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# The Use of Sodium Bicarbonate in Complete Rations for Lactating Cows

Brian C. Bogart
*University of Tennessee - Knoxville*

To the Graduate Council:

I am submitting herewith a thesis written by Brian C. Bogart entitled "The Use of Sodium Bicarbonate in Complete Rations for Lactating Cows." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Science.

Monty J. Montgomery, Major Professor

We have read this thesis and recommend its acceptance:

R. N. Heitman, C. C. Chamberlin

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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C. C. Chamberlain

Accepted for the Council:

L. Evans Roth

Vice Chancellor
Graduate Studies and Research

# THE USE OF SODIUM BICARBONATE IN COMPLETE RATIONS FOR LACTATING COWS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Brian C. Bogart

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## ABSTRACT

Sixty-two Holstein cows were assigned to respective treatments of a randomized complete block design three days postpartum. Complete rations, formulated to meet NRC requirements, were fed during the first 112 days of lactation. Diets contained, on an as-fed basis, 75% corn silage and 25% pelleted concentrate (CS:PC) or (CS:PC) + .5% feed grade sodium bicarbonate added as a percent of the total ration (CS:PC+). In addition, each cow received 5 lb of alfalfa-grass hay daily (as fed).

Data collected weekly included milk yield (lb/d), milk fat (percent), 4% fat corrected milk (lb/d), ration dry matter intake (percent of body weight), and total dry matter intake (percent of body weight). Least-square means values of these parameters were 62.76, 3.30, 56.26, 2.09, 2.44, and 60.91, 3.42, 55.66, 2.19, 2.55 for CS:PC and CS:PC+, respectively. Significant treatment differences were not observed between diets ($P > .05$). Rumen fluid, blood, and additional milk samples were collected at monthly intervals from 27 cows randomly chosen from the total. Acetate-to-propionate ratio and rumen pH values were 2.85, 6.45, and 2.66, 6.31 for CS:PC and CS:PC+, respectively. Blood serum Ca, P, Mg, and Na values (mg/100 ml) were 9.44, 5.25, 2.22, 403.13, and 10.09, 5.40, 2.14, 405.37 for CS:PC and CS:PC+, respectively. Least-square mean values for milk protein (percent), total solids (percent), and solids-not-fat (percent) were 3.95, 12.13, 8.87, and 3.98, 11.93, 8.53 for CS:PC and CS:PC+, respectively. No significant differences could be attributed to diets on data collected monthly ($P > .05$).

Results of this study indicate that incorporation of .5% sodium bicarbonate to complete rations was neither efficacious nor detrimental to dairy cows in early lactation.

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# CHAPTER I

# INTRODUCTION

The effort to maximize milk production and the expression of a cow's genetic potential has led to changes in the philosophies of dairy feeding systems. Many dairy men have experienced a positive production response with an increased level of concentrate feeding and concomitant decrease in the level of long roughage. However, numerous metabolic maladies have been observed in dairy herds fed ensiled forages combined with high levels of concentrate intake and no or limited amounts of hay.

Very early in this century, German nutritionists advocated the use of sodium bicarbonate in dairy herds fed rations with high levels of bakery products or wet brewers grains (1). Guided by research reports over the past decades, the commercial feed industry has placed increased marketing emphasis on the addition of sodium bicarbonate to rations high in soluble carbohydrates.

However, numerous research reports incorporating sodium bicarbonate in complete rations are at best contradictory and at worst chaotic. Therefore, the objective of this study was to examine the effect sodium bicarbonate had on the expression of intake and milk production response and rumen measurements of early postpartum dairy cows.

CHAPTER II

# REVIEW OF LITERATURE

## Chemical Concepts of Buffers

Buffers are substances whose presence in solution causes a resistance to change in the hydrogen ion concentration even while being reacted with acid or alkaline substances. Quintero (100) reported that buffers exist in body fluids as weak acids together with their conjugate bases. Stewart (115) described a weak acid buffer as a pH or $[H^+]$ setter rather than a $[H^+]$ or pH regulator, primarily because it resists change in pH or $[H^+]$ less effectively than the same solution without any weak acid.

Formation of the buffered complex can be shown by a fundamental reversible protolysis reaction (9).

$$HA_1 + A_2 \gtrless HA_2 + A_1$$

Protolysis shows the dissociation of an acid ($HA_1$) with a buffer ($A_2$) to form a buffered complex ($HA_2$) and conjugate base ($A_1$).

The properties of buffered solutions are commonly measured using the equation developed by Henderson and Hasselbalch (69).

$$pH = pk + \log \frac{\mu A_1}{\mu HA_1} + \log \frac{\gamma A_2}{\gamma HA_2}$$

where pk equals the negative log of the equilibrium constant as effected by temperature, $\log \frac{\mu A_1}{\mu HA_1}$ expresses the solution's buffering capacity as

effected by added acid or base and finally log $\frac{\gamma A_2}{\gamma HA_2}$ expresses the solution's salt effect as influenced by the solvent's ionic strength.

Problems are adherent all too many times when pH is the sole criteria used to evaluate the effectiveness of a buffer. A 5% increase in pH from 7.0-7.4 decreases the buffering capacity of the blood bicarbonate system by 250% (69).

Buffer Systems of the Extra-Cellular Fluids

Masoro and Siegel (77) have classified the primary buffer systems in the body as either bicarbonate or nonbicarbonate. The bicarbonate system involves $H_2CO_3$ and $HCO_3^-$ as its buffered pair. The nonbicarbonate system is comprised of individual hemoglobin, phosphate, and plasma protein systems. Winters (133) discovered that 53% of the buffering action was due to the bicarbonate system, and 37% was due to the hemoglobin system. Plasma protein and phosphate systems contributed 7% and 3% of the buffer action, respectively.

Quintero (100) stated that the terms "acidosis" and "alkalosis" describe an overall condition without utilizing pH *per se*. More specifically, acidosis is comprised of a disturbance in respiratory function resulting in primary retention of carbon dioxide ($CO_2$) and/or a disturbance in blood composition resulting in rapid decrease in plasma bicarbonate concentration. Likewise, an alkalotic condition is more specifically one in which respiratory function results in excessive elimination of $CO_2$ and/or a rapid increase in plasma bicarbonate (100).

