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Rate and Efficiency of Gains in Beef Cattle

VIII. Urinary Specific Gravity, pH, and Buffer Capacity in Beef Cattle

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VIII. Urinary Specific Gravity, pH, and Buffer Capacity in Beef Cattle

In an earlier publication (MacDonald, Krueger, and Bogart, 1956) normal variations in chemical constituents of the blood of *ad libitum* fed beef cattle were presented. This study contains an analysis of urine, with respect to specific gravity, pH, and buffer capacity from the same animals under conditions previously described (MacDonald and Bogart, 1955; MacDonald, Krueger, and Bogart, 1956). While titratable acidity (an index of buffer capacity) has been extensively studied in man and other omnivores, interest in titratable alkalinity, the counterpart in ruminants, has been slight. In man, products to be excreted frequently lead to an acid urine. In ruminants, the high dietary intake of base under normal conditions leads to an alkaline urine. Dietary and metabolic differences between ruminants and other classes of animals should be reflected in the urine; hence, this study of urinary specific gravity, pH, and buffer capacity of beef cattle was undertaken.

Review of Literature

Urine Volume

Several investigators have found that season of the year influences volume of urine excreted by cattle. For example, Ashworth and Brody (1933) found that animals which often excreted over 20 liters of urine daily during the summer only would excrete 3 or 4 liters during the winter. But increased excretion cannot be attributed entirely to the season. Fuller (1928) and Keitt (1916) found that dairy heifers excreted 3.5 to 20.3 liters, while mature cows excreted 8.8 to 50 liters of urine per day. Relationship between water and hay consumption at various temperatures is not simple (Ragsdale *et al.*, 1950).

Human studies (Wyndham *et al.*, 1952) have shown that in comfortable environments mild exertion increases rate of excretion after a water load of 1 liter. Severe exercise, on the other hand, brings about a marked inhibition in urinary excretion. In extreme cold an increase in urine secretions is observed even at rest, com-

pared to comfortable environments. Usually from 40% to 60% of the total fluid intake per 24 hours is excreted by the kidneys but quantity of urine formed and excreted varies immensely with quantity of fluid eliminated by other channels.

Urine Specific Gravity

Healy (1912) reported average specific gravity of dairy cattle urine as 1.014. Since then higher averages have been reported. Hayden (1917-18) found 1.015 to 1.045 more nearly approximates the range of specific gravity of the urine of dairy cows, while Ellenberger and Scheunert (1925) reported average and range of urinary specific gravity for cattle as 1.032 and 1.030 to 1.045, respectively. This average is comparable to that given for sheep and goats by the same investigators (Ellenberger and Scheunert, 1925).

Buffer Capacity and pH

Acidity or alkalinity of urine may be expressed with regard to its concentration in hydrogen ions (true acidity or alkalinity) or to total buffer capacity as determined by titration with N/10 NaOH or HCl using an indicator. Factors influencing urinary pH are similar to those influencing titratable acidity or alkalinity of the urine. However, urines with the same pH may have quite different titratable acidities or alkalinities. It has been suggested that pH may be considered a measure of the intensity factor or concentration of hydrogen ions, while buffer capacity is a measure of the capacity factor, or the ability to produce hydrogen or hyroxyl ions (Best and Taylor, 1950).

Titratable acidity of urine, as determined by the Folin method, is expressed in terms of amount of standard alkali necessary to bring urine from its original pH to the phenolphthalein end point (about pH 8.5 to 9.0). Henderson and Palmer (1914) described a superior method whereby urine is titrated against a color standard to pH 7.4. This has since been replaced by more accurate photometric methods (Van Slyke *et al.*, 1949). The greater part of the titratable acidity in human urine is due to the presence of the dihydrogen phosphate ion, chiefly as the sodium salt. A small portion is, however, due to free organic acids such as uric and lactic acid. The usual amount of titratable acidity in a 24-hour specimen of human urine lies between 200 and 400 ml. of N/10 standard acid. It may be as low as 100 or as high as 600 ml. (Best and Taylor, 1950). Most cattle urines are on the alkaline side of the phenolphthalein point and necessitate negative values of titratable acidity.

Problems and principles involved in base conservation in humans have been extensively studied and reviewed by Pitts (1945, 1946, and 1952) and others (Morrison, 1950; Eggleton, 1947). Principles

involved in alkaline urine formation have been neglected by students of human biology. When plasma bicarbonate concentration in man is raised above a level of 31 millimoles per 100 ml. urine usually becomes alkaline (Sendroy *et al.*, 1934). Such urine contains a high concentration of $BHCO_3$ (Gamble, 1922; Marshall, 1922; and Sendroy *et al.*, 1934). Sendroy, Seelig, and Van Slyke (1934) found that, in humans, glomerular filtrate formed per hour would contain over 20 gm of $NaHCO_3$. Hence, the relatively large concentrations of $BHCO_3$ in the urine, through incomplete reabsorption of the filtered $BHCO_3$, are sufficient to cause the maximal observed pH values (about pH 8); and by interaction of pH on phosphate and other buffers will increase markedly the urinary ratios of salts to their free acids.

Average daily output of ammonia nitrogen in urine of a human adult on a mixed diet is about 0.7 gm corresponding to about 50 milli-equivalents or 500 ml. of 0.1 N base per day. In humans, ammonia appears to function as a synthetic base capable of replacing sodium and potassium in the excretion of acids, thereby conserving fixed base when necessary (Hawk *et al.*, 1951). On the other hand, ruminants have the problem of excreting excess base and conserving ammonia as a source of nitrogen.

In studies of normal human urine Henderson and Palmer (1914) reported an average initial pH of 6.0 with a range in pH for the daily quantity from about 5.1 to 7.0. Urine samples covering a shorter period were as acid as 5.0 or as alkaline as 7.4. Pitts (1945 and 1952) reported that the most acid urine the human kidney can elaborate is in the order of pH 4.8. Sendroy, Seelig, and Van Slyke (1934) reported the maximum observed values for human urine were about pH 8.

In contrast to carnivores and omnivores, herbivores normally have an alkaline urine (Dukes, 1943; Willinger, 1924; Steenbock *et al.*, 1915; and Theiler *et al.*, 1927). Willinger found the pH of urine from the mature ox to vary from 8.6 to 9.0 with a mean of 8.7, that of suckling calves to vary from pH 7.0 to 8.3, while that of suckling bull calves was nearly always slightly acid. Ashworth and Brody (1933) in studying dairy cattle reported a urinary pH range of 7.4 to 8.4 with most of the urines having a pH of 8.0 or over.

Under some conditions other anions tend to displace bicarbonate as the most abundant anion in cattle urine. During starvation studies with dairy cattle, Dale, Gobersdham, and Brody (1954) found that plasma concentrations of cations and of anions changed only slightly but urinary concentrations changed profoundly. During starvation, total anion content and total cation content of urine were nearly equivalent. This equivalence depended upon a decreased carbonate

excretion, because of a decreased excretion of fixed base, and also because of an increased excretion of fixed acid. During starvation, maintenance of acid-base balance, normally a problem of base elimination in herbivores, becomes a problem of base conservation and acid elimination. Dale and co-workers suggested the quantity of organic acids excreted in urine may be proportional to absorption of organic acids from the rumen. A comparatively low rate of excretion of inorganic phosphate during periods of normal nutrition develop usually from the unavailability of the phytic acid phosphorus in plant materials.

Theiler, Green, and DuToit (1927) have shown an excess of basic over acid constituents in the diet of cattle is unnecessary for ruminant well being, while as early as 1898 Winterberg showed conclusively that another herbivore (the rabbit) could tolerate an acid diet.

Vegetable foods contain large amounts of such salts as potassium malate, citrate, acetate, and tartrate which, when oxidized in the body, yield bicarbonates, principally of sodium and potassium. Excess of these give the urine an alkaline reaction. In herbivores, hippuric acid formed in the body by the conjugation of benzoic acid and glycine tends to make urine acid, but the alkali present converts the acid into an hippurate (Dukes, 1943). Bathurst (1952) found that over 90% of the total amino acid in hydrolysed urine was due to glycine. Bound glycine was present as hippuric acid.

On studying buffering capacity and pH values of rumen ingesta, Ammerman and Thomas (1952) found differences in buffering capacity among the individual animals and differences that depended upon feedstuffs. The pH of rumen contents showed average values of 6.70 when the animals were fed either alfalfa or ladino hay. When the same animals were grazed on pasture, the pH readings of the ingesta averaged 6.25 and 6.23 respectively. The ingesta of blue grass had a pH average of 6.90 when fed as hay and 6.56 when grazed.

Sharma (1936) found bovine saliva had a pH of 8.8, while Reid and Huffman (1949) reported a pH of 8.53. Florey, Wright, and Jennings (1941) found the pH of juice from duodenal fistulae of ruminants to be 8.3 to 8.4.

Methods and Procedures

Data used in this study were from 45 beef calves at Oregon State College under the Western Regional Beef Cattle Improvement Project. Calves were purebred Hereford and Aberdeen Angus bulls and heifers. All were born during spring of 1952, grazed with their dams on irrigated pasture, and were weaned at approximately 450

pounds body weight or on December 3, 1952. On reaching 450 pounds calves were placed under experimental conditions which have been reported previously (Nelms, Williams, and Bogart, 1953).

One-inch pellets composed of two parts half-ground alfalfa and one part concentrate comprised the entire ration. Calves were fed individually twice daily. Feed was available in the morning from 6:30 to 9:30 and in the afternoon from 3:30 to 6:30. Quantity of feed was such that there was some weighback daily. Quantities of feed consumed daily varied from animal to animal, but each ate food regularly every day, with only minor daily variations, except for a gradually increasing intake. Calves had access to water at all times through automatic drinking cups. Pens, in which wood shavings were used for bedding, housed the calves in monosexual groups of six, (Bogart and Blackwell, 1950, Dahmen and Bogart, 1952).

All calves were weighed once weekly at a uniform time as well as upon entering and leaving the metabolism stalls.

All animals were in the same barn and had the same food over approximately 120 days (i. e., while gaining from 450 to 800 pounds body weight). Seasonal and weather conditions were not identical at the time of collections from the different animals. Seasonal variation may account for some of the individual differences.

Urine Collection

Urine from bull calves was collected by means of a Davol rubber funnel (Briggs and Gallup, 1949) strapped to the animal with a harness and connected to a rubber hose leading to a 5-gallon carboy beneath the false floor of the stall. The urine collecting funnel was an elipsoid cone with a metal ring at the top and an opening to the cone of 12.5 inch diameter length by 10.5 inch diameter width. The cone was tapered to a depth of 8 inches from the top and vented to a bore-in tube of 0.75 inch diameter. Harness straps were of webbing.

Hansard, Comar, and Plumlee (1951) described metabolism units of simple design and operation that fulfilled the essential basic requirements for heifers; these were adopted with modifications for this study. The urine conduits were constructed from a 3-inch seamless rubber tube approximately 4 feet long. Each was prepared for use by making a 3.5-to 5-inch incision along one side of the folded edge of one end of the tube and reinforcing the terminal end with a cold patch.

