THE RELATION OF THE SERUM PHOSPHATASES TO GROWTH OF GENETICALLY DIFFERENT GROUPS OF BEEF CATTLE

by

GRAHAM IRVING ALEXANDER

A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

DOCTOR OF PHILOSOPHY

June 1959

APPROVED:

Redacted for privacy

Professor of Animal Husbandry

In Charge of Major

Redacted for privacy

Chairman of Genetics Committee

Redacted for privacy

Chairman of School Graduate Committee

Redacted for privacy

Dean of Graduate School

Date thesis is presented March 10, 1959

Typed by Verna Anglemier

ACKNOWLEDGEMENT

The writer wishes to express his sincere and grateful appreciation to Doctors Ralph Bogart and Hugo M. Krueger, Professors of Animal Husbandry and Physiology respectively, for their constructive suggestions and criticisms during the preparation of the thesis.

Appreciation is expressed to Doctor J. E. Oldfield, Associate Professor of Animal Husbandry, for making available certain laboratory facilities necessary for carrying out this investigation and to Doctor R. G. Peterson for advice on some aspects of the statistical analyses.

Appreciation is expressed to my fellow graduate students for their advice and interest, and especially to R. W. Mason and S. W. Sabin for their assistance in procuring the blood samples.

Acknowledgements are also due to the staff members of the Department of Animal Husbandry for their efforts and friendship throughout the period of study.

Special recognition is due to the writer's wife, Ngare, whose encouragement and help has made this study more enjoyable.

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

TABLE OF CONTENTS
(continued)

LIST OF TABLES

LIST OF TABLES
(continued)

LIST OF TABLES
(continued)

LIST OF FIGURE

THE RELATION OF THE SERUM PHOSPHATASES TO GROWTH OF GENETICALLY DIFFERENT GROUPS OF BEEF CATTLE

INTRODUCTION

In the field of beef cattle improvement through genetic research, a considerable amount of attention has been focused on characteristics which have an immediate economic importance. Such measures of productivity as calving percentage, birth weight, suckling gain, weaning weight, and rate of gain have been assessed under a wide variety of conditions and for the various breeds of beef cattle and their crosses. The interrelationships between these characters have been examined and their relative merit as criteria for selection evaluated.

Equally important in this regard is an adequate knowledge of the fundamental physiological functions which determine growth and production characteristics. The advent of dwarfism has lent emphasis to the necessity of detailed physiological study of growth processes as an aid in more efficient selection of farm animals. Studies of this type have helped to delineate many of the underlying mechanisms in the development of the condition and physiological tests have been developed to aid in the detection of the heterozygous carrier of the dwarf syndrome. These investigations have been used in this case to attack a simply inherited condition. It is quite feasible that a similar approach in analyzing the physiological components of a polygenically controlled trait such as rate of gain may be even more fruitful.

Studies on the metabolism of rapidly and slowly gaining beef cattle have been carried out at a number of experiment stations. This type of research has been pursued actively at the Oregon Agricultural Experiment Station as an adjunct to the performance testing programme. Various constituents of the blood and urine have been determined and related to growth. These blood and urine constituents represent either intermediate or end products of enzymatic processes and so are an indirect measure of the physiological behaviour of the individual. A more direct measure would be the examination of the activity of a particular enzyme or enzyme system in the different animals. Probably the easiest and most accessible enzymes which can be studied are the serum phosphatases. For this reason and others which will be developed in the review of literature and discussion, the serum phosphatases have been the subject of this study.

REVIEW OF LITERATURE

1. The Serum Phosphatases.

The serum phosphatases belong to a class of enzymes known as the phosphomonoesterases which are specific for a single chemical bond and on orthophosphoric monoesters. Four phosphomonoesterases of different pH optima have been identified partly by pH optima and partly by differential activation by magnesium ions (20).

The two main broad groups of phosphatases present in blood serum are the phosphomonoesterases I (alkaline phosphatase) and phosphomonoesterases II (acid phosphatase). Normally these enzymes are considered to be derived from various tissues such as the liver, bone and kidney (19). Their functional significance has not been fully established.

As indicated by their classification, they are enzymes which are specific for orthophosphoric monoesters but are rather non-specific regarding other aspects of the substrate. Dixon and Webb (10) consider they attack most orthophosphoric monoesters and also catalyse transphosphorylations. Axelrod (4) cites instances of alkaline and acid phosphatases acting *in vitro* on phosphocreatine and transferring the phosphate group to glucose, glycerol and fructose. Glucose-1-phosphate, phosphopyruvate, and

5'-nucleotides have been shown to act as donors.

In investigations of pure enzymes, it is customary to measure the initial rate of the reaction by determining the concentration of end products as a function of time. However, in orientation experiments and in investigations of physiological or medical chemistry, it is sufficient to make a single determination, at a time chosen in such a way that a hydrolysis of not more than 10 per cent of the substrate has been achieved (20, p. 476). In this type of investigation, the activity of blood serum is expressed only in relative units. These can be defined only empirically and it is not possible to compare the units with each other accurately as they correspond to amounts of phosphoric acid liberated from different substrates under nonidentical conditions. The earliest unit developed and the one used in this study is the Bodansky unit which is the amount of enzyme in 100 ml. of serum liberating one mg. P in one hour from 0.5 per cent sodium beta-glycerophosphate, at pH 8.6 and at 37° (13). Another unit often used is the King and Armstrong unit which, as used by Gutman and Gutman, is defined in terms of the liberation of one mg. per cent of phenol and is approximately double the value of the phosphate unit used here. The method of Bessey, Lowry and Brock as used by Kunkel *et al*. (14) has as its unit the number of micromoles of p-nitrophenol liberated per liter of serum per hour at 38° from p-nitrophenyl phosphate. Each micromole per liter of serum per hour is approximately equivalent to 1.79 Bodansky units per 100 ml. serum per hour.

Much of the information about the serum phosphatase has been derived from the study of various pathological conditions. Normally it is considered that these enzymes are derived by diffusion from various tissues such as the liver, kidney, osseous tissue and prostate (19, 20). In various pathological conditions, a particular tissue may pour high levels of one or the other enzyme into the blood; so that the presence of a hyperphosphatasemia has been used as an aid in the diagnosis of some disease. However, studies have also been made of the variations in the levels of these serum constituents in relation to normal physiological functions.

2. The Serum Phosphatases and Sex.

The serum alkaline phosphatase level of the female rat was only 60 per cent that of the male level but this difference could be eliminated by standardizing the food intake of the two sexes (22). Acid phosphatase levels in the serum of adult males did not vary significantly from that in adult females (7, 22).

Castration of male animals caused increases in the serum alkaline phosphatase activity but no change in acid phosphatase (8). Estrogen administration to a castrate male caused a decrease in acid phosphatase (8).

Castration of and testosterone administration to females increased the serum alkaline phosphatase activity (8) but castration alone did not have any effect (22). Estrogen caused no change in the serum alkaline phosphatase level. Serum acid phosphatase was not influenced by castration, or administration of estrogen or androgen to the intact female or androgen administration to the castrate female (8).

3. The Serum Phosphatases and Growth.

Hypophysectomy decreased the serum alkaline phosphatase activity (15) and the administration of growth hormone to normal animals generally increased the serum alkaline phosphatase activity (16). No information is available on the relationship of acid phosphatase to growth hormone production.

Barnes and Munks (5) found that in children the serum alkaline phosphatase level rose from 7.1 Bodansky units per 100 cc. serum at birth to a maximum 13 Bodansky units at 5 months of age. There was then a steady decline until one year of age. Stearns and Warweg (21) examined the variation in humans over a much greater age range and found a similar trend, the plasma alkaline phosphatase level increasing by 100 per cent during the first month of life. This level was maintained during the first year, and then decreased gradually, to reach the adult level in late childhood. Kunkel et al. (14) examined the serum alkaline phosphatase activity of European and Brahman cross cattle and found a lowering of phosphatase activity with age from 3.4 micromole units per liter of serum (6.8 Bodansky units per 100 ml.) for 8 to 14 month old European cattle to 1.5 micromoles (3.0 Bodansky units) for cows 3 to 9 years of age.

No information was found in the literature on the effect of age on serum acid phosphatase levels.

4. The Serum Phosphatases and Diet.

Increased serum alkaline phosphatase activity in rats was observed in growing rats on a low calcium diet, the animals also becoming rachitic (23). In human rickets the serum alkaline phosphatase activity is elevated. Auchinachie and Emslie (3) found that, in sheep fed a diet deficient in calcium but high in phosphate, the plasma alkaline phosphatase rose to three times its initial value in six months. When the sheep were returned to pasture, the alkaline phosphatase level fell but had not reached normal levels after one month.

Serum alkaline phosphatase activity in rats was also observed to increase following ingestion of fatty acids (9). The effect of dietary proteins and amino acids on alkaline phosphatase activity has also been widely studied. Bodansky (6) showed that the feeding of large amounts of carbohydrate elevated the level of serum alkaline phosphatase in dogs. Using rats, Weil and Russel (24) showed that fasting produced a lowering of the plasma alkaline phosphatase level which was corrected on return to a normal diet.

It would appear that either the relationship of serum acid phosphatase to change in diet has not been examined or that it is remarkably resistant to the influence to diet as no reference could be found to this effect in the literature.

5. The Serum Phosphatases and Rate of Gain.

In recent years interest has been focused on the relationship of the serum phosphatases, particularly serum alkaline phosphatase, to rate of gain in beef cattle. Kunkel *et al*. (14) examined the possibility of correlations between initial and final serum alkaline phosphatase level and feed lot gain in a limited number of beef bulls. They found a correlation coefficient of 0.19 between initial phosphatase level and feed lot gain and one of 0.56 between final phosphatase level and feed lot gain.

In studies with Brahman-cross male and female cattle carried out over a period of three years, Fletcher et al. (12) found that the relationship between initial serum alkaline phosphatase activity and gain in the feed lot was quite variable, gross correlations between the two variables being .63, -.35 and .07 for bulls and -.02, .45 and .43 for heifers. However, most of the correlations between phosphatase and gain were positive, and only positive correlations (.63, .45 and .43) were significant statistically. Alexander et al. (1) examined the relationship of serum alkaline and acid phosphatase levels at 800 lbs. body weight with rate of gain in Hereford and Angus cattle. They found a correlation of 0.54 between alkaline phosphatase level and rate of gain and one of 0.37 between acid phosphatase level and rate of gain. Female calves in all lines of cattle studied showed a consistent correlation between alkaline phosphatase level and rate of gain and a somewhat less consistent one between acid phosphatase level and rate of gain.

METHODS AND PROCEDURE

Data presented in this investigation were taken from the beef cattle herd maintained at the Oregon Agricultural Experiment Station at Corvallis, Oregon. There are two breeds, Hereford and Angus, represented in the herd. The Hereford groups are made up of three closed lines of approximately 15 cows in each line while the Angus unit comprises approximately 20 cows in a closed line. The cows are pasture-mated in single bull breeding groups in June-July to calve during the spring, the bulls used being selected from the previous year's calves.

1. Management.

Two groups of calves were used in the present study. The older group of 52 calves were born in the spring of 1957 and were weaned at about 425 pounds body weight. Those calves not reaching 425 pounds before November 14, 1957, were weaned regardless of their weight. After weaning, the calves were placed under experimental conditions as described by MacDonald et al. (18).

The younger group of 46 calves born in the spring of 1958 was maintained on irrigated pastures during the summer months until they reached 425 pounds body weight or until November 14, 1958.

2. Blood Collection.

A series of blood samples were collected from each animal. Either 13 or 15 gauge bleeding needles were used. In every instance, the blood sample consisted of about 30 ml. collected in a 50 ml. graduated centrifuge tube without oxalate. The sample was allowed to clot and, after centrifugation, the serum was drawn off.

The following series of samples were taken. The cows were all bled in November, 1957. The calves born in the spring of 1957 were bled during their sojourn in the test pens under the feed performance testing regime. Four samples were collected from each calf, one at 500 pounds body weight and one each at 600, 700 and 800 pounds body weight. The blood samples were collected between 9:00 and 10:00 a.m.