Houpt (53) reported that acids and bases are continuously added to body fluids in response to normal physiology. However, during disease or conditions of dyspnea, emesis, diarrhea, or renal

insufficiency, the body utilizes three mechanisms to prevent the onset of acidosis or alkalosis (53). All body fluids are supplied with acid base buffer systems which combine immediately with exogenous acid or base to prevent change in hydrogen ion concentration. The respiratory center is also stimulated upon excessive change in hydrogen ion concentration. Baker and Harrison (7) reported that if pH decreased, chemoreceptors regulating pulmonary rate increased and more $CO_2$ is expired in the lungs. Therefore, the bicarbonate-to-$CO_2$ ratio is maintained at 20:1. Conversely, when pH of plasma increases, pulmonary ventilation rate decreases, and $CO_2$ release from the animal is reduced. Regulation of acid base homeostasis is also performed by the kidney where hydrogen ions are either formed and secreted or excreted or retained (53). Baker and Harrison (7) reported that when excessive $CO_2$ accumulates in the plasma, renal tubules absorb more bicarbonate and produce an acid urine in an effort to maintain blood pH. Again, the bicarbonate ratio to $CO_2$ is 20:1. Conversely, if excessive $CO_2$ is exhausted from the lungs, renal tubules excrete a basic urine high in bicarbonate.

Houpt (53) reported that the buffer system can react swiftly to prevent excessive changes in hydrogen ion concentration. Reaction time required for complete restoration of acid base homeostatis ranges from a few seconds to a few days, depending on the primary regulating mechanism (45,53).

Masoro and Siegel (77) reported that the effectiveness of a buffer system is optimized at a pH nearest to pk of its weak acid above and over a range extending one pH unit above and one pH unit below its pk value.

The plasma proteins buffer system. Typical buffering proteins in plasma include albumin and globulin that posses imidazole groups of histidine different from those of hemoglobin. Masoro and Siegel (77) reported that at pH of 7.2, the buffering activity of plasma proteins is limited to either the addition of a proton to the imidazole group when acid is buffered or the removal of a proton from the imidazole group when a base is being buffered. The imidazdole group of histidine has a wide magnitude of pk's, primarily influenced by neighboring amino acid residues (77). With pk values ranging from 5.5-8.5, plasma proteins offer buffer pairs throughout pH ranges commonly incurred in plasma during periods of health and disease. Therefore, it has been concluded that plasma proteins operate in both acidic and basic buffering systems and that the acid system operates antagonistically to the basic system (45).

The hemoglobin buffer system. Sixty percent of the buffering activity possessed by erythrocyte residues when fixed acids are buffered lie within the hemoglobin system (77). Trenkle (121) reported hemoglobin takes up 0.7 meq of $H^+$ per millimole of $O_2$ liberated by oxygenated hemoglobin. Therefore, the importance of the hemoglobin buffer system is paramount.

The majority of the buffering done in the hemoglobin system is performed by the imidazole group of histidine because of the large number of acidic and basic groups its molecule contains (18,23).

Masoro and Siegel (77) reported that N terminal amino acid groups of hemoglobin have a pk of approximately 7.8. They thus serve well as a buffer at the pH of 7.2 found in erythrocytes.

The phosphate buffer system. The classical phosphate buffer system has been described as an inorganic orthophosphate system of dihydrogen phosphate ($H_2PO_4$-) and monohydrogen phosphate ($HPO_4$=) (77). With a pk of 6.8, the acid member $H_2PO_4$- readily donates protons, while its conjugate base, $HPO_4$=, readily accepts them at a pH of 7.4, theoretically making this buffer system an effective one in plasma (77). However, even though its pk value allows this system to buffer plasma at a maximum, its effectiveness is limited. This is primarily due to the fact that the extra-cellular fluid (ECF) is very low and 60% less than bicarbonate buffer (45).

The relationship between phosphate metabolism and the renal tubules of the kidney attest for the inefficiency of this system (45).

The bicarbonate buffer system. Chief buffering components of the bicarbonate buffer system include carbonic acid ($H_2CO_3$) and bicarbonate ($HCO_3$). The overall efficiency of these buffering components are excellent, even though they have several inconsistencies.

Guyton (45) stated that carbonic acid is weak in comparison to other acids. This is primarily due to the fact that 799 out of every 800 $H_2CO_3$ molecules dissolved in the body fluids are dissociated to form $CO_2$ and water (53). However, the bicarbonate system is efficient because the supply of $CO_2$ is plentiful and can be altered rapidly by the rate it is removed by pulmonary respiration (53). In addition, copious amounts of bicarbonate are regulated by the kidney (7,100).

Trenkle (121) reported that the pk of the bicarbonate buffer system is 6.1, an inefficient system at normal pH of 7.4. However, the system's efficiencies are attested by the fact that the body is an open

system whose metabolic activities provide a continuous source of $CO_2$ (77). Thus, the body can once again manipulate the $CO_2$ concentration in the ECF by controlling the rate of pulmonary ventilation as regulated by a biofeedback mechanism.

## The Isohydric Principle

The body fluids of mammals contain each buffer system mentioned in this discussion, in addition to several other smaller systems. Any condition that alters the hydrogen ion concentration of one system alters the overall balance in all systems (45). The isohydric principle relies on the concept that all buffer pairs in a homogenous solution are in equilibrium with the same hydrogen ion (77).

## Buffering Systems in the Rumen

There are three buffering systems of major importance within the rumen. The bicarbonate, phosphate, and volatile fatty acid (VFA) systems play essential roles at normal pH ranges.

Several factors influence the overall efficiency of these systems (34). Both amount and composition of saliva secreted from the parotid and concentration and rate of absorption of end products of microbial fermentation, especially VFA and $CO_2$, regulate efficiency (5,61,122). Final factors include physical forms of the diet, buffers contained in that diet, and the rate of feed passage through the gastrointestinal tract (91). Kromann (68) reported that of these factors, physical form of the diet that affects energy consumption and rate of microbial metabolism within the rumen has the greatest influence on buffering capacity. Rumen buffering capacity of a feed may be accurately measured in pH

ranges of 5.8-6.5 under conditions of high partial pressures of $CO_2$ and VFA titration (81).