Attachment and operation were similar to those described for swine and cattle (Hansard, Comar, and Plumlee, 1950, 1951, and 1951). The split end of the conduit was placed around the vulva and secured to the heifer by means of branding cement. The most con-

venient order to follow in assembling the conduit and making the attachments was that outlined by Hansard, Comar, and Plumlee (1951). Metabolism stalls were locally constructed with minor modifications of the design proposed by Briggs and Gallup (1949).

Because sudden changes of environment affect the feed and water consumption of beef cattle to a varying degree (Carpenter, 1927 and Morrison, 1950), all animals were kept from both feed and water during the 24-hour confinement in the urine collection stalls. To standardize effects of diurnal rhythms (Schlegel *et al.*, 1953) each animal was placed in a stall at 7 to 7:30 a.m. and removed 24 hours later. All animals were weighed upon entering and leaving the metabolism stalls. Urinalysis was initiated immediately upon completion of the collection. All urine samples were collected under toluene. Incomplete collections or collections from animals showing undue excitement while confined in the metabolism stalls were not included in this study.

Urinanalysis

Titratable acidities were determined according to a method suggested by Krueger. Two 25-ml. aliquots were taken from the 24-hour collection of urine. The pH of the first aliquot was obtained at the start and after repeated additions of 1 ml. of N/10 HCl until a pH of 3.0 was obtained. The pH of the second aliquot was obtained at the start and after repeated additions of 1 ml. of N/10 NaOH until a pH of 10.0 was obtained. Readings to the nearest first decimal of the logarithmic notation scale were obtained using a Beckman pH meter, while a modified electric mixer was employed to stir the solutions between readings. Readings were obtained at or corrected to 25° C. in all cases. Wesson (1953) found the mean rate of pH decrease per degree increase between room temperature and 38° C. was approximately 0.005 for all human urines.

Specific gravities were determined in duplicate using urinometers and 50-ml. aliquots. All readings were taken at or adjusted to 25° C. Total 24-hour urine volume was measured by means of graduated cylinders.

Experimental Findings

Data obtained have been reported on a 24-hour basis for urinary excretion at body weights of approximately 460 and 800 pounds. Age, type, feed consumption, rate of gain, and efficiency of gain of experimental animals during this segment of growth have been described previously (MacDonald and Bogart, 1955). Only data from animals that showed no undue excitement during the confinement period and from which a complete 24-hour urine sample was avail-

able, were recorded. It is readily apparent that animals were far better conditioned to a period of metabolism stall confinement at the end of the feeding period (800 pounds) than at commencement of the study.

Observations permit an analysis of the effects of body weight, breed (Hereford vs. Aberdeen Angus), and sex on the variates studied. Simple statements of statistical significance of differences will imply that the probability of occurrence by chance is less than 0.05. Because of small numbers, caution is necessary in inferring from the nonsignificance of observed differences the absence of real differences. Furthermore, some of the variates, particularly buffer capacity, appear to depart from normal distributions (Figure 1) in which case statistical analyses must be considered approximations only. "Highly significant" implies differences having less than a 0.01 probability of occurring by chance.

Comparisons will first be made of changes between 460-and 800-pounds body weight, then of differences between breeds and finally of differences between sexes. For the differences developing between 500-and 800-pounds body weight statements concerning Hereford males will be given first, Hereford females second, and Angus females third. For differences between breeds, comparisons will be made first between Hereford and Angus females at 500 pounds, then at 800 pounds; subsequently, Hereford and Angus males will be compared at 800-pounds body weight. For differences between the sexes comparisons will be made first of male and female Herefords at 500 pounds and then at 800 pounds; finally a comparison will be made between Angus males and females at 800 pounds. Comparisons involving Angus males at 500 lbs. cannot be given because of insufficient data.

Metabolism Stall Weight Loss

Each animal was weighed upon entering and leaving the metabolism stalls. Average weight loss increased from approximately 28 to 47 pounds per head per 24 hours of confinement in metabolism stalls with the increase in body weight from 460 to 800 pounds (Table 1). There was virtually no change in percentage weight loss with the increase in weight, and variations between groups were minor. During the initial test, at 460 pounds body weight, weight losses varied from a low of 15 pounds to a high of 37 pounds representing percentage body weight losses of 3.2 and 8.5 respectively. Average weight loss during the initial test period was 28.2 pounds with a standard deviation of 6.9 pounds. During the final test at 800 pounds body weight, weight losses varied from a low of 23 pounds to a high of 64 pounds, and represented percentage body weight losses of

Table 1. Average Weight Losses of Hereford and Angus Calves per 24 Hours in Metabolism Stalls

Group	Initial test (460 pounds)					Final test (800 pounds)				
	Number of calves	Weight on	Weight off	Loss		Number of calves	Weight on	Weight off	Loss	
		Pounds	*Pounds*	*Pounds*	*Percent*		*Pounds*	*Pounds*	*Pounds*	*Percent*
Hereford males	6	456	430	26.4	5.8	12	793	745	48.6	6.2
Hereford females	9	461	432	28.4	6.2	14	779	735	44.4	5.7
Angus males	1	454	425	29.0	6.2	6	790	744	46.0	5.8
Angus females	5	459	429	30.0	6.6	10	780	732	47.5	6.1
All males	7	456	429	26.8	5.9	18	791	744	47.1	6.0
All females	14	460	430	29.0	6.4	24	779	733	45.8	5.9
All Hereford	15	458	431	27.6	6.1	26	785	739	46.3	5.9
All Angus	6	458	428	29.8	6.5	16	783	736	47.0	6.0
All calves	21	458	430	28.2	6.2	42	784	738	46.6	5.9

Table 2. Percentage of Weight Loss in Metabolism Stalls Due to Urine Excreted

Group	Initial test (460 pounds)			Final test (800 pounds)		
	Males	Females	Both	Males	Females	Both
Hereford ..	40.5(6)*	33.9(9)	36.7(15)	33.9(11)	37.5(14)	35.9(25)
Angus	25.0(1)	25.9(5)	25.7(6)	31.3(6)	39.1(10)	36.2(16)
Both breeds	31.3(7)	31.0(14)	33.4(21)	33.0(17)	38.2(24)	36.0(41)

* Number of animals represented in parentheses.

3.0 and 8.0 respectively. Average body weight loss during this test was 46.6 pounds with a standard deviation of ± 8.1 pounds.

Urine represented a variable portion of the total weight lost (Table 2). During the initial test period it varied from a low of 17.0% to a high of 55.2%. Average weight loss in the form of urine was 33.4% in the initial test and 36.0% in the final test. At the heavier weight, loss from urinary excretion ranged from 21.5% to 74.8% during the 24-hour period of confinement.

Daily Volume of Urine Excreted

Average total urine excretion per 24 hours almost doubled with the increase from 460 to 800 pounds in body weight (Table 3). Variation within and between individuals and groups was great. Hereford males showed an increase in average urine volume from 3,787 to 7,021 ml. or 86%; Hereford females increased from an average of 3,712 to 6,814 or 84%; however, Angus females developed an increase in urine volume from 3,110 to 7,748 or 150% above the volume at 460 pounds.

Hereford females had a significantly greater urine output at 460 pounds than did Angus females; but, at 800 pounds body weight the Angus females had significantly higher urine volumes than did the Hereford females. Hereford males had a significantly higher daily urine volume at 800 pounds than did the Angus males.

Herefords showed no sex difference in volume of urine excreted at either 460 or 800 pounds body weight. Daily volume of urine from Angus males at 800 pounds body weight was significantly lower than from Angus females.

Average urinary excretion per day was well below the 14.2 kg. average listed by Fuller (1928) for dairy cows, but was within the range listed for heifers by Keitt (1916) or for animals maintained under unfavorably cold conditions (Ashworth and Brody, 1933).

However, these calves were not maintained under unfavorably cold conditions.

Average daily urinary excretion *per kilo body weight* increased from 17.1 ml/kilo at 460 pounds to 19.3 ml/kilo at 800 pounds (Table 4).

Individual excretions, however, varied from 8.2 to 31.4 ml/kilo at 460 pounds and from 9.7 to 33.2 ml/kilo at 800 pounds. Urine output increased somewhat *more* than body weight between 460 to 800 pounds, but individual variations were large. This relationship of urine volume to body weight is not entirely predictable from anatomical studies (Brody, 1945), since with the exception of

Table 3. Average Volume of Urine per 24 Hours for Hereford and Angus Calves

Group	Initial test (460 lbs.)			Final test (800 lbs.)		
	Males	Females	Both	Males	Females	Both
	*ml.**	*ml.*	*ml.*	*ml.*	*ml.*	*ml.*
Hereford.....	3,787	3,712	3,751	7,021	6,814	6,905
	(1,773)	(809)	(1,404)	(1,655)	(2,056)	(1,892)
	46.9%	21.8%	37.4%	23.6%	30.2%	27.4%
	(10)	(9)	(19)	(11)	(14)	(25)
Angus.....	3,040	3,110	3,098	6,080	7,748	7,122
		(841)	(841)	(803)	(1,845)	(1,555)
		27.0%	27.1%	13.2%	23.8%	21.8%
	(1)	(5)	(6)	(6)	(10)	(16)
Both breeds.....	3,719	3,497	3,594	6,689	7,203	6,990
	(1,773)	(820)	(1,316)	(1,429)	(1,973)	(1,772)
	47.7%	23.5%	36.6%	21.4%	27.4%	25.4%
	(11)	(14)	(25)	(17)	(24)	(41)

* Values reported in the following sequence: average in ml.; (standard deviation in ml.); coefficient of variations and (number of calves).

Table 4. Average Volume of Urine Excreted per Kilo per 24 Hours by Hereford and Angus Calves

Group	Initial Test			Final Test		
	Males	Females	Both	Males	Females	Both
	ml.	*ml.*	*ml.*	*ml.*	*ml.*	*ml.*
Hereford	18.0 (10)*	17.5 (9)	17.8 (19)	19.4 (11)	18.9 (14)	19.1 (25)
Angus	14.0 (1)	15.0 (5)	14.9 (6)	16.8 (6)	21.4 (10)	19.7 (16)
Both breeds	17.6 (11)	16.7 (14)	17.1 (25)	18.5 (17)	19.9 (24)	19.3 (41)

* Number of animals represented in parentheses.

the heart, thyroid, and spleen, relative increase in weight of the visceral organs is *less* than that of the body as a whole. In steers (Brody, 1945) kidney weight increases approximately as the square root of body weight. On this basis kidney weight would increase only 32% between 460 and 800 pounds body weight, while body weight increased 74% and urine volume 94%.

Urine Specific Gravity

Average urinary specific gravity decreased with the increase in body weight and the accompanying increase in daily volume of urine excreted (Table 5, and Figure 10). Urinary specific gravity of each animal fell within the range given by Hayden (1917-18) for the dairy cow. Averages, however, were considerably higher than that given by Healy (1912). Many individuals fell below the range listed by Ellenberger and Scheunert (1925), but none exceeded it. Averages somewhat exceeded that of 1.032, given by Ellenberger and Scheunert during the test at 460 pounds, but fell below 1.032 at 800 pounds.