Blood samples were taken from the calves born in the spring of 1958 at birth or as near to it as possible, at three months of age, and at six months of age. The calves were bled on the Wednesday nearest the appropriate age during the regular weighing procedure. It was deemed advisable to bleed these younger calves at constant ages rather than at constant weights as was done with the performance-tested animals. If they had been bled at 100, 200, 300 and 400 pounds body weight, some would have had to be bled in the test pens after weaning which would introduce changes in their nutritional status.

3. Chemical Analyses.

The serum drawn off was frozen over-night and the serum inorganic phosphate and alkaline and acid phosphatases analyzed the following day.

Alkaline phosphatase was determined according to Hawk, Oser and Summerson (13, p. 583-586). The incubation procedure of Bodansky was used with modifications to permit the use of the method of Fiske and Subbarow for the determination of the phosphate liberated. The procedure described by Shinowara, Jones and Reinhart modified by Hawk, Oser and Summerson to permit the use of the Fiske and Subbarow phosphate method was chosen for the determination of serum acid phosphatase.

The method for determination of serum inorganic phosphate was that of Fiske and Subbarow (11).

4. Statistical Analyses.

The means, standard deviations, regression coefficients and correlations have been obtained according to statistical techniques as outlined by Li (17). In addition the blood constituents were regressed on certain performance criteria by the method of least square analysis as described by Anderson and Bancroft (2). The data have been tabulated with subdivisions to allow comparisons between sexes and lines.

EXPERIMENTAL FINDINGS

A. The Suckling Period

The information compiled on each calf included birth weight and average rate of gain to six months of age (suckling gain). Analyses were made for serum alkaline phosphatase, serum acid phosphatase and serum inorganic phosphate during the first week, and at 3 and 6 months of age. Tabulations of the data have been made to facilitate comparisons between sexes within lines, within sexes between lines and an overall sex comparison. It was considered that the Hereford lines were sufficiently divergent to be compared directly with the Angus line rather than be pooled in a comparison of Hereford and Angus animals.

The least squares method of analysis (2) was used to estimate the line, sex and line x sex interaction effects for the suckling gain and blood constituent data. Each observation was assumed to be the sum of the influences of other variables as follows:

$$Y_{ijk} = M + S_i + L_j + (SL)_{ij} + e_{ijk}$$

Where Y_{ijk} = the observation on the kth calf of the ith sex in the jth line.

M = the overall effect.

S_i = the added effect of the ith sex.

L_j = the added effect of the jth line.

$(SL)_{ij}$ = the added effect of the ith sex in the jth line.

e_{ijk} = random error.

Differences were determined between the estimates of the effects of each line and of each sex and were tested for significance at the five and one per cent levels of probability.

1. Birth Weight.

The mean birth weight of the calves was 66.8 pounds (Table 1). The sex difference was too slight to be regarded as significant (Table 5). The Angus males averaged 56.5 pounds at birth, 1.8 pounds lighter than the Angus females. The only line in which the males or in fact any sex was heavier on the average was the Prince in which the average male birth weight of 77.1 pounds was significantly heavier than the average female birth weight of 61.0 pounds ($P < 0.01$).

In a comparison of the male calves of the different lines, the Lionheart and Prince males (which averaged 73.8 and 77.1 pounds respectively) were significantly heavier than the Angus males ($P < 0.01$). The Lionheart and Prince male calves also outweighed the David males ($P < 0.05$).

Table 1

Mean Birth Weight and Suckling Gain with Corresponding Standard Deviations for the Calves

Group	No. of Calves	Birth Weight (lb.)	Suckling Gain (lb. per day)
Lionheart Males	9	73.8 ± 7.0	1.61 ± .38
Lionheart Females	5	74.2 ± 15.6	1.66 ± .13
Prince Males	8	77.1 ± 11.5	1.73 ± .24
Prince Females	3	61.0 ± 3.0	1.26 ± .17
David Males	2	60.0 ± 2.8	1.72 ± .14
David Females	5	62.8 ± 4.4	1.57 ± .14
Hereford Males	19	73.7 ± 5.2	1.67 ± .31
Hereford Females	13	66.8 ± 11.3	1.53 ± .21
Angus Males	6	56.5 ± 4.5	1.78 ± .15
Angus Females	8	58.3 ± 6.1	1.55 ± .29
All Males	25	69.6 ± 11.6	1.70 ± .29
All Females	21	63.5 ± 10.3	1.54 ± .24
All Animals	46	66.8 ± 11.4	1.63 ± .28

Within the females, the Lionheart females with a mean weight of 74.2 pounds outweighed the Angus females ($P < 0.01$). The Lionheart female calves also had superior birth weights on the average to the Prince and David females ($P < 0.05$) (Table 1).

2. Suckling Gain.

The mean rate of gain from birth to six months for all calves was 1.63 pounds per day. While the male calves averaged 0.16 pounds per day more gain than the female calves, this difference was not statistically significant. There was little variation between the sexes within the lines except in the Prince line in which the male calves with a mean rate of gain of 1.73 pounds per day were superior to the females with an average daily gain of 1.26 pounds ($P < 0.05$).

When the male calves of the various lines were compared, no significant differences in suckling gains were observed. Similarly, no marked differences were found between the female calves of the various lines (Table 1).

3. Serum Alkaline Phosphatase.

(a) At Birth: The mean serum alkaline phosphatase activity of all the calves at birth was 11.51 Bodansky units per 100 ml. serum (Table 2). There was marked variation in the levels at this age as indicated by the

Table 2

Mean Serum Alkaline Phosphatase Levels and Standard Deviations at Birth, 3 Months and 6 Months of Age

Group	Serum Alkaline Phosphatase (Bodansky units per 100 ml.)		
	At Birth	3 Months	6 Months
Lionheart Males	10.09 ± 2.34	8.23 ± 2.67	6.11 ± 1.41
Lionheart Females	15.32 ± 3.77	10.08 ± 2.01	4.49 ± 0.82
Prince Males	10.64 ± 4.53	9.00 ± 2.50	5.83 ± 2.34
Prince Females	10.46 ± 2.26	8.90 ± 2.31	5.70 ± 2.03
David Males	13.94 ± 0.74	7.01 ± 0.60	4.75 ± 0.11
David Females	16.03 ± 9.03	5.88 ± 1.94	4.95 ± 0.69
Hereford Males	10.73 ± 3.43	8.42 ± 2.46	5.85 ± 1.78
Hereford Females	14.47 ± 6.17	8.19 ± 2.71	4.96 ± 1.14
Angus Males	9.12 ± 5.65	5.48 ± 1.44	5.91 ± 1.82
Angus Females	10.36 ± 3.93	8.39 ± 3.16	8.26 ± 3.05
All Males	10.34 ± 3.84	7.72 ± 2.57	5.86 ± 1.75
All Females	12.90 ± 5.70	8.27 ± 2.81	6.22 ± 2.59
All Animals	11.51 ± 4.96	7.97 ± 2.67	6.02 ± 2.16

standard deviation of 4.96. As would be expected with such a wide individual variation, no sex differences were observed. Also when the male calves were studied according to line no significant differences were observed.

In the female calves, the Angus females were found to have a serum alkaline phosphatase activity significantly lower than the David females ($P < 0.05$).

(b) At 3 Months of Age: At this age the mean serum alkaline phosphatase level had dropped to 7.97 Bodansky units per 100 ml. serum for all calves and the standard deviation had almost halved to 2.67. Again, however, no sex differences were observed with the exception of the Angus line in which the males had a much lower level (7.72 Bodansky units per 100 ml. serum) than the females which averaged 8.39 Bodansky units per 100 ml. ($P < 0.05$).

When compared with the male calves of the other lines, the Angus males had significantly lower levels than the Lionheart and Prince males ($P < 0.05$).

In the comparison between the female calves of the various lines the Lionheart females with an average of 10.08 Bodansky units per 100 ml. serum exceeded the average alkaline phosphatase activity of the David females by 4.20 Bodansky units per 100 ml. serum (Table 2).

(c) At 6 Months of Age: The mean alkaline phosphatase activity of all calves had fallen still further to 6.02 Bodansky units per 100 ml. with a slight reduction in the individual variation (Table 2). As was the case with the two previous ages, males had a lower average alkaline phosphatase level than females but the difference was not significant. The only significant sex difference was again between the Angus male and female calves where the females exceeded the males by 2.35 Bodansky units per 100 ml. ($P < 0.05$).

There were no significant differences between the male calves of the various lines. However, the Angus females were found to have significantly higher levels than both the Lionheart and David females. The differences of 2.77 and 3.31 Bodansky units per 100 ml. serum respectively were both significant at the one per cent level.

(d) When considered on an overall basis, there was no significant line or sex effect (Table 11).

4. Serum Acid Phosphatase.

(a) At Birth: At birth, the calves had a mean serum acid phosphatase level of 0.64 Bodansky units. No significant differences were recorded between the sexes. Also when the male calves of the various lines and the female calves of the lines were compared, no differences were recorded (Table 3).

(b) At 3 Months of Age: At three months of age the mean serum acid phosphatase level had fallen to 0.58 Bodansky units per 100 ml. Once again all groups of calves were similar so that neither sex nor line differences were observed.

(c) At 6 Months of Age: The mean serum acid phosphatase level of all calves at this age was 0.80 Bodansky units per 100 ml. The variation from individual to individual was once again sufficiently great that the differences between sexes or lines were not statistically significant.

5. Serum Inorganic Phosphate.

(a) At Birth: The mean serum inorganic phosphate level of all calves when taken during the first week of life was 9.05 mg. phosphorus per 100 ml. serum (Table 4). No sex differences were observed at this stage. Also when the male calves were compared no line differences were noted.

In the comparison between the females of the lines, the Lionheart females had a phosphate level of 10.23 mg. per 100 ml. serum which was significantly higher than the

Table 3

Mean Serum Acid Phosphatase Levels and Standard Deviations at Birth, 3 Months and 6 Months of Age

Group	Serum Acid Phosphatase (Bodansky units per 100 ml.)		
	At Birth	3 Months	6 Months
Lionheart Males	0.58 ± 0.25	0.51 ± 0.15	0.78 ± 0.24
Lionheart Females	0.66 ± 0.30	0.58 ± 0.22	0.87 ± 0.30
Prince Males	0.55 ± 0.29	0.67 ± 0.22	0.87 ± 0.33
Prince Females	0.71 ± 0.16	0.52 ± 0.09	0.86 ± 0.20
David Males	0.70 ± 0.12	0.48 ± 0.04	0.57 ± 0.17
David Females	0.79 ± 0.49	0.54 ± 0.28	0.72 ± 0.20
Hereford Males	0.58 ± 0.25	0.57 ± 0.19	0.80 ± 0.28
Hereford Females	0.72 ± 0.35	0.55 ± 0.21	0.81 ± 0.24
Angus Males	0.83 ± 0.42	0.57 ± 0.14	0.84 ± 0.41
Angus Females	0.53 ± 0.30	0.64 ± 0.21	0.76 ± 0.19
All Males	0.64 ± 0.31	0.57 ± 0.18	0.81 ± 0.31
All Females	0.65 ± 0.33	0.58 ± 0.21	0.79 ± 0.22
All Animals	0.64 ± 0.31	0.58 ± 0.19	0.80 ± 0.27

Table 4

Mean Serum Inorganic Phosphate Levels and Standard Deviations at Birth, 3 Months, and 6 Months of Age

Group	Serum Inorganic Phosphate (Mg. P per 100 ml.)		
	At Birth	3 Months	6 Months
Lionheart Males	9.47 ± 3.98	9.98 ± 0.54	9.80 ± 1.00
Lionheart Females	10.23 ± 0.89	9.46 ± 0.69	9.20 ± 0.97
Prince Males	8.28 ± 1.86	9.80 ± 0.94	9.20 ± 1.47
Prince Females	9.11 ± 0.13	10.14 ± 0.75	10.59 ± 0.70
David Males	10.33 ± 1.85	9.65 ± 0.13	9.26 ± 0.28
David Females	9.20 ± 1.97	9.46 ± 1.42	9.55 ± 1.60
Hereford Males	9.06 ± 1.67	9.87 ± 0.66	9.49 ± 1.17
Hereford Females	9.58 ± 1.36	9.62 ± 1.01	9.65 ± 1.25
Angus Males	8.69 ± 1.21	9.61 ± 0.65	9.15 ± 1.05
Angus Females	8.46 ± 1.80	8.49 ± 1.07	8.57 ± 1.53
All Males	8.97 ± 1.55	9.81 ± 0.65	9.41 ± 1.13
All Females	9.15 ± 1.60	9.45 ± 1.03	9.24 ± 1.43
All Animals	9.05 ± 1.56	9.64 ± 0.85	9.33 ± 1.27

level of 8.46 mg. per 100 ml. for the Angus females.