The pH of the rumen comes as a result of the complex interactions of the factors influencing efficiency of its buffering systems (68). Maintaining rumen pH is the primary objective of the three buffering systems in the rumen. Changes in rumen pH are caused by movement of differently ionized forms of weak electrolytes in and out of solution (3). In response to reduced rumen pH, both the rumen mucosa and lamina propria become thickened. The papillae become clumped and mucosa folded, which results in the intrapment of food and hair. Hairs penetrate the rumen epithelium and cause an inflammatory reaction (40,63).

VFA buffering system. Kay and Hobson (62) reported that within normal pH, rumen neutrality depends principally on the balance achieved between absorption of VFA and the buffering capacity of contents in the reticulorumen. However, as microbial fermentation in the rumen progresses, VFA accumulate while pH and bicarbonate decline (122). Scott (108) reported that the fall in rumen pH is generally considered to be a combined effect of VFA production together with a reduction in the amount of buffer added to the rumen by saliva.

Rumen VFA becomes a major component to the alteration of hydrogen ion concentration at pH values below 5.5 (122). With a pk of 4.65, it would be expected that rumen VFA acts as an effective buffer system at this pH range (3). Buffer values of VFA in this pH range of 4.0-6.0 were 75.62-80.0β before feeding and reached a maximum range of 123-133.75β one hour after feeding (34). Emmanuel et al. (34) stated that

buffering capacity (β) is expressed as the quantity of titrant (meq titrant/l. rumen fluid) required to bring about two unit changes in pH.

In the rumen, VFA are produced in their acid form, absorbed in an undissociated state, and finally dissociated upon entering the blood (3,70). This allows the plasma to neutralize the fatty acids produced in the rumen through the mediation of tissue buffers (3). The amount of fatty acid neutralized in this way appears to be similar to the amount neutralized by saliva (70).

Phosphoric acid buffering system. Pauling (97) reported that the pk value of the phosphoric acid buffer system was 7.2. Therefore, it can act as an effective buffer at normal rumen pH. Turner and Hodgetts (122) stated that this system reaches maximum efficiency at rumen pH of 7.2 because of the relationship with its pk value. However, at pH values less than 5.5, the phosphate system decreases in efficiency because 98% of its phosphate is undissociated. Phosphate is a weak buffer of rumen fluid because of its low concentration. The phosphate concentration in the fasting rumen has been determined to be 0.025 meq/l, whereas in the fermentating rumen its concentration ranged from 0.01-0.15 meq/l (122).

Counotte et al. (20) agree that phosphate is of little value as a buffer in rumen fluid. However, they did report that the phosphate portion of saliva is of considerable importance in neutralizing acids in the rumen. Phosphate concentration in bovine parotid saliva ranges from 20.6 meq/l (98) to 23 meq/l (6).

Explanations as to why the phosphate system has poor buffering capacity have been offered (20). The average pH of saliva is approximately 8.0. At this pH, 86% of the phosphate is in a monohydrogen

phosphate ($HPO_4^{2-}$) form. As monohydrogen phosphate enters the rumen (pH = 6.25), it will react with $H_3O^+$ in the following reaction:

$$HPO_4^{2-} + H_3O^+ \rightleftarrows H_2PO_4 + H_2O.$$

This reaction will continue until 10% is in the $HPO_4^{2-}$ form and 90% is in the $H_2PO_4^-$ form. Thus, the reaction will raise the pH in the rumen and simultaneously reduce the buffering capacity of the phosphate system.

Bicarbonate buffering system. Emmanuel et al. (34) stated that in view of high $CO_2$ levels in the rumen, it would be obvious that bicarbonate, $HCO_3^-$, with its pk value of 6.37, was the principle buffer system in the rumen. Turner and Hodgetts (122) reported that after microbial fermentation begins, organic acids accumulate. The rising $[H^+]$ is accompanied by a decrease of both $CO_2$ and $[HCO_3^-]$. Rumen pH decreased concomitantly. The overall reaction can be expressed in the following reaction.

$$CO_2 + H_2O \rightleftarrows HCO_3^- + H^+.$$

At rumen pH of 6.25, the bicarbonate buffer system is most important.

The primary mode of action for this system has been explained (3). It lies with the fact that there is a two-way exchange of $CO_2$ across the rumen with the equilibrium lying in the region of blood $CO_2$ partial pressure. In this way, the $CO_2$, which makes up a considerable amount of rumen gas, can be utilized.

Saliva. Saliva, the ruminant's natural buffering agent, maintains fluidity and pH stability of reticulorumen contents (62). Reasons

for the composition and volume of saliva produced have been reviewed (8). Physical form of diet is the primary factor regulating saliva production. Daily saliva production by cattle ranges from 33.5 to 190.1/day (5,99).

Trenkle (121) reported that ruminant saliva is strongly alkaline with a pH of approximately 8.1. Between pH 6 and 7, it has a high buffering capacity due to its high bicarbonate and moderate phosphate content. A cow producing 150 liters of saliva per day with 120 meq/l of sodium bicarbonate would produce 1512 grams of salivary sodium bicarbonate per day (121). Ninety percent of the anion content in parotid saliva is composed of bicarbonate and phosphate (8). Kay and Hobson (62) reported that as the rate of parotid saliva increases, there is a reciprocal rise in sodium bicarbonate content and a decrease in phosphate content.

Enhancement of the total rumen buffering capacity is dependent on the salivary activity of specific glands. Kay (61) reported that parotid, inferior molar, palatine, buccal, and pharyngeal gland saliva is strongly buffered with high levels of bicarbonate and phosphate. Saliva from the submaxillary, sublingual, and labial glands is weakly buffered with low levels of bicarbonate and phosphate (98).

## The Effect of Sodium Bicarbonate on Parameters of Dairy Cows

Sodium bicarbonate is a white crystalline powder prepared from sodium carbonate, water, and carbon (94,132). Sodium bicarbonate is also known as sodium hydrogen carbonate, sodium acid carbonate, or baking soda (94,132). It has a chemical formula of $NaHCO_3$ and is composed of 14.29% C, 1.2% H, 27.37% Na, and 57.14% O (132). Sodium bicarbonate has a molecular weight of 84.01 (132). The bicarbonate of commerce is

on a dry basis 99.8% pure (94). Sodium bicarbonate is used as a gastric antacid, electrolyte replacer, urine alkalinizer, and to combat systemic acidosis (15,94,132).

A partial listing of the research discussed in the following sections can be found on pages 13, 16, 22, and 24.