Neither at 460 pounds nor at 800 pounds was there evidence of significant breed or sex differences in specific gravity. Average differences for specific gravity appear to be abnormally low, but a perusal of ranges and of standard deviations of specific gravities indicates that the agreement between the averages may mainly occur because 0.001 is a relatively wide interval in the distribution range for specific gravity at given body weights.

Urine Buffer Capacity

Total Buffer Capacity. Total volume of N/10 NaOH, required to titrate the total 24 hour urine sample to pH 10, *plus* the total volume of N/10 HCl to titrate to pH 3 (i. e., roughly titratable acidity plus titratable alkalinity), are given in Table 6 as averages. Frequency distributions of total buffer capacity are illustrated by the

Table 5. Average Urine Specific Gravity for Hereford and Angus Male and Female Calves

Group	Initial test (460 lbs.)			Final test (800 lbs.)		
	Males	Females	Both	Males	Females	Both
Hereford	1.036 (10)*	1.036 (9)	1.036 (19)	1.027 (11)	1.029 (14)	1.028 (25)
Angus	1.033 (1)	1.035 (5)	1.035 (6)	1.027 (6)	1.026 (10)	1.026 (16)
Both breeds	1.036 (11)	1.036 (14)	1.036 (25)	1.027 (17)	1.028 (24)	1.027 (41)

* Number of animals represented in parentheses. Specific gravities are corrected to 25°C.

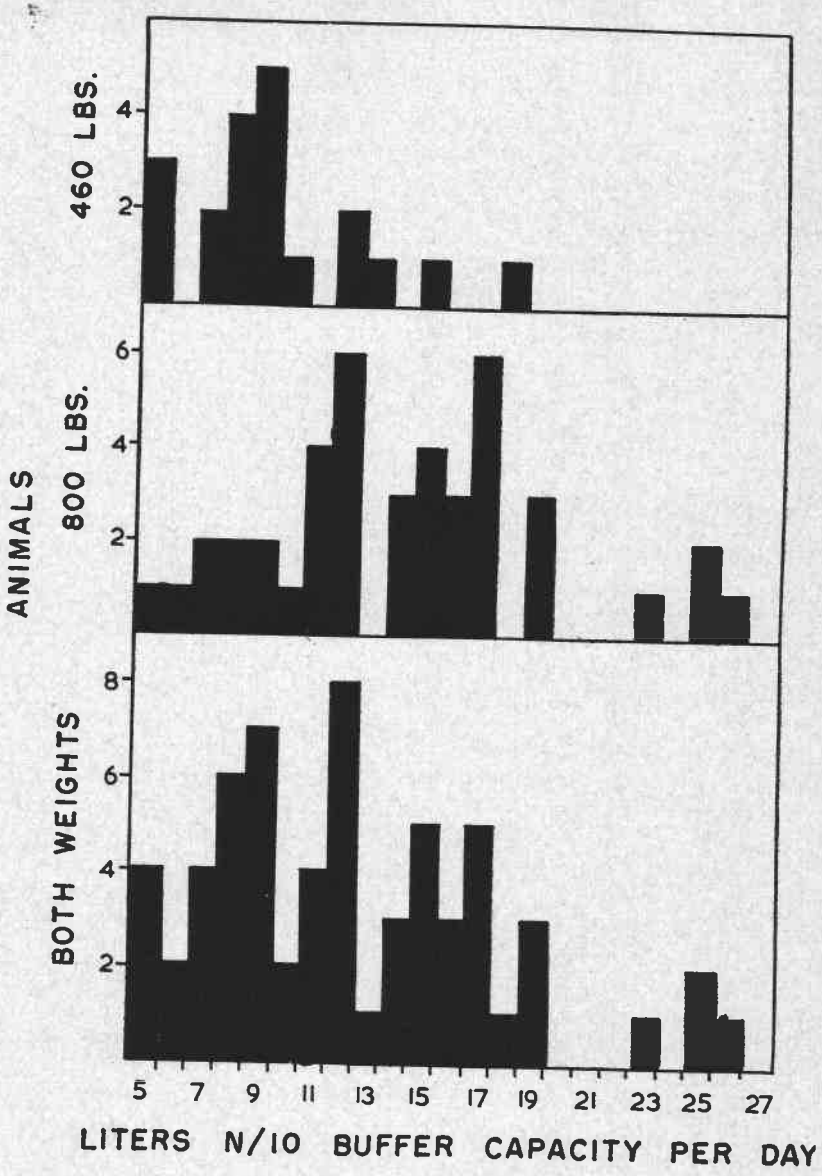


FIGURE 1. Frequency diagram of urinary buffer capacities of Hereford and Angus calves at 460 and 800 pounds body weight. (The abscissa is divided into intervals of one liter, and the numbers indicate liters of buffer capacity at the midpoint of the interval. The ordinates give the number of animals whose 24-hour urine sample had buffer capacities in the indicated intervals.)

Table 6. Average Daily Buffer Capacity of Urine from Hereford and Angus Calves

Group	Initial test (460 lbs.)			Final test (800 lbs.)		
	Males	Females	Both	Males	Females	Both
Hereford	10,506 (3,832) 36.5% (9)	8,583 (2,209) 25.7% (9)	9,545 (3,128) 32.8% (18)	17,510 (4,335) 24.8% (11)	12,912 (5,958) 46.1% (14)	14,935 (5,313) 36.6% (25)
Angus	9,058 (1)	6,443 (2,010) 31.2% (5)	6,879 (2,010) 29.2% (6)	13,040 (1,779) 13.6% (6)	12,766 (4,569) 35.8% (10)	12,875 (3,814) 29.6% (16)
Both breeds	10,361 (3,832) 37.0% (10)	7,818 (2,145) 27.4% (14)	8,878 (2,939) 33.5% (24)	15,932 (3,686) 23.1% (17)	12,855 (5,432) 42.3% (24)	14,131 (4,801) 34.0% (41)

Values reported in the following sequence in each subdivision: average, 0.1 normal buffer capacity between pH 3 and 10 in ml.; (standard deviation); coefficient of variation; (number of calves).

use of histograms in Figure 1. In the initial test (460 pounds) total buffer capacity ranged from 4,647 ml. to 17,598 ml. In the final test (800 pounds) the range was much greater, varying from 5,508 ml. to 26,190 ml. On average, buffer capacity increased 59%, while body weight increased 74% and urine volume 94%.

Hereford and Angus females were similar at 460 and at 800 pounds body weight. A possible statistically significant breed difference between Hereford and Angus females at 460 pounds body weight may have been obscured by the small number of data on Angus females. At 800 pounds body weight the difference between Hereford and Angus males was significant.

Sex difference in Herefords was found to be statistically significant, with urine of males having the greater buffering capacity at both 460 and 800 pounds body weight. Angus males and females could not be compared at 460 pounds, and at 800 pounds body weight the Angus showed no sex difference.

Total buffer capacity of urine, on a per kilo body weight per day basis, decreased slightly with the increase from 460 to the 800 pounds body weight for Hereford males and females but increased in the case of Angus females. Variations within groups and between groups were large. Group averages have been presented in Table 7. As comparisons were made at the same body weights, sex and breed differences for buffering capacity on a per kilo basis have the same

Table 7. Average Total Buffer Capacity of Urine on a per Kilo per Day Basis for Hereford and Angus Calves

Group	Initial test (460 lbs.)			Final test (800 lbs.)		
	Males	Females	Both	Males	Females	Both
	ml.	*ml.*	*ml.*	*ml.*	*ml.*	*ml.*
Hereford	57 (6)*	41 (9)	47 (15)	49 (11)	36 (14)	42 (25)
Angus	43 (1)	31 (5)	33 (6)	36 (6)	36 (10)	36 (16)
Both breeds	55 (7)	37 (14)	43 (21)	44 (17)	36 (24)	40 (41)

* Number of animals in parentheses.

directions as those given in the paragraph above for total daily buffer values.

Patterns of Daily Total Buffer Excretion. Distribution of buffer capacity over unit ranges in pH is presented in Tables 8, 9, and Figures 3, 4, 5, and 6. Hereford females at 800 pounds body weight yielded higher titration values over the entire range from pH 3 to pH 10 than they did at 460 pounds body weight. On the basis of the increased metabolism with increase in body weight, an increase in the urinary output of buffer substances was expected, and was obtained, at the higher weight. However, there was a change in the quantity of buffer capacity within specific pH ranges. For the 7 unit increments in pH between 3 and 10, increases of 17%, 31%, 54%, 52%, 59%, 46%, and 75% in titrations were noted between 460 and 800 pounds. Only the last value paralleled closely the 74% increase in body weight. The irregularly increasing increments from 17% to 75% indicate a change in buffer pattern (such as changing concentrations and perhaps even changing moieties of anions and cations excreted in the urine) as body weight increases.

Titration patterns for Hereford males at 460 and at 800 pounds body weight differed from each other. At 800 pounds body weight an increase occurred in buffer capacity over the range pH 4 to pH 7, and from pH 8 to pH 10. The increase was very marked between pH 5 and pH 6 (137%), between pH 6 and pH 7 (93%), between pH 8 and pH 9 (118%) and between pH 9 and pH 10 (186%). However, between pH 7 and pH 8, although the difference was not statistically significant, the buffer capacity at 460 pounds body weight was greater than for 800 pounds body weight. Further, between pH 3 and pH 4, the buffer capacity at 460 pounds body weight was significantly higher than at 800 pounds body weight. The change-in-pattern with increasing weight was different in Hereford males from the change-in-pattern observed in Hereford females.

Angus females at 800 pounds body weight yielded higher titration values over the entire range of pH from 3 to 10 than they did at 460 pounds. For the seven unit increments in pH between 3 and 10, increases of 66%, 62%, 122%, 102%, 99%, 95%, and 118% were noted between 460 and 800 pounds body weight. These increases were much greater than those demanded by a simple increase in body weight. The change-in-pattern of buffer excretion between 460 and 800 pounds body weight for Angus females is not the same as the change-in-pattern for Hereford females, nor as that of Hereford males. At 460 pounds body weight over the entire range from pH 3 to pH 10, there were differences between Hereford and Angus females which bordered on significance at the 0.05 level, and for two intervals were significant at the 0.05 level (pH 5-6, and 6-7). At 800 pounds body weight the urine from Hereford and Angus females had similar buffer capacities at all seven unit intervals between pH 3 and pH 10. None of the differences were statistically significant. At 800 pounds body weight differences between Hereford and Angus males were significant at the 0.05 level between pH 5 and pH 7 and between pH 8 and pH 10 but not from pH 3 to pH 5, or pH 7 to pH 8. At 460 pounds body weight there was a statistically significant sex difference in the buffer capacity over the range between pH 7 and pH 8 for Herefords. At 800 pounds body weight there was highly significant sex difference in the Herefords over the range pH 8 and 9; over other unit ranges, the differences were not significant at the 0.05 level. Sex differences at 800 pounds were not established for the Angus.