(b) At 3 Months of Age: At 3 months of age the mean inorganic phosphate level had risen to 9.64 mg. per 100 ml. for all calves (Figure 1). The various sexes and lines were similar throughout so that no significant sex or line differences were recorded at this age.

(c) At 6 Months of Age: Three months later the mean serum inorganic phosphate level for all calves was 9.33 mg. per 100 ml. serum. No significant sex differences were observed. In the comparison of the males of the various lines, no significant differences were determined (Table 4).

The Angus female calves had a mean serum inorganic phosphate level of 8.57 which was significantly less than the Prince female level of 10.59 ($P < 0.05$).

6. Correlation Between the Performance Data.

A correlation coefficient was calculated between birth weight and suckling gain and was found to be 0.18.

7. Correlations Between the Blood Constituent Data.

The serum alkaline phosphatase level at 3 months of age was correlated with that at birth and at 6 months (Table 6). The correlation of 0.28 between the levels at birth and 3 months of age was significant at the 5 per

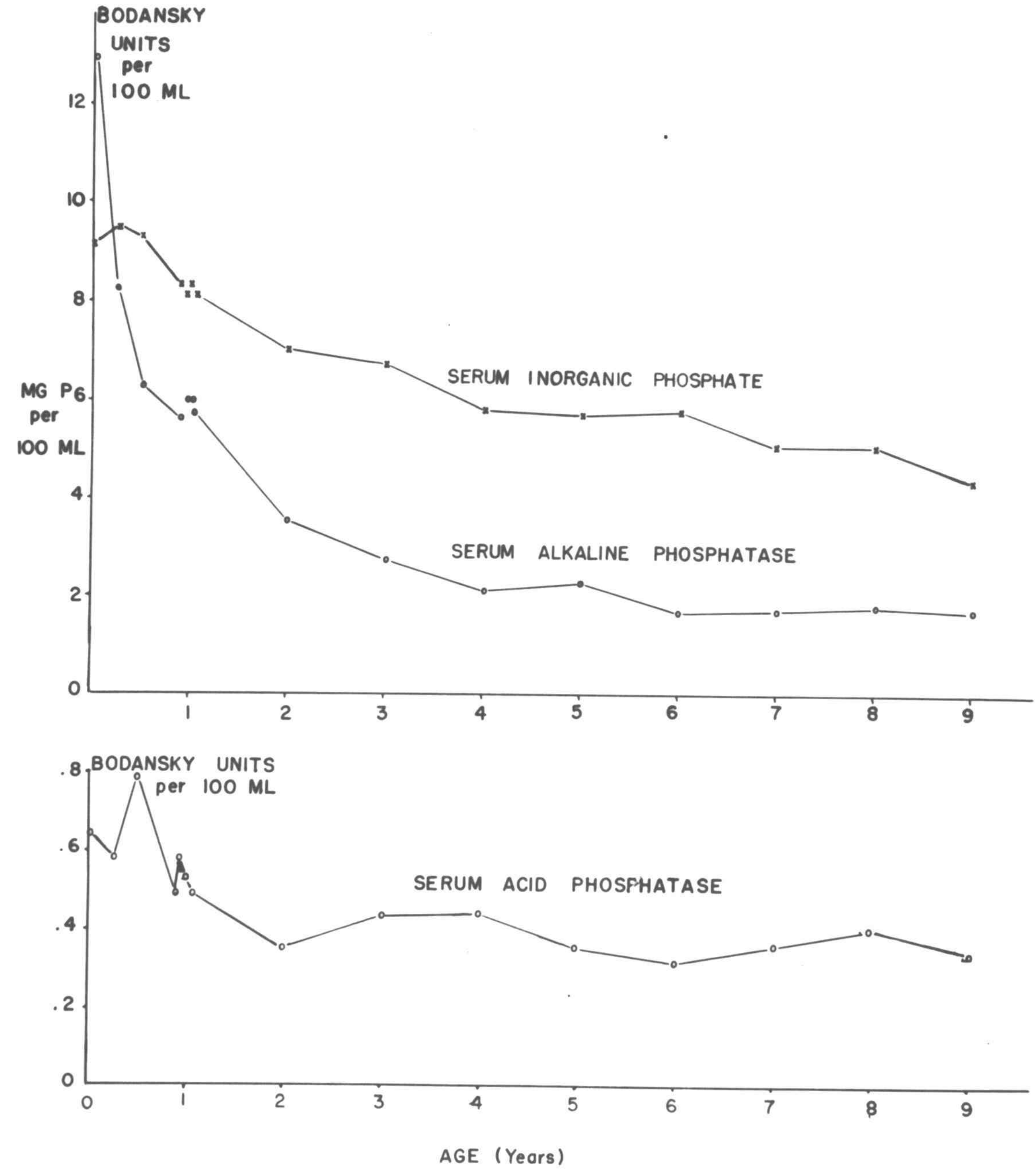

Figure 1. The relationship of serum alkaline phosphatase, serum acid phosphatase and serum inorganic phosphate with age when the values for all animals were pooled.

Table 5

Analysis of Variance of the Performance and Blood Constituent Data

	Mean Squares			
	Error	Sex	Line	Line x Sex Interaction
Birth Weight	72.24	9.25	111.55	.15
Suckling Gain	0.08	0.05	.01	.01
Alkaline Phosphatase				
at birth	22.33	5.22	.41	1.80
at 3 months	5.89	0.93	4.22	.09
at 6 months	3.91	.05	.15	.58
Acid Phosphatase				
at birth	0.11	.00	.01	.00
at 3 months	0.03	.00	.00	.00
at 6 months	0.08	.00	.01	.00
Inorganic Phosphate				
at birth	2.35	.01	.01	.00
at 3 months	0.75	.05	.01	.52
at 6 months	1.58	.02	.24	.17
Degrees of Freedom	38	1	3	3

N.B. None of the mean squares were significant.

cent level (Table 6). There was no correlation between the level at birth and that at 6 months of age but the level at 3 months was significantly correlated with that at 6 months of age (r = .32).

Table 6

Correlation Coefficients Between the Alkaline Phosphatase Levels at Birth, 3 Months and 6 Months of Age

Alkaline Phosphatase Level at	Alkaline Phosphatase Level at 3 Months	6 Months
Birth	.28*	0
3 Months		.32*

* Significant at the 5 per cent level

There was a rather different relationship between the acid phosphatase levels. The acid phosphatase level at birth was negatively related to those at 3 months and 6 months of age (r = -.22 and -.27 respectively). However, there was virtually no correlation between the levels at 3 and 6 months of age (Table 7).

Table 7

Correlation Coefficients Between the Acid Phosphatase Levels at Birth, 3 Months and 6 Months of Age

Acid Phosphatase Level at	Acid Phosphatase Level at 3 Months	6 Months
Birth	-.22	-.27
3 Months		.08

There was a more consistent pattern to the serum inorganic phosphate levels. The level at birth was positively correlated with that at 3 and 6 months of age. The correlation coefficient of .35 between the level at birth and 6 months of age was significant at the 5 per cent level. There was a lower correlation between the levels at 3 and 6 months of age as shown in Table 8.

Table 8

Correlation Coefficients Between the Inorganic Phosphate Levels at Birth, 3 Months and 6 Months of Age

Inorganic Phosphate Level at	Inorganic Phosphate Level at 3 Months	6 Months
Birth	.20	.35*
3 Months		.19

* Significant at the 5 per cent level

At birth, a correlation coefficient of .17 was recorded between the alkaline and acid phosphatase levels (Table 9). The alkaline phosphatase level was also positively related to the level of inorganic phosphate ($r = .26$). A lower correlation of .11 was observed between acid phosphatase and inorganic phosphate.

At 3 months of age the alkaline phosphatase level had little relationship with the acid phosphatase level but a correlation coefficient of .20 was recorded with inorganic phosphate. A correlation coefficient of .27 was found to exist between acid phosphatase and inorganic phosphate at this age.

Table 9

Correlation Coefficients Between the Alkaline Phosphatase, Acid Phosphatase and Inorganic Phosphate Levels at Birth, 3 Months, and 6 Months of Age

	Acid Phosphatase	Inorganic Phosphate
(a) At Birth		
Alkaline Phosphatase	.17	.26
Acid Phosphatase		.11
(b) At 3 Months of Age		
Alkaline Phosphatase	.04	.20
Acid Phosphatase		.27
(c) At 6 Months of Age		
Alkaline Phosphatase	.14	.04
Acid Phosphatase		.10

However, at 6 months of age, there was a correlation of .14 between alkaline and acid phosphatase, practically none ($r = .04$) between alkaline phosphatase and inorganic phosphate and one of .10 between acid phosphatase and inorganic phosphate (Table 9).

8. Correlations Between the Blood Constituent and Performance Data.

At birth, there was virtually no correlation between the alkaline phosphatase level and the birth weight. Acid phosphatase level was slightly and negatively related to birth weight and inorganic phosphate was slightly and positively related to birth weight (Table 10).

Table 10

Correlation Coefficients Between the Blood Constituent and Performance Data

	Birth Weight	Suckling Gain
Alkaline Phosphatase		
at birth	-.02	.02
3 months		.18
6 months		.04
Acid Phosphatase		
at birth	-.07	-.06
3 months		.01
6 months		-.07
Inorganic Phosphate		
at birth	.12	.24
3 months		.15
6 months		.09

Alkaline phosphatase at birth bore little relationship to suckling gain. There was a correlation of 0.18 between the alkaline phosphatase level at 3 months of age and suckling gain but at 6 months of age there was again virtually no relationship between alkaline phosphatase activity and suckling gain.

Acid phosphatase at birth was only slightly and negatively related to suckling gain. At 3 months of age, there was no relationship to suckling gain and at 6 months of age, there was again a low negative relationship between acid phosphatase activity and suckling gain.

At birth, the serum inorganic phosphate level was correlated with rate of gain (r = .24). The degree of correlation decreased as the animals grew older so that at 3 months of age the correlation coefficient was .15 and at 6 months of age it was .09 (Table 10).

9. Overall Relationship Between the Blood Constituent and Performance Data.

In the main, the correlations between the blood constituent data were low and none have been significant excepting where the interrelationship was determined between the same constituent at different ages. On this account no regression coefficients were presented.

However, it was felt that while there might be low relationships when a blood constituent taken at a certain age was considered, there might be higher relationships between that blood constituent and a performance characteristic when the samples taken at the different ages were considered together.

Since line x sex interaction was shown not to be significant (Table 5), this interaction was ignored in the following least squares analysis which was set up. Each observation was assumed to be the sum of the influences of other variables as follows:

$$Y_{ijkl} = M + S_i + L_j + A_k + Bx_{1ijk} + Gx_{2ijk} + e_{ijkl}$$

where Y_{ijkl} = the observation on the lth calf

M = the overall effect

S_i = the added effect of the ith sex

L_j = the added effect of the jth line

A_k = the added effect of the kth sample

B = a proportionality constant estimating the change in the blood constituent with birth weight

x_1 = birth weight

G = a proportionality constant estimating the change in the blood constituent with suckling gain

x_2 = suckling gain

e_{ijkl} = random error

The effects of line, sex, birth weight and suckling gain on alkaline phosphatase, acid phosphatase and inorganic phosphate levels were tested for significance. None were found to be significant (Table 11).

Table 11

Analysis of Variance of the Blood Constituent Data When the Observations at all Ages are Considered

	Degrees of Freedom	Alkaline Phosphatase	Acid Phosphatase	Serum Inorganic Phosphate
Sex Effect	1	71.33	.00	.29
Line Effect	3	11.79	.01	4.15
Birth Weight	1	9.03	.06	.34
Suckling Gain	1	34.12	.01	6.99
Error	39	41.42	.25	5.24

B. Feed Test Period

The information compiled on each animal included average rate of gain on feed test, average feed consumed per 100 pounds gain, and age in days at 500 pounds body weight. Analyses were made for serum inorganic phosphate, serum alkaline phosphatase and serum acid phosphatase. As before, tabulations of the data have been made to facilitate comparisons between sexes within lines, within sexes between lines and an overall sex comparison.