Milk fat. The economic pressure to reach the maximum of a dairy cow's genetic potential is paramount in today's dairy industry. Emery (33) stated that the average dairy cow sustained strictly on roughage can produce 4500 kg of milk per year, where most possess the genetic potential to produce a minimum of three times that amount with concentrate supplement.

However, milk yield is not the only criterion determining milk value. Rations with wide concentrate-to-forage ratio have been known to cause a decrease in milk fat tests (56,76,84,105). Obviously, fat percent is important in determining economic value of milk. Since the early 1960's, researchers were aware that the addition of sodium bicarbonate would aid in the low milk fat syndrome (24,30,32,83,110,119). Stanley et al. (112) utilized two levels of sodium bicarbonate with four levels of roughage to determine its effects on milk fat concentration. Mid-lactation Holstein cows were fed concentrate according to milk production. Pineapple hay and pineapple bran served as the roughage source and were offered at levels of 5.46 kg, 7.28 kg, 9.10 kg, or 10.90 kg daily as fed. Sodium bicarbonate was fed at 0 or .34 kg per cow per day. Results of this study indicated that sodium bicarbonate caused significant increases in milk fat test at all roughage levels when compared to controls (Table 1). Increase in milk fat test due to sodium bicarbonate

Table 1. Research summary on the influence of sodium bicarbonate on production and rumen parameters of dairy cows in middle lactation

| | | | | | Ration Consumed[1] | | Rumen Data | | | Production Data | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Duration (wk) | No. Cows | Level Fed | Method Fed | Forage (kg) | Concentrate (kg) | Method | $C_2:C_3$ | pH | Milk (kg) | Fat (%) | 4% FCM (kg) | DM Intake (kg) |
| (16) | 10 | | 0 | Complete Ration | 60 CS:40 | $20.6^{a}$ | | | | 26.7 | 3.58 | 25.0 | |
| | | | 2.5% DMB | | | $22.2^{b}$ | | | | 26.5 | 3.43 | 24.2 | |
| (57) | 4 | 36 | 0 | in Concentrate | 2.5 alf hay + $24.6^{a}$ SS | $8.9^{a}$ | ST | $2.95^{a}$ | $6.81^{a}$ | 16.5 | 3.68 | 15.7 | |
| | | | 1.6% | | 3.1 alf hay + $27.0^{b}$ SS | $8.7^{a}$ | | $3.03^{a}$ | $7.14^{b}$ | 17.0 | 3.75 | 16.4 | |
| | | | 5% | | 3.1 alf hay + $28.0^{b}$ SS | $8.2^{b}$ | | $3.22^{b}$ | $7.0^{c}$ | 17.0 | 3.75 | 16.2 | |
| (86) | 5 | 18 | 0g | | 10.6 hay | 8.9 | | | | 22.0 | 3.2 | 20.6 | |
| | | | 157.5 | | 10.5 hay | 9.0 | | | | 22.6 | 3.1 | 21.4 | |
| | | | 455 | | 10.7 hay | 9.1 | | | | 22.0 | 3.2 | 21.1 | |
| (112) | 6 | 12 | 0g | in Concentrate | 4.2 pinebran + | 6.5 | | $1.9^{c}$ | | 17.8 | $2.96^{c}$ | $15.0^{a}$ | |
| | | | 340 | | 4.1 pinebran | 6.5 | | $2.3^{d}$ | | 17.9 | $3.42^{d}$ | $16.4^{b}$ | |
| (112) | 6 | 12 | 0g | in Concentrate | 3.3 pinebran + | $8.6^{a}$ | ST | $2.0^{a}$ | $6.25^{a}$ | 21.3 | $2.63^{a}$ | $16.7^{a}$ | |
| | | | 340 | | 3.1 pine/hay | $8.6^{a}$ | | $2.5^{b}$ | $6.30^{a}$ | 21.1 | $3.24^{b}$ | $18.4^{b}$ | |
| | | | 0g | | 4.9 pinebran + | $6.5^{b}$ | | $2.1^{a}$ | $6.40^{a}$ | 20.1 | $3.04^{b}$ | $17.2^{a}$ | |
| | | | 340 | | 4.7 pine hay | $5.4^{b}$ | | $2.5^{b}$ | $6.70^{b}$ | 21.0 | $3.26^{b}$ | $18.4^{b}$ | |
| (112) | 6 | 12 | 0g | in Concentrate | 2.4 pinebran + | 9.9 | | | | 19.6 | $3.23^{a}$ | $16.9^{a}$ | |
| | | | 357 | | 2.4 pine hay | 9.3 | | | | 19.3 | $3.85^{b}$ | $18.6^{b}$ | |

Table 1. (Continued)

| Reference | Duration (wk) | No. Cows | Level Fed | Method Fed | Ration Consumed: Forage (kg) | Ration Consumed: Concentrate (kg) | Rumen Data: Method | Rumen Data: $C_2:C_3$ | Rumen Data: pH | Production Data: Milk (kg) | Production Data: Fat (%) | Production Data: 4% FCM (kg) | Production Data: DM Intake (kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (56) | 2 | 6 | 0g | in Capsules | 17.6 hay | pelleted corn | ST | | 6.6 | 11 | 4.2 | 11.4 | .82$[a] |
| | | | 174 | | 17.6 hay | pelleted corn + 2% urea | | | 6.4 | 9.6 | 3.7 | 9.1 | 1.1 [b] |
| (113) | 3 | | 0g | in Concentrate | 18.2 CS + 4.6 pinebran | 11.4 | | | | 23.5 | 3.29 | 20.5 | |
| | | | 205 | | | | | | | 23.8 | 3.55 | 21.9 | |
| | | | 318 | | | | | | | 23.9 | 3.32 | 21.1 | |

DMB = Dry matter basis.

g = Gram.

% = Percent of concentrate.

alf = Alfalfa.

pine = pineapple.

CS = Corn silage.

[a,b]Values with unlike superscripts are significantly different ($P < .05$).

[$]Percent of body weight.

ST = Stomach Tube.

conc = Concentrate.

$C_2:C_3$ = Acetate to propionate ratio.

[1]DM Basis.

SS = Sorghum silage.

supplementation was highest for animals fed 7.28 kg of roughage. The increase in milk fat test was 23.2% ($P < .05$). Along with their inherent differences, several similarities can be observed among these studies (88). Experiments were short in duration, lasting only 21-63 days. Wide ranges in amount and quality of roughage were used. When concentrates were offered, they were on an ad libitum basis. Cows were assigned to experimental treatments after reaching peak lactation. Complete rations were not used.