Percentage Distribution of Buffer Capacity. Percentage distribution of buffer capacity within the pH range studied showed some similarity in all groups studied (Figure 2). Maxima for buffering capacity were obtained between pH 5 and pH 7 and between pH 9 and pH 10 with Hereford and Angus males and females at both 460 and 800 pounds body weight. Hereford males had, in addition, a pronounced maximum between pH 3 and pH 4 at 460 pounds body weight, but not at 800 pounds body weight.

Angus females at 460 pounds differed from Hereford females in that a much larger fraction of the buffer capacity of the urine lay between pH 5 and pH 7 for the Angus females. At 800 pounds Hereford and Angus females had similar distributions of buffer capacity over the pH range 3 to 10. Hereford and Angus males at 800 pounds had a similar distribution of urinary buffer capacity over the pH range 3 to 10.

Hereford male and female distributions of urinary buffer capacity over the pH range from 3 to 10 were different at 500 pounds but were similar at 800 pounds. At 800 pounds Angus males and

Table 8. Distribution of Urinary Buffer Capacity over pH Range (Initial Test [approximately 460 lbs.])

Group	Males				Females				Both Sexes			
	Average	Standard deviation	S.D./Ave. x100	Number of Animals	Average	Standard deviation	S.D./Ave. x100	Number of Animals	Average	Standard deviation	S.D./Ave. x100	Number of Animals
	ml.	*ml.*	*Percent*		*ml.*	*ml.*	*Percent*		*ml.*	*ml.*	*Percent*	
pH 3-4												
Hereford	2,341	2,347	100	10	1,055	218	21	9	1,732	1,714	99	19
Angus	851			1	841	222	26	5	843	222	26	6
Both Breeds	2,206	2,347	106	11	979	219	22	14	1,519	1,545	102	25
pH 4-5												
Hereford	1,084	293	27	10	855	202	24	9	975	255	26	19
Angus	790			1	746	239	32	5	753	239	32	6
Both Breeds	1,057	293	28	11	816	215	26	14	922	252	27	25
pH 5-6												
Hereford	1,379	418	30	10	1,559	416	27	9	1,464	417	29	19
Angus	1,702			1	1,027	355	35	5	1,140	355	31	6
Both Breeds	1,408	418	30	11	1,369	396	29	14	1,386	406	29	25
pH 6-7												
Hereford	1,845	551	30	10	1,753	587	34	9	1,801	568	32	19
Angus	1,824			1	1,145	622	54	5	1,258	622	49	6
Both Breeds	1,843	551	30	11	1,536	598	39	14	1,671	578	35	25
pH 7-8												
Hereford	1,215	775	64	10	594	174	29	9	921	577	63	19
Angus	547			1	538	187	35	5	540	187	35	6
Both Breeds	1,154	775	67	11	574	179	31	14	829	525	63	25
pH 8-9												
Hereford	965	406	43	10	984	193	20	9	974	331	34	19
Angus	1,155			1	782	232	30	5	845	232	28	6
Both Breeds	982	406	42	11	912	207	23	14	943	314	33	25
pH 9-10												
Hereford	1,644	724	44	10	1,783	617	35	9	1,710	676	40	19
Angus	2,189			1	1,362	400	29	5	1,500	400	27	6
Both Breeds	1,694	724	43	11	1,633	554	34	14	1,660	633	38	25

Table 9. Distribution of Urinary Buffer Capacity over pH Range (Final Test [approximately 800 lbs.])

Group	Males				Females				Both Sexes			
	Average	Standard deviation	S.D. / Ave. ×100	Number of Animals	Average	Standard deviation	S.D. / Ave. ×100	Number of Animals	Average	Standard deviation	S.D. / Ave. ×100	Number of Animals
	ml.	*ml.*	*Percent*		*ml.*	*ml.*	*Percent*		*ml.*	*ml.*	*Percent*	
pH 3-4												
Hereford	1,368	253	19	11	1,230	346	28	14	1,291	309	24	25
Angus	1,231	326	27	6	1,400	143	10	10	1,336	226	17	16
Both Breeds	1,319	279	21	17	1,301	282	22	24	1,309	281	22	41
pH 4-5												
Hereford	1,424	318	22	11	1,116	445	40	14	1,252	395	32	25
Angus	1,182	160	14	6	1,207	352	29	10	1,198	298	25	16
Both Breeds	1,339	276	21	17	1,154	410	36	24	1,231	361	29	41
pH 5-6												
Hereford	3,274	979	30	11	2,396	1,356	57	14	2,782	1,207	43	25
Angus	2,250	260	12	6	2,286	1,271	56	10	2,273	1,031	45	16
Both Breeds	2,913	813	28	17	2,350	1,322	56	24	2,583	1,144	44	41
pH 6-7												
Hereford	3,569	1,183	33	11	2,670	1,435	54	14	3,065	1,331	43	25
Angus	2,698	644	24	6	2,316	952	41	10	2,459	855	35	16
Both Breeds	3,201	1,035	32	17	2,523	1,260	50	24	2,829	1,174	42	41
pH 7-8												
Hereford	1,063	287	27	11	942	456	49	14	996	393	39	25
Angus	995	274	28	6	1,073	234	22	10	1,044	249	24	16
Both Breeds	1,039	283	27	17	997	382	38	24	1,014	345	34	41
pH 8-9												
Hereford	2,107	574	27	11	1,434	577	40	14	1,730	536	33	25
Angus	1,384	196	14	6	1,528	720	47	10	1,474	589	40	16
Both Breeds	1,851	482	26	17	1,473	640	43	24	1,630	581	36	41
pH 9-10												
Hereford	4,706	1,101	23	11	3,123	1,637	52	14	3,820	1,429	37	25
Angus	3,300	577	18	6	2,965	1,430	48	10	3,091	1,197	39	16
Both Breeds	4,210	959	23	17	3,058	1,556	51	24	3,535	1,346	38	41

Table 10. URINE BUFFER CAPACITY (ml. of N/10 HCl) BETWEEN INITIAL pH AND pH 7.4

Group	Initial test (460 lbs.)			Final test (800 lbs.)		
	Males	Females	Both	Males	Females	Both
Hereford	1,465	564	1,038	1,188	676	901
	(1,338)	(367)	(1,005)	(376)	(368)	(371)
	91.3%	65.0%	96.8%	31.6%	54.4%	41.2%
	(10)	(9)	(19)	(11)	(14)	(25)
Angus	426	*226	*260	956	507	675
		(161)	(161)	(576)	(365)	(452)
		71.1%	62.0%	60.3%	72.1%	67.0%
	(1)	(5)	(6)	(6)	(10)	(16)
Both breeds	1,317	434	*851	1,106	606	813
	(1,338)	(314)	(908)	(452)	(367)	(404)
	97.6%	70.8%	106.6%	40.9%	60.6%	49.7%
	(11)	(14)	(25)	(17)	(24)	(41)

* Includes one observation value of zero. Angus female B-59 excreted urine with a pH of 7.3 and had a negligible NaOH titration between the initial pH and pH 7.4. See Figure 9.

Angus females had similar curves and these did not differ markedly from the curves of the Hereford males and females at 800 pounds. Variation from the typical pattern by the Hereford male groups at 460 pounds may be explained by noting that urine of two bulls (B-12 and B-4) had 45.4% and 38.5% respectively of their total urinary buffer capacity between pH 3 and pH 4. These values are more than twice as high as those of any other calf studied. Upon eliminating these two animals from the group, the Hereford male average at 460 pounds conforms with the general pattern of the distribution of urinary buffer capacity over the pH range 3-10.

Partition of Buffer Intensity or Buffer Concentration. To bring out more clearly the physiological differences due to growth, breed, and sex, buffer capacity has been partitioned into several components. These components embrace titrations determined over the following ranges of pH:

(a) Initial pH to pH 7.4
(b) pH 7.4 to pH 10.0
(c) pH 4.5 to pH 7.4

Titration from the initial pH (pH to urine as excreted) to pH 7.4 is a measure in chemical equivalents of the excess of basic compounds over the acid compounds excreted in the urine. Titration procedure may be pictured as reversing the change in acid-base relationship effected by the kidneys during the formation of urine from glomerular filtrate. The volume of N/10 acid, required to effect

Table 11. URINE BUFFER CAPACITY (ml. of N/10 HCl) BETWEEN pH 7.4 AND pH 10

Group	Initial test (460 lbs.)			Final test (800 lbs.)		
	Males	Females	Both	Males	Females	Both
Hereford	3,282	3,081	3,187	7,420	5,064	6,101
	(1,104)	(845)	(994)	(1,748)	(2,392)	(2,136)
	33.6%	27.7%	31.2%	23.6%	47.2%	35.0%
	(10)	(9)	(19)	(11)	(14)	(25)
Angus	3,041	2,335	2,453	5,191	5,145	5,162
		(661)	(661)	(619)	(2,184)	(1,789)
		28.3%	27.0%	11.9%	42.4%	34.7%
	(1)	(5)	(6)	(6)	(10)	(16)
Both breeds	3,260	2,814	3,011	6,633	5,098	5,735
	(1,104)	(795)	(940)	(1,471)	(2,309)	(2,012)
	33.9%	28.2%	31.2%	22.2%	45.3%	35.1%
	(11)	(14)	(25)	(17)	(24)	(41)

this reversal, is a measure of the net movement of buffer substance by the kidney against a hydrogen ion gradient.

The range from pH 7.4 to pH 10.0 yields data on the amounts of basic substances whose effects on pH were decreased by neutralization with acid buffers such as carbonic acid or the dihydrogen phosphate ion. Organic acids, in amounts quantitatively significant, may contribute to the buffer effects in this range.

The titration range from pH 4.5 to pH 7.4 gives values of buffer capacity due to phosphates, creatinine and other substances usually encountered in human urine. Current information is insufficient to decide whether compounds other than those of human urine are components for the buffer capacity of bovine urine between pH 4.5 and pH 7.4. The value 7.4 was chosen as representing the pH of bovine blood.

Buffer Capacity, Initial pH to pH 7.4. Titration of urine from the initial level to a pH of 7.4 yields the physiological counterpart, in ruminants, to titratable acidity of human urine. The HCl titration volume may thus be termed *titratable alkalinity*. Group averages, standard deviations, and coefficients of variability, for titratable alkalinity or urine buffer capacity from initial pH to pH 7.4 are presented in Table 10. None of the growth differences were statistically significant, although the average value of titratable alkalinity for Hereford males tended to decrease with the weight increase, while values for Hereford females did not alter noticeably, and Angus females exhibited an increased buffer concentration with the increase in weight. Breed differences also were not statistically significant.