The least squares method of analysis (2) was used to estimate the line, sex, and line x sex interaction effects for the blood constituents and the performance test data, as was done for the calves during the suckling period.

1. Age at 500 Pounds Body Weight.

The mean age of the calves going on test at 500 pounds was 251 days (Table 12). There was a significant overall sex difference, male calves being 16 days younger than female calves ($P < 0.01$). The Angus males were 28 days younger than the Angus females, a difference which approached statistical significance. The Lionheart males were 42 days younger than the Lionheart females. This difference was significant at the 5 per cent level while the difference of 52 days between the Prince males and females was significant at the 1 per cent level.

In a comparison of the males of the different lines, the Angus males were significantly younger than the males of the Prince and David lines ($P < 0.05$).

The Angus females with a mean age of 246 days at 500 pounds were significantly younger than the Lionheart, Prince and David females. The differences of 39, 57 and 39 days were significant at the one per cent, 5 per cent and one per cent levels of probability respectively.

2. Rate of Gain on Test.

For all animals the mean rate of gain on performance test from 500 to 800 pounds was 2.44 pounds per day (Table 12). There was a marked sex difference in rate of gain, the male calves gaining 0.56 pounds per day faster than

Table 12

Means for Age at 500 Pounds Body Weight, Rate of Gain, Feed Consumption per Unit Gain and Their Standard Deviations

Group	No. of Calves	Age at 500 Pounds (days)	Rate of Gain (lb. per day)	Feed Consumption Per Unit of Gain (lb. feed per 100 lb. gain)
Lionheart Males	6	240 ± 14.5	2.88 ± .31	628.8 ± 15.6
Lionheart Females	3	282 ± 48.9	2.14 ± .08	882.1 ± 68.2
Prince Males	6	251 ± 25.2	2.79 ± .35	631.7 ± 72.0
Prince Females	9	303 ± 27.0	2.15 ± .27	838.2 ± 128.4
David Males	10	252 ± 20.5	2.63 ± .33	712.3 ± 75.7
David Females	3	282 ± 13.1	2.51 ± .15	807.0 ± 37.6
Hereford Males	22	248 ± 20.2	2.74 ± .34	667.5 ± 77.6
Hereford Females	15	268 ± 30.1	2.22 ± .26	840.7 ± 104.4
Angus Males	5	218 ± 17.7	2.61 ± .34	729.1 ± 96.5
Angus Females	10	246 ± 33.2	2.04 ± .28	1012.7 ± 114.5
All Males	27	243 ± 22.8	2.71 ± .34	678.9 ± 83.0
All Females	25	259 ± 39.1	2.15 ± .28	909.5 ± 136.7
All Animals	52	251 ± 35.4	2.44 ± .42	789.8 ± 160.7

the females. The Angus males gained weight significantly faster than the Angus females which gained 2.04 pounds per day ($P < 0.01$). The Lionheart males gained 0.74 pounds per day faster than the Lionheart females and the Prince males 0.64 pounds per day faster than the Prince females. Both these differences were significant at the one per cent levels. However, the superiority of the David males over the David females was not so marked. They gained only 0.12 pounds per day faster than the David females.

No significant differences were observed between the male calves of the different lines. Also there were no significant differences between the female calves with the exception of the comparison between the David females and the Angus females where the David females gained 0.47 pounds per day faster than the Angus females ($P < 0.05$).

3. Feed Consumption per 100 Pounds Gain.

In the overall analysis of the feed economies of the calves there was a sex effect significant at the 5 per cent level of probability (Table 12).

Within the various lines, the Angus, Lionheart, and Prince males ate 183.6, 153.3, 206.5 pounds of feed less for each 100 pounds gain in body weight than the corresponding females. These differences were all significant at the one per cent level of probability.

There were no significant differences in feed consumption per unit of gain between the male calves of the various lines. In the comparisons between the feed economies of the female calves, it was found that the difference of 130.6 pounds of feed per 100 pounds between the averages of the Lionheart and Angus was significant at the 5 per cent level. The difference of 205.7 pounds feed consumed per 100 pounds gain between the David and Angus females was significant at the one per cent level.

4. Serum Alkaline Phosphatase.

(a) At 500 Pounds: The mean level of serum alkaline phosphatase of all animals at 500 pounds was 5.97 Bodansky units per 100 millilitres (Table 13). Males had a mean alkaline phosphatase level of 0.71 higher than that of the females. There were no significant differences between lines or sexes at this weight.

(b) At 600 Pounds: At this weight the mean alkaline phosphatase level of all animals had risen to 6.22 Bodansky units per 100 millilitres (Table 13) and there was considerable variation among lines and sexes. No significant differences were observed between males and females or Angus males and Angus females. The Lionheart males had lower levels of alkaline phosphatase than the Lionheart females with a mean serum alkaline phosphatase level of

Table 13

Mean Serum Alkaline Phosphatase Levels and Their Standard Deviations at 500, 600, 700, and 800 Pounds Body Weight

Group	Serum Alkaline Phosphatase (Bodansky units per 100 ml.)			
	at 500 lb.	600 lb.	700 lb.	800 lb.
Lionheart Males	6.02 ± 1.90	6.21 ± 1.69	6.71 ± 1.93	6.22 ± 1.15
Lionheart Females	4.81 ± 0.89	6.44 ± 0.30	5.57 ± 0.20	5.08 ± 1.20
Prince Males	6.26 ± 1.71	5.93 ± 2.22	6.94 ± 0.87	7.58 ± 1.58
Prince Females	5.80 ± 1.77	6.01 ± 0.98	5.65 ± 1.15	5.93 ± 1.35
David Males	6.18 ± 1.47	6.84 ± 2.07	6.51 ± 1.29	6.16 ± 1.37
David Females	7.11 ± 1.99	5.71 ± 1.26	4.71 ± 0.22	5.21 ± 0.97
Hereford Males	6.16 ± 1.58	6.42 ± 1.96	6.68 ± 1.41	6.57 ± 1.46
Hereford Females	5.86 ± 1.74	6.04 ± 0.92	5.44 ± 0.96	5.62 ± 1.24
Angus Males	6.96 ± 2.65	6.31 ± 1.95	6.52 ± 1.53	8.20 ± 1.81
Angus Females	5.22 ± 1.42	6.01 ± 1.57	5.50 ± 1.04	5.85 ± 1.67
All Males	6.31 ± 1.76	6.40 ± 1.92	6.65 ± 1.40	6.87 ± 1.62
All Females	5.60 ± 1.62	6.03 ± 1.19	5.47 ± 0.97	5.71 ± 1.40
All Animals	5.97 ± 1.73	6.22 ± 1.61	6.08 ± 1.34	6.31 ± 1.61

6.44 Bodansky units per 100 millilitres. The Prince males also had lower alkaline phosphatase levels than the Prince females while the David males had higher levels than the David females. However, none of these differences were significant and no significant line differences were determined.

(c) At 700 Pounds: While the overall mean alkaline phosphatase level was 6.08 Bodansky units per 100 ml., the males with a mean level of 6.65 units had significantly higher levels than the females ($P < 0.01$) (Table 16). Angus males had higher alkaline phosphatase levels than the Angus females. Also within the Hereford lines the males were consistently higher in alkaline phosphatase level than the females but only in the case of the David males compared with the David females was the difference significant ($P < 0.05$).

No significant differences were recorded between the various lines when either the male or female calves were compared.

(d) At 800 Pounds: At this weight, the mean alkaline phosphatase level was 6.31 Bodansky units per 100 ml. and there was a significant difference of 1.16 Bodansky units per 100 ml. between males and females ($P < 0.01$) (Table 16). Angus males had significantly higher levels than the Angus females ($P < 0.05$). Of the Hereford lines, the Prince males were the only ones to show a significantly higher alkaline phosphatase level than the Prince females.

In the comparison between the male calves the Prince males with a mean level of 7.58 Bodansky units had a significantly lower alkaline phosphatase level than the Angus males which averaged 8.20 Bodansky units ($P < 0.05$). The David males with an average level of 6.16 Bodansky units were also significantly lower than the Angus males. This difference was also significant at the 5 per cent level.

(e) Overall Relationship: When the levels at all four weights are considered together, the sex effect approaches significance but there is no line effect (Table 24).

5. Serum Acid Phosphatase.

(a) At 500 Pounds: At the commencement of the feed test period, the calves had a mean serum acid phosphatase level of 0.48 Bodansky units per 100 ml. No significant differences were recorded between the sexes either when all the males and all the females or males and females within the individual lines were considered.

Within the male calves the mean serum acid phosphatase level of 0.58 Bodansky units per 100 ml. for the

Prince calves was significantly higher than that of 0.31 Bodansky units for the Angus male calves ($P < 0.01$). The David calves also had significantly higher acid phosphatase levels than the Angus males ($P < 0.01$).

Within the female calves, the same line differences existed but they were only significant at the 5 per cent level.

(b) At 600 Pounds: The mean acid phosphatase value for all animals was 0.57 Bodansky units per 100 ml. of serum (Table 14). No significant sex differences were noted at this weight. Also within the male and female calves, the only significant line difference was between the Prince and David male calves. The Prince males with a mean serum acid phosphatase level of 0.48 were significantly lower than the level of 0.63 Bodansky units recorded for the David males.

(c) At 700 Pounds: The mean acid phosphatase level at 700 pounds body weight was the same as that at 600 pounds body weight namely 0.57 Bodansky units per 100 ml. serum. A difference significant at the 5 per cent level was noted between males and females (Table 16). No other significant differences were observed either between the sexes within the various lines or within the sexes and between the lines.

Table 14

Mean Serum Acid Phosphatase Levels and Standard Deviations at 500, 600, 700 and 800 Pounds Body Weight

Group	Serum Acid Phosphatase (Bodansky units per 100 ml.)			
	at 500 lbs.	600 lb.	700 lb.	800 lb.
Lionheart Males	0.49 ± 0.26	0.58 ± 0.08	0.52 ± 0.11	0.64 ± 0.12
Lionheart Females	0.41 ± 0.11	0.57 ± 0.15	0.43 ± 0.09	0.53 ± 0.06
Prince Males	0.58 ± 0.15	0.48 ± 0.17	0.70 ± 0.20	0.60 ± 0.38
Prince Females	0.55 ± 0.12	0.60 ± 0.12	0.57 ± 0.13	0.55 ± 0.15
David Males	0.56 ± 0.13	0.63 ± 0.13	0.65 ± 0.18	0.63 ± 0.25
David Females	0.65 ± 0.10	0.67 ± 0.06	0.45 ± 0.17	0.62 ± 0.15
Hereford Males	0.55 ± 0.17	0.58 ± 0.14	0.63 ± 0.18	0.62 ± 0.25
Hereford Females	0.54 ± 0.13	0.61 ± 0.12	0.52 ± 0.14	0.56 ± 0.13
Angus Males	0.31 ± 0.08	0.50 ± 0.08	0.56 ± 0.15	0.62 ± 0.07
Angus Females	0.41 ± 0.16	0.52 ± 0.15	0.55 ± 0.21	0.36 ± 0.12
All Males	0.50 ± 0.18	0.56 ± 0.14	0.62 ± 0.17	0.62 ± 0.23
All Females	0.49 ± 0.16	0.58 ± 0.13	0.53 ± 0.17	0.48 ± 0.16
All Animals	0.48 ± 0.17	0.57 ± 0.13	0.57 ± 0.17	0.55 ± 0.21

(d) At 800 Pounds: At this weight the mean acid phosphatase level for all calves was 0.55 Bodansky units per 100 ml. serum. The only significant sex difference was that between the Angus males and females. No other significant differences, either sex or line, were recorded.

(e) Overall Relationship: When the acid phosphatase levels of the calves at the four weights were considered, no sex effect was observed (Table 24). But, there was a line effect significant at the 5 per cent level indicating that the lines differed significantly.