Feeding dairy cows complete rations with or without sodium bicarbonate in early lactation did not increase milk fat percent when alfalfa or grass hay served as the roughage source (36,66,124). However, a cooperative effort was undertaken by four universities feeding dairy cattle a complete ration of 50% corn silage and 50% concentrate (17). Sodium bicarbonate was supplemented at 0%, .4%, .8%, and 1.6% as a fraction of total dry matter. Results indicated that actual milk fat percents were significantly ($P < .05$) effected by treatment (Table 2). Means of treatments were 3.40, 3.44, 3.39, and 3.56 over an entire lactation.

Factors contributing to the low fat milk syndrome have been reviewed (2,25,33,56,72,126). Rations offering high amounts of energy-rich digestible concentrates from ensiled forages and concentrates and restricting amounts of long roughage with suitable buffering capacity promote this syndrome. The concentration of acetic acid decreases in molar percent, but its production rate is changed slightly, if at all (33). The concentration of acetic acid in the blood is reduced due to decrease entry from endogenous (nonruminal) sources (33). Ruminal propionic acid production and blood plasma glucose were both increased.

Table 2. Research summary on the influence of sodium bicarbonate on production and rumen parameters of dairy cows fed complete rations in early lactation

| | | | | | Rumen Data | | | Production Data | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Duration (wk) | No. Cows | Level Fed (%) | Forage: Concentrate Ratio | Method | $C_2:C_3$ | pH | Milk (kg) | Fat (%) | 4% FCM (kg) | DM Intake (kg) |
| (17) (111) | 19[1] | 149 | 0 DM8 | 50 CS:50 | | 2.13 | 6.33 | 30.7 | 3.40[c] | 27.94 | 19.9 |
| | | | .4 | | ST | 2.17 | 6.46 | 32.0 | 3.44[c] | 29.31 | 19.6 |
| | | | .8 | 60 CS:40 | | 2.43 | 6.49 | 32.2 | 3.39[c] | 29.25 | 19.6 |
| | | | 1.6 | | | 2.30 | 6.45 | 29.2 | 3.56[d] | 27.2728 | 19.2 |
| (35) | 8 | 10 | 0 DMB | 40 CS:60 | | | | 35.9 | 3.50 | | 17.5[c] |
| | | | 1.5 | | | | | 35.2 | 4.2 | | 19.9[d] |
| (36) | 8 | 20 | 0 DMB | 40 CS:60 | ST | 1.70[c] | 6.46 | 34.5[e] | 3.80 | 32.5[a] | 18.5[c] |
| | | | 1.5 | | | 2.16[d] | 6.52 | 36.1[f] | 3.96 | 35.1[b] | 20.7[d] |
| (66) | 9 | 45 | 0 DMB | 60 CS:40 | ST | 2.46 | 6.7 | 29.7[c] | 3.88 | 28.9[a] | 18.9[a] |
| | 11 | | .72[2] | | | 2.75 | 6.6 | 32.5[d] | 3.92 | 31.9[b] | 21.4[b] |
| | 9 | | .6+.72[3] | | | 2.74 | 6.6 | 32.5[d] | 3.90 | 31.7[b] | 19.7[ab] |
| (67) | 14 | 12 | 0 DM8 | 50 CS:50 | | 1.59 | 6.70 | 27.6 | | | 2.49% |
| | | | .8 | | | 1.76 | 6.36 | 30.3 | | | 2.75 |
| (74) | | | 0 TD | 35% NDF alf:0 | | | | 18.5 | 3.08 | 16.9* | 16.8 |
| | | | .75 | 35% NDF alf:0 | | | | 18.7 | 3.37 | 17.3* | 17.2 |
| (74) | | | 0 TD | 35% NDF C8:0 | | | | 16.1 | 2.88 | 14.9* | 17.0 |
| | | | .75 | 35% NDF C8:0 | | | | 18.4 | 3.11 | 16.9* | 16.8 |
| | | | 0 TD | 26% NDF C8:0 | | | | 19.6 | 2.47 | 16.4* | 17.1 |
| | | | .75 | 26% NDF C8:0 | | | | 20.5 | 2.84 | 18.5* | 17.3 |

Table 2. (Continued)

| Reference | Duration (wk) | No. Cows | Level Fed (%) | Forage: Concentrate Ratio | Rumen Data | | | Production Data | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Method | $C_2:C_3$ | pH | Milk (kg) | Fat (%) | 4% FCM (kg) | DM Intake (kg) |
| (124) | 16 | 8 | 0 DMB | 30 HCS:70 | | | | 40.1 | 3.43 | 36.6 | |
| | | | 1 | | | | | 38.5 | 3.41 | 35.1 | |

[a,b]Values with unlike superscripts are significantly different ($P<.01$).

[c,d]Values with unlike superscripts are significantly different ($P<.05$).

[e,f]Values with unlike superscripts are significantly different ($P<.1$).

TD = Total diet (as fed).

DMB = Dry matter basis.

% = Percent of body weight.

CS = Corn silage.

CB = Coastal Bermudagrass

alf = Alfalfa.

HCS = Hay crop silage.

NDF = Neutral detergent fiber.

ST = Stomach tube.

[1]First 16 weeks forage to concentrate ratio 50:50; last 3 weeks forage to concentrate ratio 60:40.

[2]0% sodium bicarbonate prepartum, .72% sodium bicarbonate postpartum.

[3].6% sodium bicarbonate prepartum, .72% sodium bicarbonate postpartum.

$C_2:C_3$ = Acetate to propionate ratio.

*Solids corrected milk.

Between cow variation is large for severity or milk fat reduction, which could be due to the enhanced production by the rumen of butyrate in lieu of propionate. Proporations of trans-octadecenoic in milk and fat are increased, but changes in the concentration and mammary extraction of blood fat are equal.