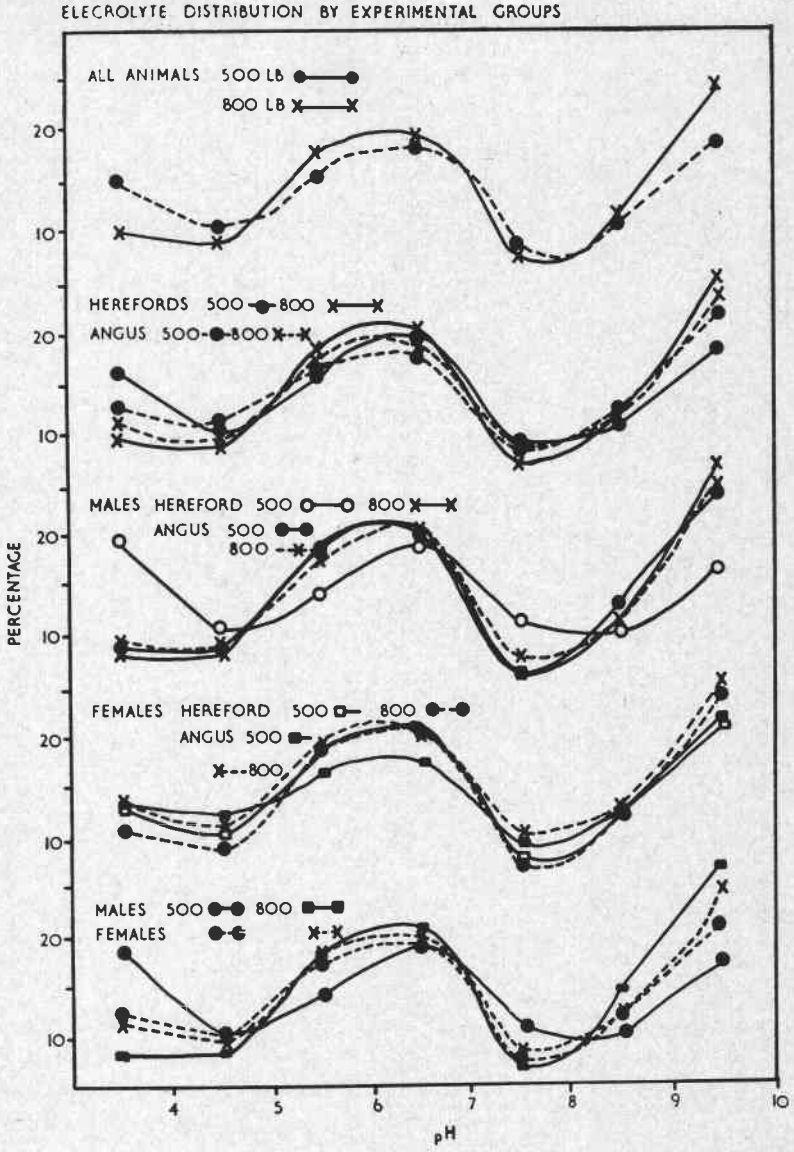
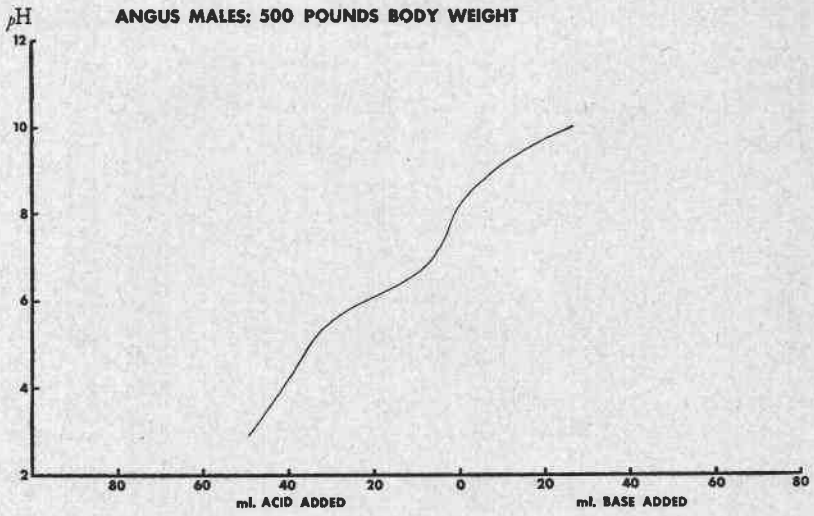


FIGURE 2. Average distribution of buffer capacity of urine between pH 3 and pH 10 for Hereford and Angus calves. (The abscissa has been divided into unit intervals of change in pH. The total buffer capacity from pH 3 to pH 10 was taken as 100%. The percentage of total buffer capacity over each unit change in pH was plotted on the ordinate at the midpoint of the pH interval.)



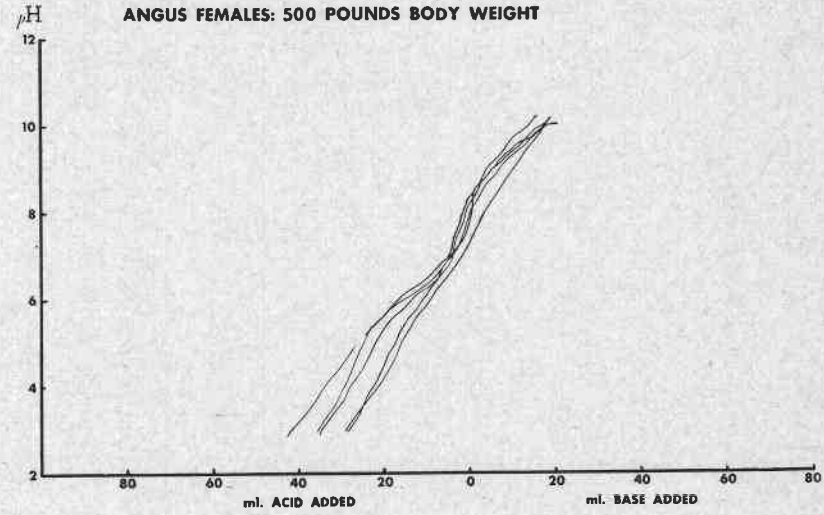
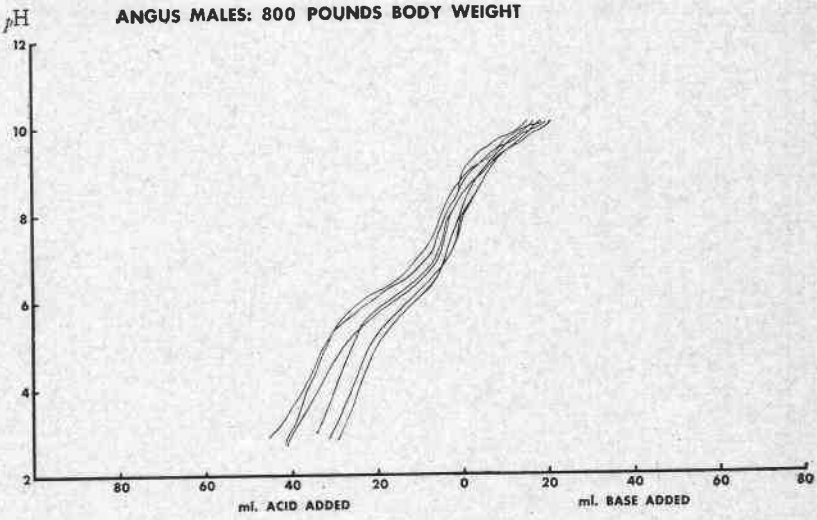


FIGURE 3. Titration patterns for urine from Angus calves at 460 pounds body weight. (Volumes of N/10 HCl added are plotted on the abscissa to the right of the zero point and volume of N/10 NaOH added are plotted to the left of the zero point. Urinary pH corresponding to volumes of N/10 HCl or NaOH added or plotted on the ordinate.)



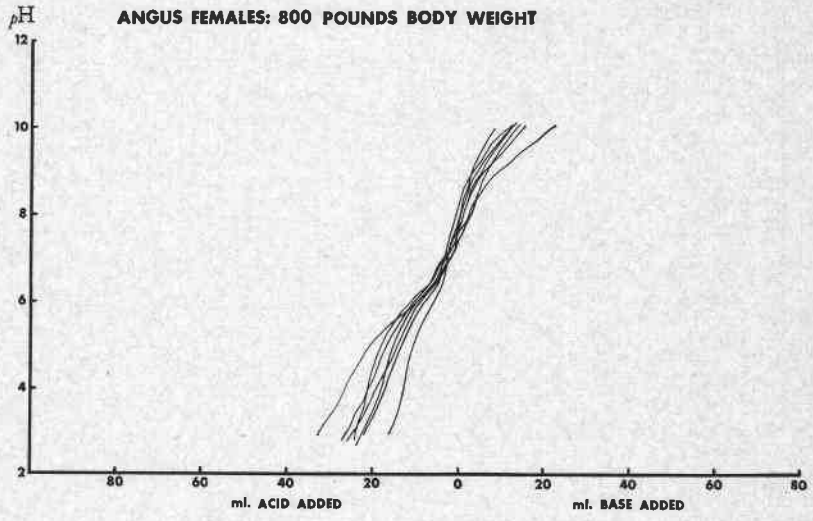
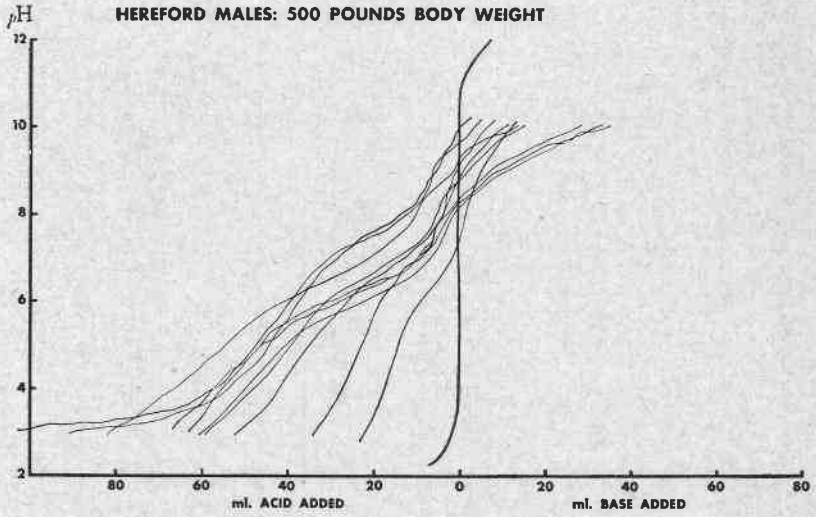


FIGURE 4. Titration patterns for urine from Angus calves at 800 pounds body weight. (Volumes of N/10 HCl added are plotted on the abscissa to the right of the zero point and volume of N/10 NaOH added are plotted to the left of the zero point. Urinary pH corresponding to volumes of N/10 HCl or NaOH added or plotted on the ordinate.)