6. Serum Inorganic Phosphate.

(a) At 500 Pounds: For all animals, the mean serum inorganic phosphate level was 8.4 mg. per 100 ml. (Table 15). No sex differences were recorded and the only line difference was that between Prince females and Angus females. The inorganic phosphate level of the Prince females was 1.2 mg. per cent lower than the Angus female level of 8.9 mg. per 100 ml. ($P < 0.05$).

(b) At 600 Pounds: At this weight, the mean serum inorganic phosphate level was 8.2 mg. per 100 ml. for all animals. Males exhibited a significantly higher level than females ($P < 0.05$) (Table 16). No sex differences were recorded within the lines. In the comparisons

Table 15

Mean Serum Inorganic Phosphate Levels and Standard Deviations at 500, 600, 700 and 800 Pounds Body Weight

Group	Serum Inorganic Phosphate (mg. per 100 ml.)			
	at 500 lb.	600 lb.	700 lb.	800 lb.
Lionheart Males	8.2 ± 1.2	8.3 ± 0.7	7.9 ± 0.6	8.6 ± 0.6
Lionheart Females	8.0 ± 0.5	7.4 ± 0.3	7.7 ± 1.3	7.1 ± 1.1
Prince Males	8.6 ± 2.1	8.0 ± 0.9	8.3 ± 0.9	8.3 ± 1.1
Prince Females	7.7 ± 0.4	7.5 ± 1.0	8.0 ± 0.6	7.4 ± 0.7
David Males	8.5 ± 0.8	8.6 ± 0.8	8.8 ± 0.9	8.8 ± 1.0
David Females	8.7 ± 0.4	8.7 ± 0.6	8.7 ± 1.1	9.4 ± 0.1
Hereford Males	8.5 ± 1.3	8.4 ± 0.8	8.4 ± 0.9	8.6 ± 1.0
Hereford Females	8.0 ± 0.9	7.7 ± 1.0	8.1 ± 0.9	7.7 ± 1.1
Angus Males	8.0 ± 1.0	8.8 ± 0.7	8.2 ± 0.3	7.4 ± 0.2
Angus Females	8.9 ± 1.3	8.0 ± 0.9	8.1 ± 0.9	8.2 ± 0.8
All Males	8.4 ± 1.2	8.4 ± 0.8	8.4 ± 0.8	8.4 ± 1.0
All Females	8.3 ± 1.0	7.8 ± 0.9	8.1 ± 0.9	7.9 ± 1.0
All Animals	8.4 ± 1.1	8.2 ± 0.9	8.2 ± 0.9	8.2 ± 1.0

Table 16

Analysis of Variance of the Performance and Blood Constituent Data

	Mean Square			
	Error	Line	Sex	Line x Sex Interaction
Degrees of Freedom	44	3	1	3
Age at 500 Pounds	684.88	340.79	15171.18**	35.83
Rate of Gain	.09	.00	27.96**	.07
Feed Efficiency	8840.77	4335.11	46486.71*	12258.24
Alkaline Phosphatase				
at 500 pounds	3.03	.37	4.10	2.58
600 pounds	2.87	.00	.81	.21
700 pounds	1.61	.14	18.25**	.19
800 pounds	2.12	.02	24.61**	.14
Acid Phosphatase				
at 500 pounds	.02	.00	.01	.00
600 pounds	.02	.00	.02	.01
700 pounds	.03	.00	.12	.01
800 pounds	.04	.00	.12	.02
Inorganic Phosphate				
at 500 pounds	1.25	.15	.00	.01
600 pounds	.69	.45	2.97*	.37
700 pounds	.69	.22	.33	.00
800 pounds	.74	.32	.70	.00

between the female calves of the different lines, the Prince female level of 7.5 mg. per 100 ml. was significantly lower than that of 8.7 mg. per 100 ml. for the David females ($P < 0.05$). No other line differences were found within either of the two sexes.

(c) At 700 Pounds: Again at this weight practically no significant differences were observed. The mean level for all calves was 8.2 mg. per cent phosphorus (Table 15) and the only significant difference was between the Lionheart and David males. The David males had a level of 8.8 mg. per 100 ml. which was significantly higher than the level of 7.9 mg. per 100 ml. for the Lionheart males ($P < 0.05$).

(d) At 800 Pounds: There was little variation in the mean level of inorganic phosphate for all calves, the level at 800 pounds body weight being 8.2 mg. per 100 ml. The Lionheart males had a significantly higher inorganic phosphate level than the level of 7.1 mg. per 100 ml. for the Lionheart females ($P < 0.05$).

In the comparisons between the male calves of the different lines, the Lionheart male level of 8.6 mg. per 100 ml. was significantly higher than the Angus level of 7.4 mg. per 100 ml. ($P < 0.05$). The David males also had a higher level than the Angus males ($P < 0.01$).

Within the female calves, both the Prince and David females were significantly higher in their inorganic phosphate level than Lionheart females ($P < 0.01$). The David females also had a higher level than the Angus females with a mean level of 8.2 mg. per 100 ml. This difference was significant at the 5 per cent level.

(e) Overall Relationship: When the serum inorganic phosphate levels of the calves were pooled so that the overall sex and line effects could be observed, there was no effect of sex. However, the line effect was significant at the one per cent level (Table 24).

7. Correlations Between the Performance Data.

Simple correlations were calculated between the three performance criteria (Table 17). Rate of gain was found to be negatively related with feed per unit of gain. The negative correlation coefficient of -0.80 was significant at the one per cent level. Rate of gain was also negatively correlated with age at 500 pounds body weight (Table 17).

Feed consumption per unit of gain was positively related to age at 500 pounds body weight.

Table 17

Correlation Coefficients Between Rate of Gain, Feed Consumption per 100 Pounds Gain and Age at 500 Pounds Body Weight

	Feed Consumption Per Unit Gain	Age at 500 Pounds
Rate of Gain	-.80**	-.24
Feed Consumption per Unit Gain		.26

**Significant at the one per cent level.

8. Correlations Between the Blood Constituent Data.

The serum alkaline phosphatase levels at the four weights of 500, 600, 700 and 800 pounds body weight were positively correlated with each other (Table 18). The correlation coefficient of 0.35 between the level at 500 pounds body weight and that at 700 pounds body weight was significant at the five per cent level. The alkaline phosphatase activity at 700 pounds body weight was also correlated with the levels at 600 and 800 pounds body weight. These two correlation coefficients of 0.36 and 0.50 were significant at the one per cent level.

The serum acid phosphatase levels at the four body weights did not show the same consistency as the alkaline phosphatase (Table 19). No significant correlations were observed.

The inorganic phosphate levels were rather more consistent than the alkaline phosphatase, significant

Table 18

Correlation Coefficients Between the Alkaline Phosphatase Levels at 500, 600, 700, and 800 Pounds Body Weight

	Alkaline Phosphatase Level at		
	600	700 (pounds)	800
Alkaline Phosphatase Level at			
500 Pounds	.18	.35*	.26
600 Pounds		.36**	.25
700 Pounds			.50**

* Significant at the 5 per cent level.
** Significant at the 1 per cent level.

Table 19

Correlation Coefficients Between the Acid Phosphatase Levels at 500, 600, 700 and 800 Pounds Body Weight

	Acid Phosphatase Level at		
	600	700 (pounds)	800
Acid Phosphatase Level at			
500 Pounds	.10	.08	.11
600 Pounds		-.20	.13
700 Pounds			.12

correlations being recorded between the levels at every body weight except at 500 and 700 pounds body weight (Table 20).

Table 20

Correlation Coefficients Between the Serum Inorganic Phosphate Levels at 500, 600, 700 and 800 Pounds Body Weight

	Serum Inorganic Phosphate Level at		
	600 Pounds	700 Pounds	800 Pounds
Serum Inorganic Phosphate Level at			
500 Pounds	.34*	.23	.53**
600 Pounds		.42**	.38**
700 Pounds			.31*

** Significant at the one per cent level.
* Significant at the five per cent level.

At 500 pounds body weight, a correlation coefficient of -0.46 was recorded between the alkaline phosphatase and inorganic phosphate levels. This was significant at the one per cent level. Practically no correlation was observed between the alkaline phosphatase activity and the acid phosphatase activity at this weight. A low correlation of -0.21 was observed between acid phosphatase activity and inorganic phosphate level (Table 21).

At 600 pounds body weight, the blood constituents were all closely interrelated. A correlation coefficient

Table 21

Correlation Coefficients Between the Serum Alkaline Phosphatase, Acid Phosphatase and Inorganic Phosphate Levels at 500, 600, 700 and 800 Pounds Body Weight

	Acid Phosphatase	Inorganic Phosphate
(a) 500 Pounds		
Alkaline Phosphatase	.03	-.46**
Acid Phosphatase		-.21
(b) 600 Pounds		
Alkaline Phosphatase	.55**	.33*
Acid Phosphatase		-.79**
(c) 700 Pounds		
Alkaline Phosphatase	-.01	-.82**
Acid Phosphatase		.58**
(d) 800 Pounds		
Alkaline Phosphatase	.36**	-.06
Acid Phosphatase		.09

** Significant at the one per cent level.

* Significant at the five per cent level.

of 0.55 was recorded between the alkaline and acid phosphatase levels ($P < 0.01$). The alkaline phosphatase activity was significantly correlated with the inorganic phosphate level ($P < 0.05$) (Table 21). Acid phosphatase activity was very closely and inversely related to inorganic phosphate level ($r = -.79$, which was significant at the one per cent level).

Again, at 700 pounds body weight, no relationship was observed between the alkaline and acid phosphatase activities. This was reminiscent of the lack of relationship at 500 pounds body weight. Alkaline phosphatase was significantly and negatively related to the inorganic phosphate level ($r = -.82$, Table 21). The acid phosphatase level was positively related to the inorganic phosphate level ($r = .58$).

The situation was reversed at 800 pounds body weight. At this weight the alkaline and acid phosphatase levels were significantly and positively correlated but almost no correlation was observed between either of these two constituents and inorganic phosphate.

9. Correlations Between the Blood Constituent and Performance Data.

(a) Rate of Gain: Rate of gain on feed test was positively correlated with alkaline phosphatase activity at 500 pounds body weight (r = .40, Table 22). However, at 600 pounds body weight, there was no correlation between rate of gain and alkaline phosphatase activity. At 700 and 800 pounds body weight, significant correlations of .35 and .34 were recorded between rate of gain and alkaline phosphatase activity.

Rate of gain was slightly correlated with the acid phosphatase level at 500 pounds body weight (r = .21) and at 600 and 700 pounds virtually no correlations were observed. However, at 800 pounds, a significant correlation between rate of gain and acid phosphatase activity was recorded (r = .47).

A negative correlation of -.27 was observed between rate of gain and inorganic phosphate level at 500 pounds body weight. At 600, 700, and 800 pounds body weight, positive correlations were observed between rate of gain and the inorganic phosphate level but none were significant.

(b) Feed Consumption per Unit Gain: Feed consumption per unit of gain was inversely related to the alkaline phosphatase levels at all four weights. At 500 pounds body weight, a correlation coefficient of -.23 was recorded. At 600 pounds body weight there was virtually no relationship between feed consumption per unit gain and the alkaline phosphatase level. As seen with the

Table 22

Correlations Between the Blood Constituent and Performance Data

	Rate of Gain	Feed Consumption Per Unit Gain	Age at 500 Pounds
Alkaline Phosphatase at			
500 pounds	.40**	-.23	.04
600 pounds	.09	-.05	-.08
700 pounds	.35*	-.28*	-.13
800 pounds	.34*	-.36**	-.27
Acid Phosphatase at			
500 pounds	.21	-.23	.34*
600 pounds	.06	-.05	.11
700 pounds	.13	-.17	-.01
800 pounds	.47**	-.47**	-.05
Inorganic Phosphate at			
500 pounds	-.27	.21	-.26
600 pounds	.27	-.24	-.27*
700 pounds	.21	-.24	-.15
800 pounds	.16	-.11	.19

** Significant at the 1 per cent level.

* Significant at the 5 per cent level.

correlations between rate of gain and alkaline phosphatase level, there was a significant correlation at 700 pounds and at 800 pounds body weight. The correlations of -.28 and -.36 were significant at the 5 and 1 per cent levels.