Milk production. The effect of sodium bicarbonate on milk production has been quite variable. Many studies have reported either decline (30,32,83,112) or no change (31,82) in milk yield during supplementation. Ibbetson (57) fed two different groups of dairy cattle forage sorghum silage ad libitum and 3.6 kg of alfalfa hay per day. Flaked milo was offered to a maximum of 9.1 kg per head daily, to which sodium bicarbonate was added at a rate of 0, 1.6, or 5.0% of the total grain mix. Milk production for all cows was 16.5, 17.0, and 17.0/d, respectively (Table 1, page 13). Means across high-producing cows (those producing a minimum of 22.7 kg daily at the beginning of the study) were 21.2, 23.0, and 22.5 kg per head per day, respectively. Although differences were not significant, the effects of sodium bicarbonate on milk production when all 36 animals were considered appears to be negligible. However, when only nine high-producing cows were considered, it appears that those animals receiving the buffer produced more milk.

Studies employing sodium bicarbonate in complete rations show similar inconsistencies. Milk production was slightly decreased when a 60:40 complete ration of corn silage and concentrate was offered to cows in mid-lactation (16). Sodium bicarbonate composed either 0 or 2.5% of total ration. Corn silage was the sole roughage and was mixed on a dry matter basis. When compared to controls, cattle consuming the

treated ration produced .2 kg/day less milk (26.7 kg vs. 26.5, Table 1, page 13).

Vandenmark et al. (124) assigned early postpartum Holstein cows to one of two treatments. These were either a control or treated with 1% sodium bicarbonate. All cows received a total mixed ration of 70% concentrate:30% haycrop silage (D.M. basis) throughout the 112-day study. Cows on control treatment produced an average of 40.1 kg of milk per day, whereas animals on the sodium bicarbonate treatment produced an average of 38.5 kg of milk daily (Table 2, page 16).

An isonitrogenous and isocaloric complete ration was fed in a Pennsylvania study (66). Holstein cows were assigned to one of three dietary treatments: a control, control prepartum with .72% sodium bicarbonate (total ration dry matter) postpartum, or .6% sodium bicarbonate prepartum and .72% sodium bicarbonate postpartum (total ration dry matter). Cattle were abruptly switched from a complete ration of 85% chopped grass hay:15% concentrate prepartum (total ration dry matter) to 60% corn silage:40% concentrate (total ration dry matter) on the fourth day postpartum. Actual milk (kg/d) and 4% fat corrected milk (kg/d) production was 29.7 and 28.9 for the control group, 32.5 and 31.9 for the control prepartum with .72% sodium bicarbonate postpartum, and 32.5 and 31.7 for the .6% sodium bicarbonate prepartum and .72% postpartum sodium bicarbonate group. Milk production and FCM was significantly ($P < .05$) lower in the control groups than buffered groups (Table 2, page 16.)

Erdman et al. (36) experienced a significant ($P < .1$) 1.6 kg per day increase in milk yield by adding sodium bicarbonate to a corn silage based ration (Table 2, page 16). Milk yield mean for the control

treatment was 34.5 vs. 36.1 kg/d for buffered treatments. Significant FCM increase was also seen for cows receiving sodium bicarbonate ($P < .01$). Means were 32.5 and 35.1, control vs. treated.

Chase et al. (17) investigated the milk yield response to four different levels of sodium bicarbonate in early lactation. For the first 112 days of lactation, completely mixed rations consisting of 50% corn silage and 50% concentrate that contained 0, .4, .8, and 1.6 sodium bicarbonate added as a percent of total ration dry matter were used. Covariate adjusted means for milk production were 30.7, 32.0, 32.2, and 29.2 kg/d, respectively (Table 2, page 16).

*Feed intake*. Common criticism reported concerning the supplementation of sodium bicarbonate to dairy rations has been a decrease in dry matter intake. Ration palatability has been significantly decreased when sodium bicarbonate is added at a rate greater than 2.2 kg (56,105, 118,119). Obviously, a decrease in palatability is concomitant with a decrease in dry matter intake.

Stout et al. (116) fed mid-lactating dairy cattle alfalfa hay *ad libitum* with a pelleted concentrate that contained either 0% or 1.5% mixture of sodium and potassium bicarbonate. Intake as a percent of that which was offered was higher with the control concentrate than with the concentrate containing the bicarbonate buffers (75.5% vs. 41.33%). However, it was concluded from this study that the occurrence of the decreased intake of mixed buffers was systemic in nature. It was not due to the taste of the buffered mixtures. This agrees with the findings of Muller et al. (87), who concluded that dairy cattle did not consume sodium bicarbonate to a specific attitude or need.

Studies with sodium bicarbonate in early lactation have shown it to benefit dry matter intake. Kilmer et al. (66) found that addition of .72% sodium bicarbonate to a postpastum corn silage based ration significantly increased ($P < .01$) dry matter intake as percent of body weight when compared to controls (3.51 vs. 3.04). Erdman et al. (36) obtained similar results with a diet of corn silage and concentrate mixed as a complete ration on a 40:60 dry matter ratio. Results indicated that cattle fed the buffered ration containing 1.5% sodium bicarbonate (total ration dry matter) consumed 2.2 kg per day greater dry matter intake than those fed control rations (Table 2, page 16). Significantly different ($P < .05$) means were 18.5 vs. 20.7 for control and treated rations, respectively.

Donker and Marx (27) utilized 1.5% sodium bicarbonate in the concentrate to evaluate its effects on feed intake throughout an entire lactation (Table 3). Concentrate was fed at 1 kg per 2 kg milk above 9.1 kg milk daily. Holstein cattle were assigned to either the control or treated diet with equal quantities by weight of corn silage and alfalfa haylage.

Results indicated that concentrate consumption between groups was equal. Cows of the bicarbonate group consumed significantly more forage throughout lactation ($P < .02$) and the crude fiber content of that dry matter consumed was significantly higher ($P < .01$). The incorporation of 1.5% sodium bicarbonate to the concentrate caused animals offered that treatment to consume a significantly greater amount of dry matter as a percent of body weight. Controls ate 3.35% of body weight

Table 3. Research summary on the influence of sodium bicarbonate on production and rumen parameters of dairy cows in late and throughout lactation

| Reference | Duration (wk) | No. Cows | Level Fed (g) | Ration Consumed: Forage (kg) | Ration Consumed: Concentrate (kg) | Method Fed | Rumen Data: Method | Rumen Data: $C_2:C_3$ | Rumen Data: pH | Production Data: Milk (kg) | Production Data: Fat (%) | Production Data: 4% FCM (kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (31) | 3 | 6 | 0 | .9 alf hay** | 12.1** | | ST | 1.76 | 6.00 | 14.1 | 2.8[a] | 11.3 |
| | | | 2.2 | | 8.8** | | ST | 3.0 | 6.46 | 13.6 | 3.66[b] | 12.9 |
| | 4 | 10 | 0 | 1.4 hay** | 13.0** | | | .61 | 6.44 | 19.3 | 2.28[c] | 14.3 |
| | | | 2.2 | | 11.4** | | | 1.27 | 6.46 | 19.4 | 3.14[d] | 16.9 |
| (27) | 52 | 62 | 0 DMR | CS alf hay[$] | 1 kg/2 kg milk above 9.1 kg | in Concentrate | | | | | 3.71[e] | 24.1 |
| | | | 1.5* | | | | | | | | 3.78[f] | 24.6 |

[a,b]Values with unlike superscripts are significantly different (P<.01).