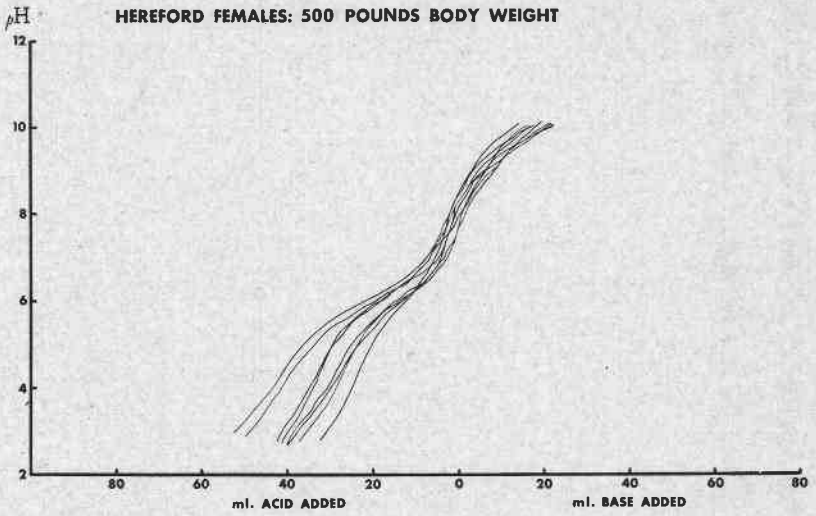
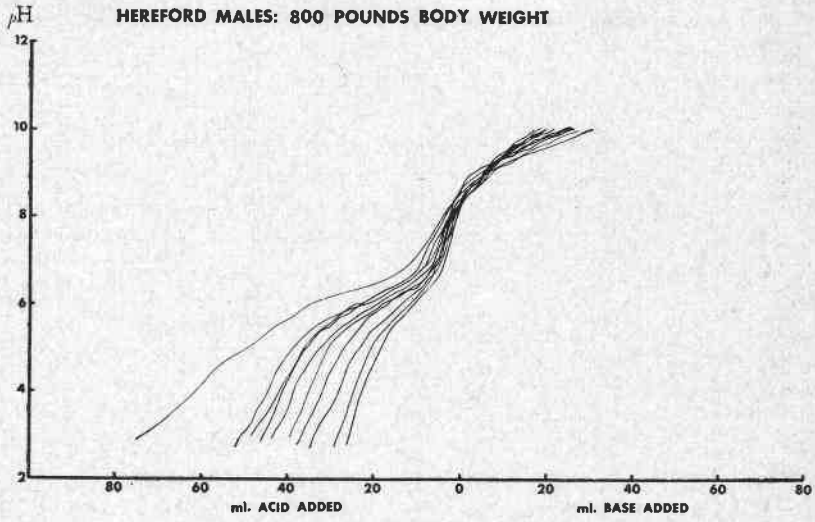


FIGURE 5. Titration patterns for urine from Hereford calves at 460 pounds body weight. (Volumes of N/10 HCl added are plotted on the obscissa to the right of the zero point and volume of N/10 NaOH added are plotted to the left of the zero point. Urinary pH corresponding to volumes of N/10 or NaOH added or plotted on the ordinate.)



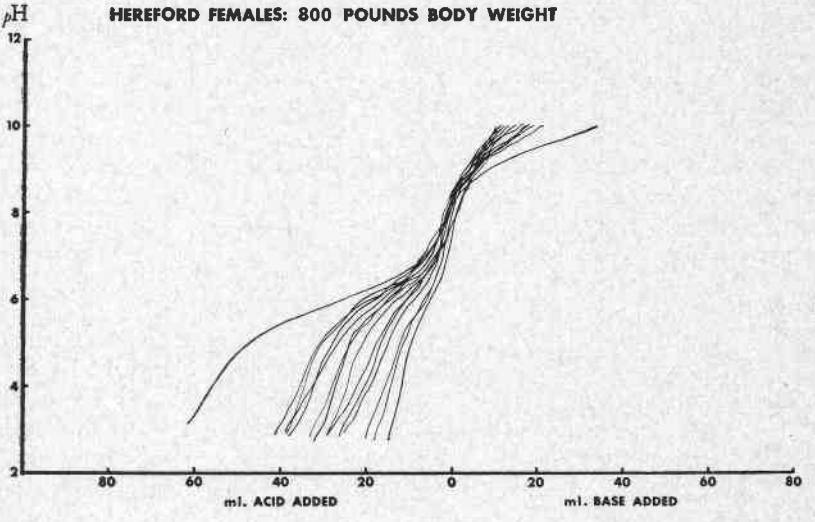


FIGURE 6. Titration patterns for urine from Hereford calves at 800 pounds body weight. (Volumes of N/10 HCl added are plotted on the obscissa to the right of the zero point and volume of N/10 NaOH added are plotted to the left of the zero point. Urinary pH corresponding to volumes of N/10 HCl or NaOH added or plotted on the ordinate.)

Values were higher for Hereford bulls than for Hereford heifers at both weights, and the difference was statistically significant. No difference was found between Angus males and Angus females. Angus female B-59 excreted urine with a pH of 7.3 and had a negligible acid titration between the initial pH and pH 7.4.

Buffer Capacity between pH 7.4 and pH 10.0. Upon titrating urine aliquots from the accepted pH of normal blood plasma to pH 10 it was found that the urine of Hereford and Angus males and females required far more NaOH to reach pH 10 at 800 pounds than was required at 460 pounds body weight. Data are presented in Table 11. No breed difference in buffer capacity was noted between pH 7.4 and pH 10.0 for females, while a breed difference for males, with higher values among the Herefords, was found at 800 pounds body weight. Urine from Hereford males required more NaOH to reach pH 10 than that from Hereford females at 800 pounds body weight, but not at 460 pounds body weight.

Buffer Capacity between pH 4.5 and pH 7.4. Buffer capacity in the range from pH 4.5 and pH 7.4 increased for Hereford and Angus males and females with the increase in body weight (Table 12). Buffer capacities of the urine of Hereford females was greater than that of the Angus females at both weights but the difference was statistically significant only at the 460 pound weight. Buffer capacity in the range 4.5 to 7.4 was greater in the urine from Hereford males than in the urine from Angus males at 800 pounds body weight. Buffer capacities between pH 4.5 and pH 7.4 were similar for urine from Hereford males and females at 460 pounds body weight, but capacity was greater in urines from Hereford males at 800 pounds body weight. Differences between Angus males and females were not found.

Initial pH

Initial urinary pH at 460 pounds body weight showed a greater range, especially on the alkaline side, than that exhibited at 800 pounds body weight. This has been illustrated in Figures 9 and 10. There was a greater concentration of individual values near the mean at 800 pounds body weight than at 460 pounds body weight.

Average pH of urine as collected from both male and female Herefords at 460 pounds was higher than at 800 pounds body weight (Table 13). The difference was not statistically significant in the case of the Hereford females, and asymmetry of the distribution makes it difficult to establish whether the difference was significant in the case of the Hereford males. Angus females produced urines with a similar average and range of pH both at 460 and 800 pounds body weight.

At both body weights the urine of Hereford females was more alkaline than that of the Angus females, and the differences were statistically significant. No difference was found between Hereford and Angus males. It is noteworthy (Figure 9) that only one animal, Angus female B-59 in the initial test, excreted urine of a pH lower than the normal pH of bovine blood plasma. The urine of Angus females was generally more acid than the urine of the other three groups (Hereford males, Hereford females, and Angus males).

Correlations Between Various Factors Studied

Urine Volume and Initial pH. Studies involving human subjects indicate generally that the greater the pH the lower the volume of urine excreted, and the greater the urine volume excreted the lower the urinary pH. (Best and Taylor, 1950). A similar relation does not hold for beef calves since correlations between initial pH and urinary volume did not approach significance. In fact, Figure 7 would suggest that because of the frequency of initial pH at about pH 8.3, pH was independent of urinary volume.

Urine Volume (initial test) and Urine Volume (final test). There was no correlation between volumes of urine excreted by given animals at 460 pounds and at 800 pounds body weight.

Urine Volume and Urine Specific Gravity. Ignoring breed and sex classifications, which were not significantly different, the negative correlations between urine specific gravity and urine volume

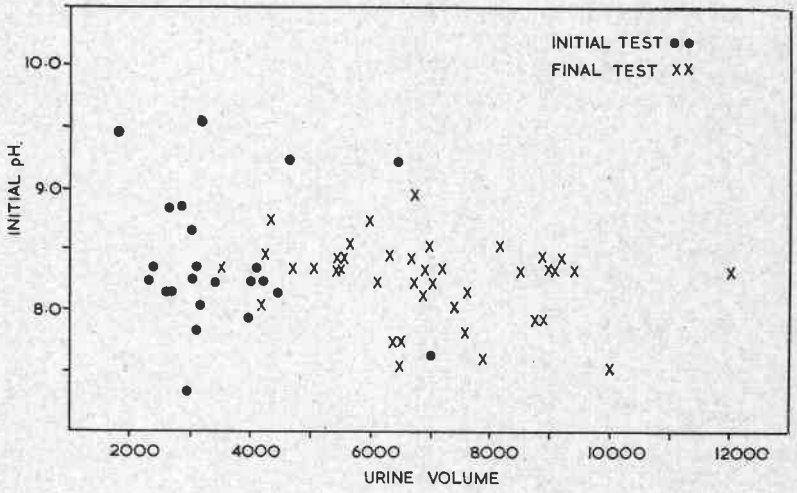


FIGURE 7. Relation of initial urinary pH to daily volume of urine.

was significant for the initial test (460 pounds) ($r = -0.74$) but was not significant at 800 pounds ($r = -0.28$). (See Figure 8).

Specific Gravity (initial test) and Specific Gravity (final test). There was no relation between urine specific gravity values obtained in the initial test (460 pounds) and urine specific gravity values obtained in the final test (800 pounds).

Urine Volume and Total Buffer Capacity of Urine. If allowance is made for breed and sex effects, the correlation between urine volume and total buffer capacity is significant (Figure 9). At 460 pounds there was a correlation ($r = 0.46$) with 17% of the residual variation in buffer capacity accounted for by concomitant variation in urine volume. The corresponding figures at 800 pounds are $r = 0.52$ and 25%. The regression slopes are not markedly affected by sex or breed. Sex differences in total buffer capacity excretion, adjusted for breed and urine volume, were significant at 800 pounds and approached significance at 460 pounds. Correspond-

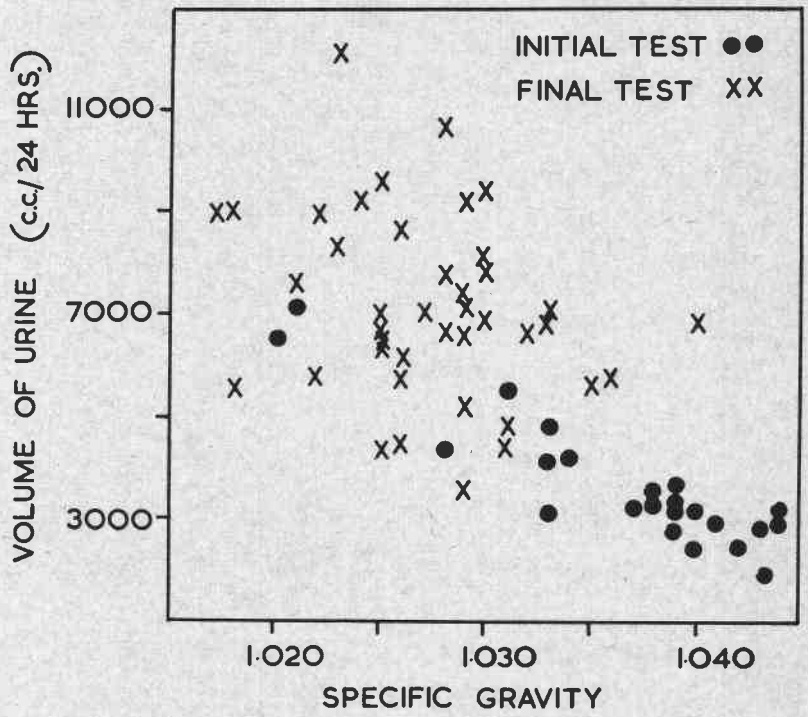


FIGURE 8. Relation of daily urine volume to specific gravity of urine.