When feed consumption per unit of gain was considered in relation to acid phosphatase level a somewhat similar pattern was observed. There was a consistent inverse relationship between the two sets of data. At 500 pounds, a correlation of -.23 was found which fell off to one of -.05 at 600 pounds body weight. At 700 pounds there was a correlation coefficient of -.17, and at 800 pounds there was a correlation coefficient of -.47 which was significant at the one per cent level.

The relationship of feed per unit gain with the inorganic phosphate level was not as consistent as that between the phosphatases and feed consumption per unit of gain. At 500 pounds body weight, a positive correlation of 0.21 was observed while at subsequent weights, there was a negative relationship. At both 600 and 700 pounds body weight there was a correlation coefficient of -.24 but at 800 pounds, there was a lower correlation of -.11.

(c) Age at 500 Pounds Body Weight: Age at 500 pounds body weight bore little relationship to the alkaline phosphatase levels at 500 and 600 pounds body weight.

There was a low inverse correlation of age at 500 pounds body weight with alkaline phosphatase level of -.13 at 700 pounds body weight and a larger one of -.27 at 800 pounds body weight (Table 22).

The acid phosphatase level at 500 pounds body weight was positively and significantly related to age at 500 pounds body weight ($P < 0.05$). There was a much lower positive correlation of age at 500 pounds body weight with acid phosphatase level of 0.11 at 600 pounds body weight and at 700 and 800 pounds, very low negative relationships were observed.

At 500, 600 and 700 pounds body weight serum inorganic phosphate was inversely related to age at 500 pounds. However, at 800 pounds body weight there was a positive relationship.

10. Regression Coefficients Between the Blood Constituent and Performance Data.

The regression coefficients between the blood constituents as the independent variable and the performance characteristic as the dependent variable are presented in Table 23. It is only proposed to consider in any detail the regression coefficients corresponding to the significant correlation coefficients reported in Table 22.

(a) Rate of Gain: At 500 pounds body weight,

Table 23

Regression Coefficients and Their 95 Per Cent Confidence Intervals of the Performance Criteria and the Blood Constituents

x / y	Rate of Gain[1]	Feed Efficiency[2]	Age at 500 Pounds[3]
Inorganic Phosphate			
at 500 pounds	-.10 ± .73	+ 30.69 ± 283.01	-83.34 ± 61.47
600 pounds	.13 ± .90	- 43.18 ± 350.06	-10.77 ± 76.32
700 pounds	.10 ± .97	- 45.78 ± 371.75	- 9.68 ± 81.97
800 pounds	.07 ± .82	- 16.77 ± 315.80	6.40 ± 68.66
Acid Phosphatase			
at 500 pounds	.59 ± 4.85	-217.06 ± 1854.33	70.04 ± 394.54
600 pounds	.19 ± 6.34	- 62.01 ± 2440.98	29.63 ± 534.32
700 pounds	.32 ± 4.86	-157.23 ± 1858.43	- 2.81 ± 414.71
800 pounds	.93 ± 3.57	-362.25 ± 1368.91	- 9.16 ± 340.98
Alkaline Phosphatase			
at 500 pounds	.10 ± .45	- 21.75 ± 182.42	0.88 ± 41.24
600 pounds	.02 ± .52	- 5.39 ± 201.41	- 1.68 ± 44.24
700 pounds	.11 ± 1.86	- 33.80 ± 232.09	- 3.32 ± 52.79
800 pounds	.09 ± .49	- 34.86 ± 187.78	- 5.95 ± 42.61

[1] Pounds per day increase in rate of gain for each increase of one Bodansky unit or each mg. in the case of inorganic phosphate.

[2] Increase in pounds of feed consumed for each 100 pounds gained resulting from each increase of one Bodansky unit or each mg. phosphate.

[3] Number of days older at 500 pounds body weight for each increase of one Bodansky unit or one mg. phosphate per 100 ml.

average rate of gain increased 0.10 pound per day for each increase in alkaline phosphatase activity of one Bodansky unit. At 700 pounds body weight, the average rate of gain could be expected to increase 0.11 pound per day for each increase of one Bodansky unit in alkaline phosphatase activity. An increase of one Bodansky unit in alkaline phosphatase activity at 800 pounds body weight would, on the average, result in an increase of 0.09 pound in the daily rate of gain.

Each increase of one Bodansky unit in acid phosphatase level at 800 pounds body weight was associated with an average increase in rate of gain of 0.93 pound per day.

(b) Feed Consumption per Unit Gain: An increase of one Bodansky unit in alkaline phosphatase level at 700 pounds body weight could be expected to be associated with an average decrease in feed consumption of 33.80 pounds for each 100 pounds of gain. At 800 pounds body weight, an increase of one Bodansky unit in alkaline phosphatase activity would result in a decrease of 35.86 pounds in feed consumption per unit gain.

For every increase in acid phosphatase activity of one Bodansky unit at 800 pounds body weight, there was a corresponding average decrease of 362.25 pounds of feed consumed per 100 pounds gain.

(c) Age at 500 Pounds: An increase of one Bodansky unit in acid phosphatase activity at 500 pounds body weight was associated with an increase in the age of the calf at 500 pounds of 70.04 days.

Each increase in the serum inorganic phosphate level of one mg. per 100 ml. at 600 pounds was paralleled by a decrease of 10.77 days in the age at 500 pounds.

(d) Overall Relationship: As with the calves during the suckling period, the overall relationship between line, sex, performance characteristics and each of the blood constituents was studied in a least squares analysis. In this, each observation was assumed to be the sum of the influences of other variables as follows:

$$Y_{ijk} = M + S_i + L_j + A_k + Bx_{1ijk} + Cx_{2ijk} + Dx_{3ijk} + e_{ijk}$$

where Y_{ijk} = the observation on the blood constituent

M = the overall effect

S_i = the added effect of the ith sex

L_j = the added effect of the jth line

A_k = the added effect of the kth sample

B = a proportionality constant which measures the rate of change of the blood constituent with age at 500 pounds body weight

x_1 = age at 500 pounds body weight

C = a proportionality constant which measures the rate of change of the blood constituent with rate of gain

x_2 = rate of gain

D = a proportionality constant which measures the rate of change of the blood constituent with feed consumption per 100 pounds gain

x_3 = feed consumption per 100 pounds gain

e_{ijk} = random error

The mean squares for the line, sex, age at 500 pounds, rate of gain and feed consumption per unit of gain are presented in Table 24.

When all the alkaline phosphatase analyses done on each animal are considered in an overall statistical analysis, rate of gain exerts a significant effect. There was an overall difference between lines in acid phosphatase and serum inorganic phosphate level. Age at 500 pounds body weight was significantly related to the inorganic phosphate level

11. Additional Examination of the Relationship Between the Blood Constituent and Performance Data.

There have been demonstrated quite a number of instances where a blood constituent at a particular weight was correlated significantly with one of the performance

Table 24

Analysis of Variance of the Blood Constituent Data When Observations at All Weights Are Considered for the Calves in the Test Pens

	Degrees of Freedom	Mean Squares		
		Alkaline Phosphatase	Acid Phosphatase	Serum Inorganic Phosphate
Sex Effect	1	7.50	.00	.18
Line Effect	3	2.87	2.95*	5.73**
Age at 500 Pounds	1	0.77	.01	5.76**
Rate of Gain	1	10.22*	.04	.09
Feed Consumption per Unit Gain	1	.17	.01	.28
Error	197	1.97	.02	.25

** Significant at the one per cent level.

* Significant at the 5 per cent level.

criteria. In order to examine these relationships more particularly, a least square analysis was set up as follows:

$$Y_{ij} = M + S_i + Bx_{1i} + Cx_{2i} + Dx_{3i} + e_{ij}$$

where Y_{ij} = the observation on the blood constituent of the *jth* calf

M = the overall effect

S_i = the added effect of the *ith* sex

B = a proportionality constant measuring the change of the blood constituent with age at 500 pounds body weight

x_1 = age at 500 pounds body weight

C = a proportionality constant measuring the change of the blood constituent with rate of gain

x_2 = rate of gain

D = a proportionality constant measuring the change of the blood constituent with feed consumption per 100 pounds gain

x_3 = feed consumption per 100 pounds gain

e_{ij} = random error

Since the line effect and line x sex interaction were shown to have no significant effect (Table 16) they were not included in this analysis. The mean squares for the effects studied are presented in Table 25. They

Table 25

Analysis of Variance of the Blood Constituents of the Performance Tested Calves

	Mean Squares				
	Error	Sex	Rate of Gain	Feed Consumption Per Unit Gain	Age at 500 Pounds
Degrees of Freedom	47	1	1	1	1
Alkaline Phosphatase					
at 500 pounds	2.58	.05	18.02*	2.22	2.39
600 pounds	2.72	.85	.28	.49	.07
700 pounds	1.48	9.30*	1.29	1.45	.74
800 pounds	3.09	.58	.35	1.30	2.57
Acid Phosphatase					
at 500 pounds	.02	.00	.01	.04	.20*
600 pounds	.02	.01	.00	.00	.01
700 pounds	.03	.08	.01	.00	.02
800 pounds	.04	.00	.05	.06	.01
Inorganic Phosphate					
at 500 pounds	.99	2.04	3.06	.76	3.73
600 pounds	.69	.83	.23	.06	.77
700 pounds	.64	.23	.04	.58	1.33
800 pounds	.99	1.11	.29	.58	.38

* Significant at the 5 per cent level.

demonstrate that there was a significant relationship between rate of gain and the alkaline phosphatase level when sex, age at 500 pounds, and feed consumption per unit gain were held constant. Also at 700 pounds body weight, there is a significant sex effect on the alkaline phosphatase levels, with rate of gain, age at 500 pounds and feed consumption per unit gain held constant.

At 500 pounds, there was a significant relationship between acid phosphatase and age at 500 pounds body weight, when sex, rate of gain and feed consumption were held constant.

Since the relationship of the alkaline phosphatases at the four weights to rate of gain was of interest the least squares analysis was varied so that the effect of different combinations of the covariants could be observed. Thus the relationship between the alkaline phosphatases and rate of gain with sex held constant was observed. Similarly sex and feed consumption per unit of gain were held constant, then sex and age at 500 pounds body weight.

Because of the type of analysis used, the performance criteria were used as the independent variables so that the regression coefficients shown in Table 26 should not be compared with those in Table 23 where the blood constituents were used as the independent variables in those linear regressions. However, the partial regression coefficients and the 95 per cent confidence limits serve to illustrate the reliability of the estimates and the influence of one covariable on another.

The relationship between the alkaline phosphatase and rate of gain was significant either at the one or five per cent level in each case. By comparison, the significant relationship between rate of gain and the alkaline phosphatase levels at 700 and 800 pounds body weight existing when linear regression was used were no longer present when sex was held constant. This would suggest that the relationship at these two weights was sex-dependent (Table 26).

A comparison of the partial regression coefficients between the alkaline phosphatase level at 500 pounds body weight and rate of gain indicated that holding sex constant did not change the direction of the regression line materially but increased markedly the reliability of the estimate. Holding sex and age at 500 pounds constant did not further improve the reliability of the estimate. However, when feed consumption was also held constant, there was a marked influence on the value of the partial regression coefficient and an increase in the variance.

From this it would appear that a fairly reliable estimate of the relationship between alkaline phosphatase and rate of gain could be obtained by using a regression

Table 26

Regression Coefficients and Their 95 Per Cent Confidence Intervals of the Serum Alkaline Phosphatase Levels at 500, 600, 700 and 800 Pounds Body Weight on Rate of Gain With Certain Variables Held Constant

x/y	Serum Alkaline Phosphatase at			
	500 pounds	600 pounds	700 pounds	800 pounds
Rate of Gain	1.66 ± 7.67**	.33 ± 7.76	1.13 ± 6.08*	1.30 ± 7.35*
Rate of Gain (with sex constant)	1.99 ± 1.48**	.05 ± 1.50	.27 ± 1.12	.64 ± 1.40
Rate of Gain (with sex and feed economy constant)	2.47 ± 1.87*	.29 ± 1.91	.67 ± 1.43	.30 ± 1.78
Rate of Gain (with sex and age at 500 pounds constant)	1.92 ± 1.47*	.06 ± 1.54	.24 ± 1.16	.71 ± 1.43
Rate of Gain (with sex, feed economy and age at 500 pounds constant)	2.43 ± 1.86*	.30 ± 1.91	.65 ± 1.41	.34 ± 2.03

equation incorporating the sex effect and the age-at-500-pounds effect.

