. Jr., C. M. Dembiczak, K. L. Dolge, H. D. Eaton, G. Beall, and L. A. Moore. 1954. Relationship between plasma vitamin A and liver vitamin A in calves fed a vitamin A depletion ration and calves fed minimum levels of vitamin A or carotene. J. Dairy Sci. 37:1376.

51. Rousseau, J. E., Jr., C. F. Helmboldt, C. M. Dembiczak, E. L. Jungherr, H. D. Eaton, and G. Beall. 1954. Effect of two levels of intake of a vitamin A depletion ration on some blood constituents and deficiency criteria in the dairy calf. J. Dairy Sci. 37:857.

52. Smithies, O. 1957. Variations in human serum β-globulins. Nature. 180:1482.

53. Smithies, O. and C. G. Hickman 1958. Inherited variations in the serum proteins of cattle. Genetics. 43:374.

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

55. Wise, G. H., M. J. Caldwell, D. B. Parrish, F. W. Atkeson, and J. S. Hughes. 1948. Relation of typical postnatal changes in the diet of the dairy calf to the concentration of carotenoids and vitamin A in the blood serum. J. Anim. Sci. 7:70.