Table 12. URINE BUFFER CAPACITY BETWEEN pH 4.5 AND pH 7.4

Group	Initial test (460 lbs.)			Final test (800 lbs.)		
	Males	Females	Both	Males	Females	Both
Hereford	4,259 ± 916 (21.5%) (10)	3,971 ±1,147 (28.9%) (9)	4,122 ±1,031 (25.0%) (19)	8,076 ±2,254 (27.9%) (11)	6,095 ±3,143 (51.9%) (14)	6,947 ±2,791 (40.2%) (25)
Angus	4,224 (1)	2,779 ±1,099 (39.5%) (5)	3,020 ±1,099 (36.4%) (6)	6,027 ± 924 (15.3%) (6)	5,628 ±2,277 (40.5%) (10)	5,778 ±1,908 (33.0%) (16)
Both breeds	4,256 ± 916 (21.5%) (11)	3,545 ±1,131 (31.9%) (14)	3,858 ±1,044 (27.1%) (25)	7,353 ±1,916 (26.1%) (17)	5,880 ±2,821 (48.0%) (24)	6,490 ±2,494 (38.4%) (41)

ingly adjusted breed differences were not significant. These relations may be summarized in the following equations:

At 460 pounds body weight: $y = 1.094 \times + 3{,}995$ (Females) $\pm$ 2,557 (29% of $\bar{y}$)
$+ 6{,}285$ (Males)

At 800 pounds body weight: $y = 1{,}364 \times + 3{,}031$ (Females) $\pm$ 4,288 (30% of $\bar{y}$)
$+ 6{,}810$ (Males)

(y=Total buffer capacity and x=urine volume).

Total Buffer Capacity and Other Factors. Total buffer capacity at both 460 and 800 pounds body weight was not significantly correlated with any of the following:

(a) Days from weaning to commencement of the test period.
(b) Age at weaning in days.
(c) Age at commencement or upon completion of test.
(d) Days on test or average daily rate of gain on test.
(e) Total feed, T.D.N., or nitrogen consumed on test.
(f) Average daily consumption of feed, T.D.N., or nitrogen on test.
(g) Efficiency of gain on test.
(h) Total urinary nitrogen, urea nitrogen or ammonia excreted per 24 hours or per ml.

Initial pH and Total Buffer Capacity. Neither during the 460 pound nor the 800 pound test was there a statistically significant correlation between initial pH and total buffer capacity over the range pH 3 to 10. This fact confirms the statement (Hawk, Oser, and Summerson, 1951) that while the factors influencing urinary pH are similar to those influencing buffer capacity of the urine, the two are not quantitatively correlated. It has been shown here that a dilute urine and a concentrated urine may have the same initial pH but

Table 13. Average Initial pH of 24-Hour Urine Collections from Male and Female Calves at Both Weights

Group	Initial test (460 lbs.)			Final test (800 lbs.)		
	Males	Females	Both	Males	Females	Both
Hereford	8.78 ±0.72 (8.2%) (10)	8.38 ±0.47 (5.6%) (9)	8.59 ±0.62 (7.2%) (19)	8.40 ±0.13 (1.5%) (11)	8.18 ±0.27 (3.3%) (14)	8.28 ±0.22 (2.6%) (25)
Angus	8.20 (1)	7.90 ±0.37 (4.7%) (5)	7.95 ±0.37 (4.6%) (6)	8.37 ±0.43 (5.2%) (6)	7.92 ±0.29 (3.7%) (10)	8.09 ±0.35 (4.3%) (16)
Both breeds	8.73 ±0.72 (8.3%) (11)	8.21 ±0.44 (5.3%) (14)	8.44 ±0.58 (6.8%) (25)	8.39 ±0.27 (3.2%) (17)	8.07 ±0.28 (3.4%) (24)	8.20 ±0.27 (3.3%) (41)

quite different buffer capacities. Note particularly the range in buffer capacities for urines with an initial pH of 8.3, (Figure 10).

Initial pH of Urine (460 pounds) and Initial pH of Urine (800 pounds). There was no correlation between initial pH of urine obtained at 460 pounds body weight and initial pH obtained at 800 pounds body weight.

Initial pH and Buffer Capacity Between Initial pH and pH of 7.4. (Titratable Alkalinity). At 460 pounds, allowing for breed and sex, titratable buffer capacity is correlated ($r=0.76$) with initial pH; 55% of the residual variation in buffer capacity is accounted for by variations in initial pH (Figure 10). Regression coefficients show marked variation in the three subclasses for which estimates are obtainable (only one Angus male) but significance of these differences cannot be established. If the pooled regression estimate is accepted, as neither breed nor sex differences approach significance, a single regression equation may be derived:

$y = 1{,}278 \times - 9{,}922 \pm 594$ (70% of $\bar{y}$)

($y =$ titratable buffer concentration and $x =$ initial pH)

At 800 pounds, if allowance is made for breed and sex differences, a highly significant correlation of 0.68 is found and 45% of the residual variation in buffer capacity is accounted for by variations in the initial pH. Regression differences between breeds and sexes are not significant, although the estimate for males is considerably greater than that for females. Neither breed nor sex differences in titratable electrolyte excretion are significant when allowance is made for variation in initial pH; in particular the sex difference in buffer

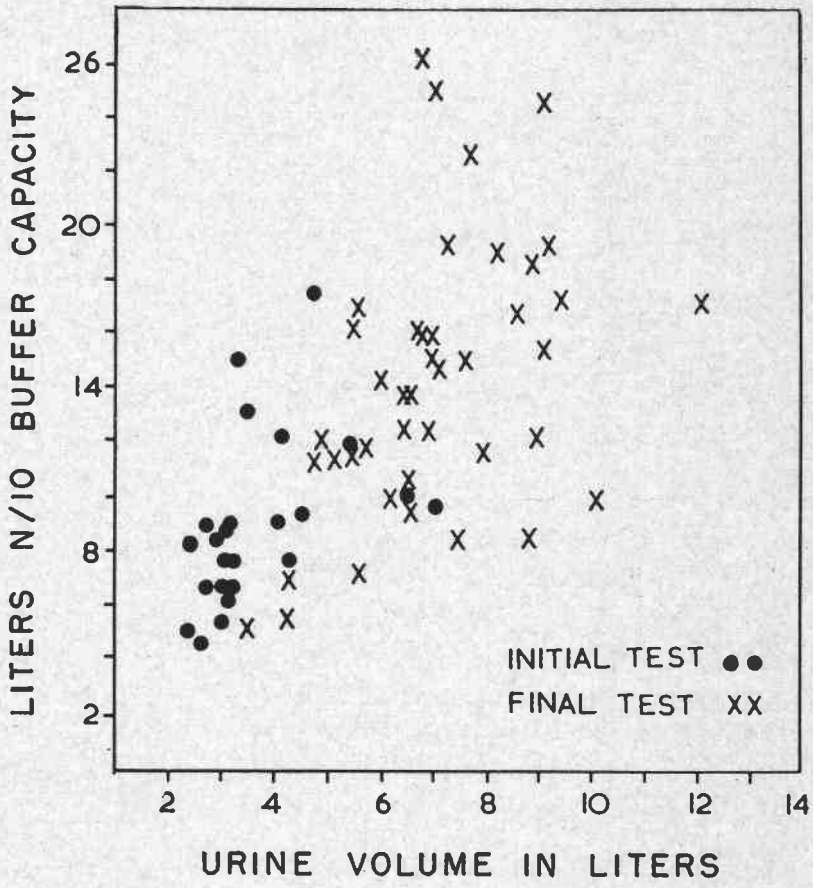


FIGURE 9. Relation of total daily buffer capacity of urine to daily urine volume.

capacity is seen to be associated with a corresponding difference in initial pH. Considering the two sexes separately, but ignoring breeds, the appropriate equations are:

Males: $y = 1{,}315 \times - 9{,}928 \pm 303$ (27% of $\bar{y}$)
Females: $y = 829 \times - 6{,}085 \pm 278$ (46% of $\bar{y}$)

Since the nonsignificant sex differences permits the combining of the data we have:

$y = 1{,}135 \times - 8{,}499 \pm 299$ (37% of $\bar{y}$)

($r = .78$ with 60% of the variance due to regression)

($y =$ buffer capacity between initial pH and pH 7.4 and $x =$ initial pH)

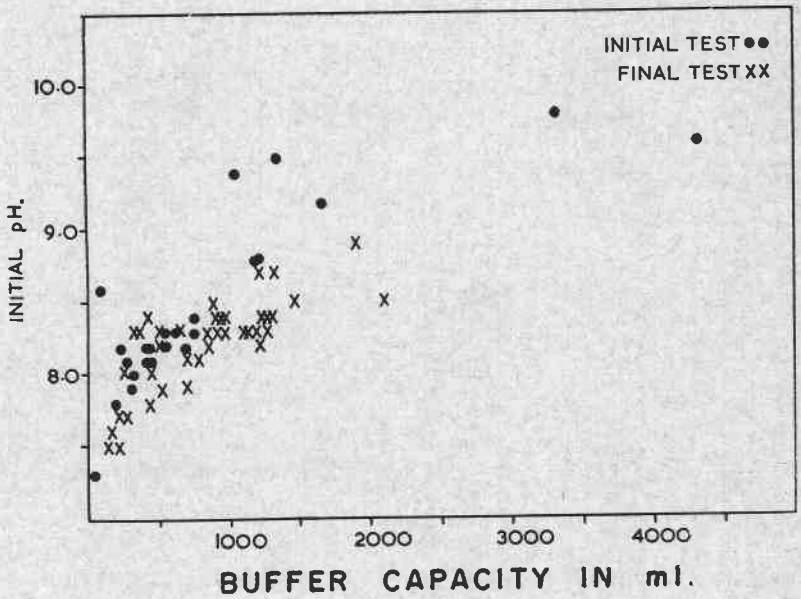


FIGURE 10. Relation of initial pH to buffer capacity over the range from initial pH to pH 7.4.

Initial pH and Buffer Capacity Between Initial pH and pH 10. It was found that at 460 pounds, buffer capacity between initial pH and pH 10 is correlated with initial pH ($r = -0.70$) and that 47% of the variation in buffer capacity was accounted for by variations in initial pH. The regression is positive, but not statistically significant for the Aberdeen Angus animals. For Herefords, the sex difference is not significant, and we find:

(Herefords only) $y = -1{,}430 \times + 14{,}454 \pm 727$ (34% of $\bar{y}$) with $r = -.79$ and variations in initial pH accounting for 60% of the variations in buffer concentration. If the pooled regression is accepted, it is found that the adjusted breed difference is significant, the appropriate equations being:

$y = -1{,}296 \times (+ 13{,}304$ (Hereford) ± 740 (34% of $\bar{y}$)

$y = -1{,}296 \times (12{,}499$ (Aberdeen Angus) ± 740 (34% of $\bar{y}$)

$y =$ titratable buffer capacity between initial pH and pH 10; and

$x =$ initial pH.