C. Adult Cows

The data collected from the adult cows in November, 1957, were subdivided according to line and age. Since there were no animals of a particular age group in some of the lines, the data in Tables 27, 28 and 29 are classified only by age and breed. However, a least squares analysis of the data was used as follows:

$$Y_{ijk} = M + L_i + A_j + e_{ijk}$$

where Y_{ijk} = the observation of the blood constituent on the k<u>th</u> cow

M = the overall effect

L_i = the added effect of the i<u>th</u> line

A_j = the added effect of the j<u>th</u> age group

and e_{ijk} = random error.

In this analysis, all four lines were considered and the cows over five years of age were grouped together since there didn't appear to be any marked age differences after this age.

A further analysis was made of the data in which only the effect of age was considered. The results of these analyses are presented in Tables 30 and 31.

Table 27

Mean Serum Alkaline Phosphatase Levels and Standard Deviations of the Cows

	Hereford Cows		Angus Cows		All Cows	
Age	No. of Animals	Serum Alkaline Phosphatase (Bu./100 ml.)	No. of Animals	Serum Alkaline Phosphatase (Bu./100 ml.)	No. of Animals	Serum Alkaline Phosphatase (Bu./100 ml.)
2	13	3.43 ± 0.85	10	3.68 ± 1.73	23	3.54 ± 1.28
3	5	2.46 ± 0.33	5	3.05 ± 0.59	10	2.76 ± 0.55
4	9	2.19 ± 0.55	2	2.03 ± 0.68	11	2.16 ± 0.54
5	3	2.81 ± 0.77	2	1.46 ± 0.58	5	2.27 ± 0.96
6	2	1.71 ± 0.71	4	1.70 ± 0.46	6	1.71 ± 0.48
7	4	1.79 ± 0.14	0		4	1.79 ± 0.14
8	4	1.78 ± 0.35	1	1.92	5	1.81 ± 0.31
8	2	1.54 ± 0.24	1	1.99	3	1.69 ± 0.31

Table 28

Mean Serum Acid Phosphatase Levels and Standard Deviations of the Cows

Age	Hereford Cows		Angus Cows		All Cows	
	No. of Cows	Acid Phosphatase (Bu./100 ml.)	No. of Cows	Acid Phosphatase (Bu./100 ml.)	No. of Cows	Acid Phosphatase (Bu./100 ml.)
2	13	0.37 ± 0.26	10	0.32 ± 0.09	23	0.35 ± 0.20
3	5	0.45 ± 0.09	5	0.47 ± 0.24	10	0.46 ± 0.16
4	9	0.51 ± 0.21	2	0.37 ± 0.24	11	0.48 ± 0.21
5	3	0.33 ± 0.05	2	0.41 ± 0.26	5	0.36 ± 0.14
6	2	0.42 ± 0.25	4	0.26 ± 0.37	6	0.31 ± 0.15
7	4	0.35 ± 0.05	0		4	0.35 ± 0.05
8	4	0.46 ± 0.13	1	0.20	5	0.40 ± 0.16
8	2	0.32 ± 0.16	1	0.37	3	0.33 ± 0.12

Table 29

Serum Inorganic Phosphate and Standard Deviations of the Cows

Age	Hereford Cows		Angus Cows		All Cows	
	No.	Inorganic Phosphate (Mg. P/100 ml.)	No.	Inorganic Phosphate (Mg. P/100 ml.)	No.	Inorganic Phosphate (Mg. P/100 ml.)
2	13	7.01 ± 0.72	10	7.11 ± 0.87	23	7.05 ± 0.77
3	5	6.43 ± 1.21	5	7.07 ± 0.57	10	6.75 ± 0.95
4	9	5.95 ± 0.68	2	5.41 ± 0.02	11	5.85 ± 0.64
5	3	5.75 ± 0.94	2	5.79 ± 1.73	5	5.77 ± 1.10
6	2	4.58 ± 0.23	4	6.46 ± 1.00	6	5.83 ± 1.25
7	4	5.08 ± 0.92	0		4	5.08 ± 0.92
8	4	5.10 ± 0.59	1	5.28	5	5.13 ± 0.49
8	2	4.02 ± 0.42	1	5.24	3	4.42 ± 0.77

Table 30

Analysis of Variance of the Blood Constituent Data of the Adult Cows

	Mean Squares		
	Error	Line	Age Group
Degrees of Freedom	59	3	4
Alkaline Phosphatase	.79	.19	11.09**
Acid Phosphatase	.03	.03	1.81
Inorganic Phosphate	.67	2.39*	12.58**

** Significant at the one per cent level.

* Significant at the five per cent level.

Table 31

Further Analysis of Variance of the Blood Constituent Data of the Adult Cows

		Years of Age			
	Error	2-3	3-4	4-5	5-
Degrees of Freedom	62	1	1	1	1
Alkaline Phosphatase	.76	4.24*	1.89	.04	1.05
Acid Phosphatase	.03	.09	.03	.05	.00
Inorganic Phosphate	.76	.65	4.22*	.23	1.11

* Significant at the five per cent level.

1. Serum Alkaline Phosphatase.

The mean serum alkaline phosphatase activity of the two-year-old cows was 3.54 Bodansky units (Table 27). There were no line differences observed in alkaline phosphatase level (Table 30). However, two-year-old cows had significantly higher levels than the three-year-old cows ($P < 0.05$). There were no significant differences between the levels of phosphatase activity among the older cows.

2. Serum Acid Phosphatase.

The mean serum acid phosphatase activity level of all two-year-old cows was 0.35 Bodansky units per 100 ml. (Table 28). There were no age or line effects observed in this blood constituent.

3. Serum Inorganic Phosphate.

The mean serum inorganic phosphate level of all cows at two years of age was 7.05 mg. per 100 ml. serum and that of the cows over eight years was 4.42. There was a significant difference between lines ($P < 0.05$) and also a significant difference between age groups ($P < 0.01$). The three year old cows had a mean level of 6.75 mg. per 100 ml. which was significantly higher than the four year old level of 5.85 mg. per 100 ml. ($P < 0.05$, Table 31).

D. Overall Relationship

The values reported for the three blood constituents during the suckling period, the feed test period and in the adult cows have been pooled and in Figure 1 a graphical presentation of the data is given. This demonstrates the changes in the blood constituents with age and shows how the data on the three different groups of animals used combine into an overall relationship. The continuity in the levels observed suggests that the data obtained from each group of animals are indicative of the information to be expected from a comparable group under the same conditions and that it is not peculiar to that particular group of individuals alone.

The graph for the serum alkaline phosphatase level shows initially a very sharp decline with age in the first year of life with a subsequent slow decline to a fairly constant level at maturity. The serum acid phosphatase does not show any consistent relationship with age. The serum inorganic phosphate level rose to a peak at three months of age and declined steadily to 9 years of age.

DISCUSSION

The phenotypic expression of a certain character at any stage in the lifetime of a given individual may be viewed as the combined result of its genetic constitution and the environment in which it develops and lives. Some traits are greatly influenced by environmental factors and so are comparatively plastic, whereas some are remarkably resistant to outside influence. Enzyme and metabolic systems represent the individual's mechanism for adaptation or non-adaptation to the influence of environment. In this discussion, the data accumulated will be considered in relation to various factors both genetic and environmental and their influences evaluated.

1. Sex.

A search of the literature revealed that slight or no sex differences in serum alkaline and acid phosphatase or inorganic phosphate level have been recorded (8, 22) so that some evaluation of the sex differences reported in this study should be made. The differences in the present study appeared towards the end of the feed test period. One possible explanation of these sex differences is that they were produced by examining the levels at constant weights rather than at constant ages. This would not influence the animals at 500 and 600 pounds body weight where the age ranges of the two sexes were similar (Table 12). When the calves had reached 700 and 800 pounds body weight, there was quite a marked difference in the average age of the two sexes and little overlap in their age ranges. At 500 pounds body weight, the mean ages and age ranges were 243 (195-284) days for males and 259 (196-334) for the females. These differences increased until at 800 pounds body weight, the mean ages and ranges were 355 (290-422) days for the males and 405 (328-479) days for females.

If there were no sex differences existing between the calves and the only differences were due to the sampling at different ages, then the regression coefficients of the blood constituent level on age at sampling for the two sexes should be similar. In the case of serum alkaline phosphatase, both regression coefficients calculated were not significantly different from zero indicating that there was no relationship between age and serum alkaline phosphatase level. Thus the differences in serum alkaline phosphatase activity while the calves were on feed test were not the result of sampling at different ages but were actually related to their size and hence rate of gain. However, in the case of the serum acid phosphatase levels for the calves while they were in the test pens, those of the female calves were found not to vary with age. There was a significant effect of age on the acid phosphatase levels of the male calves (b = 0.0012). Thus some of the sex differences observed in the level of serum acid phosphatase at the different sampling weights during the feed test period might be attributed to sampling at different ages.

The serum inorganic phosphate levels of the male calves while in the test pens were found not to vary with age during the feed test period but there was a steady decline with age in the case of the female calves. The regression coefficient of -0.0049 for the female calves was significant at the one per cent level. This indicated that any difference between male and female calves in serum inorganic phosphate level could have been due partly to the effect of age on the female calves.

It was significant that the onset of sex differences in the blood constituents was somewhat later than the appearance of sex differences in the performance characteristics. This might be due to a number of factors one of which is that these blood constituents may not be very closely associated with sex but are related to characters which are themselves modified by sex. It would appear that they are not particularly sensitive indicators of sex differences.

2. Line.

When serum alkaline phosphatase activity was examined for line differences, the David females were found to have higher levels at birth than the Angus females. The Lionheart and Prince males had higher levels at three months of age than Angus males and the Lionheart females had higher levels than the David females. At six months of age the Angus females were found to have significantly higher levels than the Lionheart and David females.

No differences were found between the various lines in serum alkaline phosphatase activity at 500, 600 or 700 pounds body weight. At 800 pounds body weight, the Angus males were found to have significantly higher alkaline phosphatase levels than either the Prince or David males.

In the adult animals, no line differences were observed in serum alkaline phosphatase activity.

While line differences appeared to exist at various times, no consistent pattern was demonstrated so that these differences should be interpreted with caution. Working with this herd in 1956, Alexander and co-workers (1) were unable to demonstrate line differences in serum alkaline phosphatase level at 800 pounds body weight. Also Kunkel and co-workers (14) found no difference in serum alkaline phosphatase activity between Angus, Hereford, Jersey and Holstein cattle.

Some line differences were observed in serum acid phosphatase activity at 500 and 600 pounds body weight. However, in general, no consistent line differences could be demonstrated for this blood constituent. Similarly many line differences in serum inorganic phosphate level have also been demonstrated but there was no consistent pattern emerging to suggest a distinct line difference throughout life. It might be that these line differences at the various stages in growth were real but larger numbers of individuals would have to be sampled for much reliance to be placed on these differences.

When one considers that these lines each of only a few individuals have been closed to outside introductions for at least seven years and that there has been a high turnover of bulls used it is rather surprising that the differences between the lines were not more marked. It would seem that both serum alkaline and acid phosphatase production are well buffered against the effect of inbreeding consequent on such small population sizes. It might be that the selection pressures for rate of gain and feed efficiency may counterbalance any effect of inbreeding and the tendency to homozygosity. Also the inbreeding may not have yet progressed to the extent where it would exert any effect on the production of these enzymes. Of course, inbreeding may not produce any such effect.

However, since modern theories of enzyme synthesis postulate a genetic control, it would seem reasonable to expect that alterations to the genetic make-up of an individual would result in an alteration to its enzymatic balances. Since ribose nucleic acid appears to be associated with protein synthesis (10) and hence alkaline phosphatase production, the genetic control may be only very indirect and therefore marked changes in the genetic constitution of the individual may be necessary before phosphatase activity is affected.