[c,d]Values with unlike superscripts are significantly different (P<.05).

DMB = Dry matter basis.

CS = Corn silage.

ST = Stomach tube.

alf hay[$] = alfalfa haycrop silage.

% = Percent of body weight

$C_2:C_3$ = Acetate to propionate ratio.

*Percent of concentrate.

**As fed basis.

[e,f]Values with unlike superscripts are significantly different (P<.005).

alf hay = alfalfa hay.

daily, whereas experimental cows consumed 3.46% of body weight daily ($P < .02$).

Possible explanations for an increased intake could be either the free acid content of silage was partially neutralized by the sodium bicarbonate (80), or sodium bicarbonate may have stabilized rumen fermentation and reduced the fluctuating pH cycles in the rumen.

VFA production. Muller (89) discussed the pattern of VFA production in response to high concentrate restricted forage rations. The supplementation of sodium bicarbonate has been shown to be effective in changing the end products of fermentation. The overall effect of sodium bicarbonate on the composition of VFA from dairy cattle fed restricted roughage rations has been discussed (123). These include a higher molar percent acetate and lower molar proportion of propionate. Variable responses include a higher molar percent of butyrate, an increase in rumen pH, and a decrease in lactate concentration.

Thomas and Emery (119) fed dairy cattle a ration of 1.36 kg alfalfa hay, 4.08 kg corn silage, and 11.1 kg concentrate, in addition to three levels of sodium bicarbonate. The levels of sodium bicarbonate were 0, 272, or 363 g. Results of this study showed that when compared to controls, buffered rations increased proportions of acetic acid ($P < .0005$) and isovaleric acid ($P < .01$) but decreased propionic, valeric ($P < .0005$), and caproic ($P < .05$) acids (Table 4). The pH of rumen contents were not significant (Table 4).

Emery and Brown (30) fed fistulated dairy cattle a ration of 5.4 kg alfalfa hay and 3.63 kg of grain and compared it with a ration of 6.35 kg grain and 454 g of dehydrated alfalfa meal with or without 454 g

Table 4. Research summary on the influence of sodium bicarbonate on production and rumen parameters of dairy cows in unclassified stages of lactation

| | | | | | Ration Consumed[$] | | Rumen Data | | | Production Data | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Duration (wk) | No. Cows | Level Fed (kg) | Method Fed | Forage (kg) | Concentrate (kg) | Method | $C_2:C_3$ | pH | Milk (kg) | Fat (%) | 4% FCM (kg) |
| (30) | 5 | 12 | 0 | in | .9 alf hay | 10.9 | | | | 12.7 | 3.4[a] | 11.6 |
| | | | 2.2 | concentrate | | | | | | 12.5 | 3.7[b] | 11.9 |
| | 6 | 6 | 0 | | .9 kg alf pellets | 10.9 | | | | 10.8 | 2.1[a] | 7.7 |
| | | | 2.2 | | | | | | | 11.0 | 2.9[b] | 9.2 |
| (30) | | | 0 | | 5.4 alf hay | 3.6 | Fistulated | 4.30 | 6.3[f] | | | |
| | | | 0 | | .45 alf pellets | 6.4 | (non- | 3.72 | 5.8[d] | | | |
| | | | 2.2 | | .45 alf pellets | 6.4 | lactating) | 3.70 | 6.4[c] | | | |
| (32) | 4 | 12 | 0 | | 1.8 hay + | 11.0 | ST | 1.10 | 6.18 | 16.8 | 2.68[f] | 13.5 |
| | | | .36 | | .9 alf pellets | 10.3 | | 1.51 | 6.39 | 15.8 | 3.12[e] | 13.7 |
| (104) | | 2 | 0 | | 8.2 alf hay** | 16.1** | Fistulated[1] | 4.44 | 6.71 | | | |
| | | | .36 or | | 8.9 alf hay** | 16.1** | | 4.46 | 6.97 | | | |
| | | | .72 infused | | 9.1 alf hay** | 16.1** | | 4.37 | 6.97 | | | |
| (83) | 3 | 8 | 0 | in | .9 alf hay | 14.9 | ST | 1.32 | 5.85 | 17.5 | 2.92[a] | 14.7 |
| | | | .38 | concentrate | | 14.2 | | 1.73 | 6.00 | 17.0 | 3.56[b] | 15.9 |
| (39) | 3 | | 0 | | 1 part chop alf hay | | Fistulated | 1.46[a] | 5.5[c] | | | |
| | | | 9-12 moles | | to 2 parts pellet | | (lactating) | 2.82[b] | 6.2[d] | | | |
| | | | continuous | | DMI 14.5-18.1 | | | | | | | |
| | | | infusion | | | | | | | | | |

Table 4. (Continued)

| | | | | | Ration Consumed | | Rumen Data | | | Production Data | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Duration (wk) | No. Cows | Level Fed (kg) | Method Fed | Forage (kg) | Concentrate (kg) | Method | $C_2:C_3$ | pH | Milk (kg) | Fat (%) | 4% FCM (kg) |
| (110) | 8 | 8 | 0 | in | 4.5 hay | 13.6 | | 1.07 | 6.4 | 14.3 | 1.17[c] | 8.2[c] |
| | | | .41 | concentrate | | | | 1.90 | 6.4 | 17.6 | 2.73[d] | 14.2[d] |
| (119) | | | 0 | | 1.36 alf hay + 4.08 CS | 11.1 | ST | | 6.67 | 17.1 | 2.82[a] | 14.1 |
| | | | .27 or .36 | | 3.60 CS + 1.36 alf hay | 11.1 | | | 6.77 | 17.2 | 3.17[b] | 15.1 |

[a,b]Values with unlike superscripts are significant ($P<.01$).