Urine pH and Other Factors. The pH of urine, from either the initial or the final test, was not correlated with any of the following factors:

(a) Days from weaning to commencement of test period.

(b) Age at weaning in days.

(c) Age at commencement or completion of test.
(d) Days on test or average daily rate of gain on test.
(e) Total feed, T.D.N., or nitrogen on test.
(f) Average daily consumption of feed, T. D. N., or nitrogen on test.
(g) Efficiency of gain on test.
(h) Total urinary nitrogen, urea nitrogen or ammonia excretion per 24 hours or per ml.

Discussion

Titratable acidity of urine, as determined by the Folin method, (Hawk, Oser, and Summerson, 1951) is expressed in terms of the amount of standard alkali necessary to bring the urine from its original pH to a phenolphthalein end point in the vicinity of pH 8.5 to 9.0. In normal human urine the acid titrated consists almost entirely of the acid phosphate ion (Pitts and Lotspeich, 1946). Additionally, monobasic organic acids are found in the urine, usually as their salts, but in this form they contribute little if anything to the total titratable acidity. As often explained (Hawk, Oser, and Summerson, 1951; Best and Taylor, 1950; Pitts and Lotspeich, 1946; and Henderson and Palmer, 1914), the Folin method is theoretically and physiologically unsound as an exact measure of acid excretion relative to the normal acid-base balance in the body. The situation is even further complicated in studies on herbivores. Many initial pH values are on the alkaline side of the phenolphthalein end point, thus yielding negative values (acid titrations) but values which would reflect the excess excretion of base, relative to normal acid-base balance in the body of the ruminant.

Several interesting points have arisen, the most obvious of which is comparative lack of variation in buffer capacity in the range of pH 7.0 to 9.0 in Herefords at 800 pounds compared to other groups, particularly Herefords in the initial test. Several factors may have contributed to variation between animals during the initial test. Weaning extended over four months, hence while some calves had partially weaned themselves on to irrigated pasture, others consumed hay or concentrates fed in a creep during the immediate preweaning period. Similarly, some cows were giving considerably more milk at weaning than others. Since it has been shown (Ammerman and Thomas, 1952) that the same forage yields different rumen pH and buffering capacity values when fed as hay or grazed as pasture, it is not unlikely that diverse nutritional treatments, prior to placement on the production test diet, had an effect on pH and/or buffering capacity of urine collected concurrently with, and even for some time subse-

quent to any given nutritional treatment. Length of time on the production test diet before the initial urine collection in the metabolism stalls varied, ranging from 11 days to 111 days. However, there was no correlation of this interval with either initial pH or total titratable buffer capacity.

Eggleton (1947) assumed that the titration curve of human urine is a straight line throughout the range from pH 8.0 to pH 4.8. Data obtained in this study (Figures 7 and 8) would suggest that for cattle at least, calculations based on such a generalization must be considered rough if not inaccurate. For there was frequently an alteration in the rate of change of pH per unit addition of acid in the region of pH 6.0. At pH 9.0 the slope of the titration curve was again frequently altered.

Eggleton's results (1946) indicate that in humans the output of NH_3 is fairly closely correlated with urine pH, the ammonia rising as the pH falls. It was shown later (1947) that a relationship existed between urine acidity and ammonia output under all conditions including times when changes in pH were induced by the ingestion or injection of urea. This study shows that there is no significant relationship between urinary ammonia excretion and initial pH or total buffer capacity. Such a finding in ruminants is not surprising in view of McDonald's (1948) ammonia cycle and the low percentage of total nitrogen excretion that appears in the form of ammonia (See Table 10). Furthermore, normal dietary intakes of surplus amounts of cations such as sodium and potassium render the utilization of ammonia for surplus anion excretion compounds quite unnecessary. Nevertheless ammonia can, in specific animals, account for 150 to 2,607 ml. of N/10 HCl at the lower weight and 150 to 2,443 ml. at the higher weight, in the vicinity of pH 9.

Capacity of the kidney to excrete a part of the buffer acid produced in the metabolism of fats and proteins in titratable form enables the nonherbivorous body to conserve its limited stores of fixed base (Pitts and Lotspeich, 1946; and Gamble, 1922). The base is then returned to the venous blood as bicarbonate. When plasma bicarbonate concentration of man is raised above a level of about 31 millemoles, the urine usually becomes alkaline (Sendroy, Seelig, and Van Slyke, 1934). There is in such urine a relatively high concentration of $BHCO_3$ (Gamble, 1922; Marshall, 1922; and Sendroy, Seelig, and Van Slyke, 1934) and in the human the excretion of $NaHCO_3$ may reach several grams per hour. Gamble's results (Gamble, 1922) showed that CO_2 tension and H_2CO_3 concentration in human urine remain relatively constant regardless of variations in total CO_2 and $BHCO_3$ content, so that a high $BHCO_3$ content tends to produce urine of high pH reading.

In highly alkaline urines then, the pH is determined chiefly by the sodium bicarbonate/carbonic acid ratio (Best and Taylor, 1950). In the human where bicarbonate of the plasma is above normal, the urine is alkaline and large quantities of base pass into the urine as bicarbonate. The small quantities of free carbonic acid and bicarbonate present in *acid* urines render these substances of negligible importance in altering the urinary pH as compared with the amounts alkaline and acid phosphates incorporated (Gamble, 1922).

In *alkaline* urines of ruminants, the reverse is true, the amounts of carbonic acid and bicarbonate being of prime importance. This may be seen in the study presented by Dale, Goberdsham, and Brody (1954), who found a decrease of only 8.3% in the total of the concentrations of *carbonate, sulphate,* and *phosphate* between the control period and the last day of starvation in dairy cattle. However, they found a simultaneous 69.3% decrease in *total anions* excreted per 24 hours. Most of this decrease in the excretions of anions was due to the decreased excretion of *carbonate.* As indicated previously, the carbonate concentration in urine measures the difference between the amount of fixed acids and the amount of fixed bases available for excretion. With starvation in the ruminant, two factors are responsible for the decrease in urinary carbonate, i. e., a decrease in fixed base and an increase in fixed acid. The remarkable rise in the excretion of phosphate results because of the conversion from vegetable nutrients, containing large amounts of salts which yield bicarbonates, to the metabolism of body tissues yielding phosphate from organic complexes during starvation.

In a study in which diuresis was induced in dairy cattle (Sellers and Roephke, 1951) in late pregnancy and in midlactation, it was found that normal urine concentrations of magnesium and potassium were inversely proportional to the volume of urine, so that there was no change in absolute excretion of these elements. Contrarily, under conditions of diuresis (3 to 7 times normal) the absolute excretion of calcium, chloride, sodium, and total phosphate was proportional to the volume of urine and these elements were washed out. This is somewhat contrary to the finding (Standbury and Thomson, 1951) that there is a clear parallelism between urinary pH, sodium, potassium, chloride, and bicarbonate. In the study here presented, there was a correlation between urine volume and total titratable buffer capacity.

The failure of initial pH or total buffer capacity to be correlated with rate or efficiency of gain is also not surprising. All animals were offered a well-balanced ration upon which they fed *ad libitum.* However, a correlation between total daily buffer capacity of urine and daily food intake might have seemed a reasonable possibility. The

failure of a correlation between daily buffer capacity and daily food intake may be dependent, among other factors, upon the complex interrelations between food intake, growth requirements, and maintainance requirements. A direct relationship between maintainance metabolism and buffer capacity seem probable, unless there is individual variation in metabolic end products requiring excretion by the kidneys, or individual variation in the loss of important or unimportant carbohydrate and protein factors (organic acids, amino acids, purines, pyrimidines, and others) by the kidneys.

In so far as Na, K, phosphate, amino acids, are impounded in new tissue, in proportions quite different from their proportions in the feed available, no direct relationship between maintenance metabolism end products and growth metabolism end products is expected, as far as these are related to unused and/or finally discarded residues from the food intake requirements associated with maintenance requirements and growth. Further, the end products of catabolic metabolism of maintenance are not necessarily the same as the end products of the catabolic aspects of growth. Thus the failure of a correlation between buffer capacity and rate of gain, efficiency of gain, or daily food intake are explained.

Willinger (1924) found the urine of the ox to have a pH range of 8.6 to 9.0 with a mean of 8.7. Urine from suckling heifer calves had an initial pH range of 7.0 to 8.3, while suckling bull calves excreted urine that was nearly always acid. This is a logical difference between mature and suckling animals because of the difference in composition of a pasture, or a bag and grain, and a milk diet (Brody, 1945). In the present study, postweaning Hereford male calves (Table 12) had the highest average initial pH reading of all groups studied (8.78) while averages for females were somewhat more alkaline than expected from the range listed by Willinger. This may well be because the Oregon State College calves described here were no longer suckling, but were on a grain and alfalfa diet.

Summary

Data from Hereford and Angus male and female calves at 460 and 800 pounds body weight have been presented for daily urine volume, specific gravity, pH, and buffer capacity.

During the 24-hour stay in the matabolism stall, calves lost 28 pounds on the average at 460 pounds and 47 pounds at 800 pounds body weight. Urine accounted for 17% to 75% of the weight loss in individual metabolism tests. There were no sex or breed differences.

Daily volume of urine increase from an average of 3,787 ml. to

7,021 ml. between 460 and 800 pounds body weight. Urine volume increased 94% while body weight increased 74% and the kidneys presumably increased 32% in weight. At 460 pounds, Hereford females put out more urine than Angus females; at 800 pounds Angus females had the greater urine volumes. At 800 pounds Hereford males had greater urine volumes than Angus males. Angus females at 800 pounds had greater urine volume than Angus males.

Urinary specific gravity decreased from 1.036 to 1.027 on the average between 460 and 800 pounds body weight. No breed or sex differences were noted.

Urinary buffer capacity between pH 3 and pH 10 increased 59% and urine volume 94%, while body weight increased 74% between 460 and 800 pounds body weight. At 800 pounds body weight, daily buffer capacity of urine from Hereford males was greater than that of urine from Angus males. At both 460 and 800 pounds body weight the urine of Hereford males had greater buffer capacity than the urine of Hereford females.

Urinary pH at 460 pounds body weight showed a greater range, especially on the alkaline side, than that exhibited at 800 pounds body weight.

Average pH of urine as collected from both male and female Herefords at 460 pounds was higher than at 800 pounds body weight.

At both body weights the urine of Hereford females was more alkaline than that of the Angus females. No difference was found between Hereford and Angus males.

The urinary titration pattern was not linear between pH 4.8 and pH 8.0.

A negative correlation was found between urine volume and specific gravity at 460 pounds, whereas at 800 pounds body weight the correlation was not significant. A correlation between urine volume and total buffer capacity was noted.

There was a correlation between initial pH and buffer capacity between the initial pH and pH 7.4 at both 460 and 800 pounds.

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