3. Growth.

A steady decline in serum alkaline phosphatase activity with age is apparent with little change after four years of age (Figure 1). This general decline with age is in keeping with the observations of Kunkel and co-workers (14) who found little change in the levels of cows between three and nine years of age. In man, there is a rise in the first four months of life and then a steady decline to a standard level after puberty (21). It is possible that sampling the calves during the first week of life and then at three months of age missed a peak in the serum alkaline phosphatase activity between those two ages. Another possibility is that a peak does not occur in calves but there is merely a steady decline in level from birth.

The serum inorganic phosphate level of the calves was at a maximum at three months of age (Figure 1). As the animals grew older there was a steady decline in the level. While in man a similar peak is observed at four to six months of age, the inorganic phosphate level stabilizes at a lower level during childhood with an abrupt drop at puberty to the adult level (21). The sampling in this study was too infrequent to demonstrate whether a similar trend at puberty exists in beef cattle.

4. Diet.

In this study, no direct assessment of the effect of diet was made but, of necessity, the diet was changed throughout the sampling periods. For this reason the effect of diet on the values obtained should be considered.

There was considerable variation in the serum alkaline phosphatase levels in the calves during the first week of life. It has been well established that fat ingestion in rats is associated with an increased serum alkaline phosphatase activity (9). On this basis, a possible cause for the extreme variation found in the calves during the first week of life might be the fat content of the milk in the diet. Calves bled shortly after suckling would be found to have higher alkaline phosphatase activities than calves bled when they had not suckled for some time. Supporting this view is the reduced variability in the serum alkaline phosphatase activity of the calves at three and six months of age when milk was making a smaller contribution to the total diet.

The calves in the test pens had a standard diet to eliminate any effect of change in the levels of the various nutrients during the performance test period. The diet was considered adequate in all nutrients and was fed ad libidum (18). This facilitates the study of non-dietary factors on the various blood constituents. In addition the calves were usually in the test pens for a month or more before they reached 500 pounds body weight so that adequate time was allowed for adjustment to the new diet and conditions. Similarly the adult cows had all been fed grass silage for over a month before sampling so that any effect of diet on the blood constituents had been stabilized. For these reasons, differences have been observed in this study which may not be found where dietary control is not so rigid and variation due to diet masks that due to other factors.

5. Rate of Gain.

It was not possible to demonstrate any significant correlations between the blood constituents and the growth criteria of the calves during the suckling period.

However, when the feed test calves were considered significant correlations were obtained between rate of gain and serum alkaline phosphatase level at 500, 700 and 800 pounds and serum acid phosphatase level at 800 pounds body weight. Since these correlations could have been produced by sex differences or by correlated effects of age or feed consumption per unit gain, these effects were examined in a multiple regression model. This examination indicated that only at 500 pounds body weight was the serum alkaline phosphatase activity significantly and directly related to rate of gain. An examination of the mean squares for each independent variate in Table 25 showed the degree of relationship each variable had with the particular blood constituent. At 700 pounds body weight, the direct relationship of sex with serum alkaline phosphatase level was significant with the next largest mean square being that of feed consumption per unit gain. Age at 500 pounds body weight was more closely associated with serum alkaline phosphatase level at 800 pounds body weight than any of the other independent variables. When the mean squares associated with serum acid phosphatase level at 800 pounds body weight were considered, it could be seen that rate of gain and feed consumption per unit gain were approximately equally related to the serum acid phosphatase level.

By reference to Table 26, it would be seen that the bulk of the association of rate of gain with the serum alkaline phosphatase levels at 700 and 800 pounds was sex-dependent.

This change in relationship with age indicates some interesting aspects. It is possible that there was no association of rate of gain with the blood constituents during the suckling period. However, the other possibility is that there was an association but that it was masked by variations due to other causes. The appearance of a highly significant association between serum alkaline phosphatase level at 500 pounds body weight and rate of gain would suggest that the latter possibility would seem more likely. When the calves were on a standard diet and under uniform conditions in the test pens, the variation in the blood constituents was reduced sufficiently for the association with rate of gain of serum alkaline phosphatase level to be demonstrated. This association was lost at 600 pounds body weight and at 700 and 800 pounds body weight, most of the relationship between serum alkaline phosphatase level and rate of gain was associated with sex differences. This indicates a change in the metabolic pattern of the calves while they were in the test pens.

The correlation between serum alkaline phosphatase level at 500 pounds body weight and rate of gain lends itself to the development of a prediction equation. Using serum alkaline phosphatase level, age at 500 pounds body weight and sex as the independent variables, rate of gain may be predicted by the following equation:

$$y = 1.65 + 0.54x_1 \text{ to } .064x_2 + 0.0005x_3$$

where y = rate of gain

x_1 = 0 for females and 1 for males

x_2 = serum alkaline phosphatase level at 500 pounds body weight

and x_3 = is the age at 500 pounds body weight.

For a 250-day-old male calf with a serum alkaline phosphatase level of 6.00 at 500 pounds body weight aged 250 days, the estimated rate of gain with its 95 per cent confidence limits would be

2.70 ± 0.26 pounds per day.

The actual serum alkaline phosphatase level for male calves at 500 pounds body weight was 6.31 ± 1.76 Bodansky units per 100 ml. Arbitrarily taking two standard deviations from the mean as the range of the samples, this range would be 2.79 to 9.83 Bodansky units. Substituting these values in the prediction equations, the rates of gain for 250-day-old male calves with these alkaline phosphatase levels would be 2.49 and 2.95 pounds per day. Similarly for the female calves the two extreme predicted rates of gain would be 1.93 and 2.34 pounds per day. Thus, for 250-day-old calves, the observed serum alkaline phosphatase levels could be used to predict the expected rates of gain from 1.93 pounds per day for females to 2.95 pounds per day for males.

SUMMARY AND CONCLUSIONS

1. The performance and certain blood constituent data have been presented for 46 suckling calves, 52 calves on performance test and 67 adult cows. Involved in the study were two breeds, Aberdeen Angus and Hereford, the latter consisting of three closed lines.

2. The performance data may be summarized as follows:

(a) The calves of the three Hereford lines had heavier birth weights than the Angus calves. No significant sex or line differences were found in the suckling gain to six months of age.

(b) At 500 pounds body weight, the male calves commenced the performance test period at a younger average age than the females. The Angus calves of both sexes were younger than the Hereford calves. A marked sex difference in rate of gain in all lines was observed, the males also making more economical gains than the females.

3. The blood constituents which were studied were serum alkaline phosphatase activity, serum acid phosphatase activity and serum inorganic phosphate level.

(a) The serum alkaline phosphatase levels during the suckling period showed a steady decline in level with age and there was less variation in the levels of the older calves. During the performance test period, the serum alkaline phosphatase level did not show any decline with age but sex differences were observed at 700 and 800 pounds body weight. In the adult animals, two-year-old cows had significantly higher levels than the older cows.

(b) Serum acid phosphatase levels during the suckling period did not show any sex or line differences. However, during the performance test period, an overall sex difference was found at 700 pounds body weight and, at 800 pounds body weight, the Angus males had higher levels than the Angus females. There was a significant increase in level due to age in the male calves. No age or line effects were observed in the adult cows.

(c) The serum inorganic phosphate levels of the suckling calves rose to a peak at three months of age and then declined at six months of age. During the performance test period, significant differences were recorded between the lines but there was no effect of sex. However, within the females there was a significant decline in level with age. In the adult cows there was a steady decline in serum inorganic phosphate level with age.

4. No correlations were found between the blood constituent and performance data for the young calves. However, during the feed test period, a number of correlations were

found between the blood constituents and performance characteristics, the most consistent of which was that between alkaline phosphatase level and rate of gain. When examined more thoroughly, the relationship at 500 pounds body weight was found to be real and not associated with sex, age or feed economy. A prediction equation was developed using sex, age at 500 pounds and serum alkaline phosphatase level at 500 pounds body weight.

BIBLIOGRAPHY

1. Alexander, G. I., H. M. Krueger and R. Bogart. Rate and efficiency of gains in beef cattle. V. Serum phosphatases of growing Hereford and Angus calves. Corvallis, Oregon State College, 1958. 22p. (Oregon. Agricultural Experiment Station. Technical Bulletin no. 42)

2. Anderson, R. L., and T. A. Bancroft. Statistical theory in research. New York, McGraw-Hill, 1952. 399p.

3. Auchinachie, D. W. and A. R. G. Emslie. The effect of diet on the plasma phosphatase of sheep. Biochemical Journal 27:351-355. 1933.

4. Axelrod, B. Enzymatic phosphate transfer. Advances in Enzymology 17:159-188. 1956.

5. Barnes, D. J. and B. Munks. Serum phosphatase, calcium and phosphorus values in infancy. Proceedings of Society of Experimental Biology and Medicine 44:327-331. 1950.

6. Bodansky, A. Phosphatase studies. VI. Non-osseous origins of serum phosphatase. Its increase after ingestion of carbohydrates. Journal of Biological Chemistry 104:473-482. 1934.

7. Buchwald, K. W. and L. Hudson. The biochemical effects of sex hormones. Acid and alkaline phosphatase activity, calcium and phosphorus. Endocrinology 35:73-82. 1944.

8. Buchwald, K. W. and L. Hudson. The biochemical effects of injections of sex hormones into castrated rats. Endocrinology 37:301-306. 1945.

9. Dickie, N., M. I. Robinson and J. Tuba. The role of alkaline phosphatase in intestinal absorption. III. The effects of various fatty acids on levels of the enzyme in intestinal mucosa. Canadian Journal of Biochemistry and Physiology 33:83-88. 1955.

10. Dixon, M. and E. C. Webb. Enzymes. New York, Academic Press, 1958. 782p.

11. Fiske, C. H., and Y. Subbarow. The colorimetric determination of phosphorus. Journal of Biological Chemistry 66:375-400. 1925.

12. Fletcher, J. L., R. R. Shrode and H. O. Kunkel. Serum alkaline phosphatase and gain in Brahman cattle. Journal of Animal Science 15:1119-1124. 1956.

13. Hawk, P. B., B. L. Oser and W. H. Summerson. Practical physiological chemistry. 12th ed. New York, Blakiston, 1951. 1323 p.

14. Kunkel, H. O. et al. Serum alkaline phosphatase in European and Brahman breeds of cattle and their crossbred types. Journal of Animal Science 12:765-770. 1953.

15. Li, C. H. et al. The effect of hypophysectomy and adrenocroticotropic hormone on the alkaline phosphatase of rat plasma. Journal of Biological Chemistry 163:715-721. 1956.

16. Li, C. H., C. Kalman and H. M. Evans. The effect of the hypophyseal growth hormone on the alkaline phosphatase of rat plasma. Journal of Biological Chemistry 169:625-629. 1947.

17. Li, J. C. R. Introduction to statistical inference. Ann Arbor, Edwards Brothers, 1957. 553 p.

18. MacDonald, M. A., H. Krueger and R. Bogart. Rate and efficiency of gains in beef cattle. IV. Blood hemoglobin, glucose, urea, amino acid nitrogen, creatinine, and uric acid of growing Hereford and Angus calves. Corvallis, Oregon State College, 1956. 34 p. (Oregon. Agricultural Experiment Station. Technical Bulletin no. 36)

19. Moog, F. The physiological significance of the phosphomonoesterases. Biological Reviews of Cambridge Philosophical Society 21:41-59. 1946.

20. Roche, J. The phosphatases. In: The enzymes: Chemistry and mechanism of action. ed. by J. B. Sumner and K. Myrback. Vol. I, Part 1. New York, Academic Press, 1950. 724 p.

21. Stearns, G., and E. Warweg. Studies of phosphorus of blood. I. The partition of phosphorus in whole blood and serum, the serum calcium, and plasma phosphatase from birth to weaning. Journal of Biological Chemistry 102:749-765. 1933.

22. Tuba, J., D. B. Baker and M. M. Cantor. The relationship of serum phosphatases to sex hormones. Canadian Journal of Research E27:202-209. 1949.

23. Tuba, J., _et al_. The relationship of dietary factors to rat serum alkaline phosphatase. IV. The effect of dietary oxalate. Canadian Journal of Medical Science 30:515-519. 1952.

24. Weil, L. and M. A. Russell. Studies on plasma phosphatase activity in relation to fat metabolism in rats. Journal of Biological Chemistry 136: 9-23. 1940.