[c,d]Values with unlike superscripts are significant ($P<.05$).

[e,f]Values with unlike superscripts are significant ($P<.06$).

DMI = Dry matter intake.

ST = Stomach tube.

alf = Alfalfa.

CS = Corn silage.

DMI% = Dry matter intake as a percent of body weight.

[1]Holstein steers utilized.

$C_2:C_3$ = Actetate to propionate ratio.

[§]As fed.

**DM basis.

of sodium bicarbonate. Although sodium bicarbonate treated ration reduced lactate levels by 50%, differences were not significant. Significant treatment differences were observed between the low roughage and low roughage with sodium bicarbonate for rumen pH (Table 4). Values were 5.8 and 6.4, respectively ($P < .05$).

Emergy et al. (31) fed dairy cattle 0.9 kg alfalfa hay daily and either a grain mix offered ad libitum or supplemented with 454 g of sodium bicarbonate. Results of this study indicated significant ($P < .05$) increases in the molar percentages of acetic and butyric acids and a decrease in propionic acid (Table 3, page 22.)

Snyder et al. (111) recently conducted research where sodium bicarbonate was added to a complete ration at 0, .4, .8, and 1.6% of total ration dry matter. Lactating cows received a complete diet of 50% corn silage and 50% concentrate from day 1 until day 112 of the trial. On day 113 postpartum, diets were changed to yield a 60:40 silage-to-concentrate ratio. Results indicated a trend toward a wider acetate: propionate ratio developed when sodium bicarbonate was added at .4 and .8 levels (Table 2, page 16). Means were 2.13, 2.17, 2.43, and 2.30 for these diets, respectively. However, no significant differences were evident among diets for individual VFA (Table 2, page 16).

Hall and Thomas (48) utilized an in vitro technique to evaluate the effect of sodium bicarbonate upon rumen fermentation parameters. In both the roughage and concentrate experiments, treatments were a positive control, negative control, or buffer. The positive control consisted of one part rumen fluid and four parts artificial saliva. In the negative control, three-fourths of the artificial saliva was

replaced by isosmotic saline. Buffered treatment was identical to that of the negative control with the exception of the addition of sodium bicarbonate at 500 mg/100 mls. Results indicated that in both experiments sodium bicarbonate significantly elevated pH levels ($P < .05$). In the roughage experiment, sodium bicarbonate increased production of acetate, propionate, and total VFA. Molar percent acetate was increased, but molar percent butyrate was decreased.

Most fermentations of carbohydrates in the rumen proceed via a pyruvate intermediate. The disparity between experimental results become clear when one realizes the alternate pathways by which pyruvate can be metabolized and the relationship that must exist in the production of VFA (123). Results are not only dependent upon amounts of sodium bicarbonate, type of diet, and adaptative changes in the population of microflora, but also on inherent differences between experimental technique (e.g., time of sampling and method of sampling) (39,121,123).

Blood. Few studies have been conducted to measure the effect of sodium bicarbonate on blood serum and/or plasma constituents.

Huntington et al. (55) added sodium bicarbonate at two levels, 2% and 4%, as aids in feeding high concentrate diets to lambs. Results of this work indicated that when compared to controls, animals consuming the buffered diets had significantly lower ($P < .05$) blood serum calcium levels. Least-square mean values for control animals in mg/100 ml were 9.62 on collection day 29 and 10.10 on collection day 97. Least-square mean values on day 29 and day 97 were 9.24 and 9.34 and 8.35 and 7.70 mg/100 ml for the 2% and 4% levels, respectively. Other minerals were not altered by treatment.

When sheep consumed a diet containing 2.5% sodium bicarbonate (dry weight of diet), levels of VFA in their blood were lower than that of controls (14). Oddly enough, sheep receiving the alkali treatment had significantly higher rumen fluid pH and total VFA ($P < .01$).

Kronfeld et al. (71) investigated blood responses to sodium bicarbonate addition during early lactation. No major differences between diets were found in blood PCV, total protein, Na, K, Ca, or P. Blood pH and bicarbonate increased significantly with dietary sodium bicarbonate but remained in normal ranges.

A recent study was conducted to characterize the physiological and metabolic changes in blood and serum of early postpartum dairy cows fed complete rations with or without sodium bicarbonate (67). Holstein cows were assigned to either a control or buffered ration containing .8% sodium bicarbonate. Complete rations consisted of 50% corn silage: 50% concentrate on a dry matter basis. Results of this study indicated that cattle consuming the buffered ration had significantly ($P < .10$) higher volumes of red blood cells (5.90 vs. $5.49 \times 10^6/mm^3$), serum calcium (9.1 vs. 8.7 mg/100 ml), and serum nitrogen (15.1 vs. 12.7 mg/100 ml) than controls. However, changes in most characteristics could not be attributed to treatment.

## Ration Adaptation

Kaufmann et al. (60) discussed several aspects concerning ration adaptation. However, their report failed to discuss the important role sodium bicarbonate plays in ration adaptation (64,101).

Emerick (29) adapted steers to high concentrate diets over a period of three to four days by increasing the corn and supplement

portion of the diet by 2.3 kg per animal daily when feeding 1.4 kg of haylage (50% moisture) daily. Treatments were control or 4% sodium bicarbonate that used six to eight steers per treatment. Weight gain advantages of 62% for sodium bicarbonate were observed during the initial 15-day period.

Patton (96) backgrounded lambs for 30 days on alfalfa pellets. They were abruptly changed to an 85% barley, 12% alfalfa, and 3% molasses plus 3% sodium carbonate diet. The respective average daily feed consumptions were 1.45 kg for controls and 1.65 kg for the buffered group during the first 10 days.

In these studies, it can be concluded that sodium bicarbonate is beneficial only for adaptation during the initial period and not for sustained periods through the finishing period (28).

In dairy cattle feeding programs, the necessity of immediate adaptation to concentrate feeding is increased because of the rapid rise in milk production during the first 30-60 days of lactation (85). The application of sound nutritional management is essential at this time (78,88).

Moseley et al. (85) used 68 early postpartum dairy cows to determine the effect of abrupt changes in forage-to-concentrate ratio of complete feeds. Dry matter ratios for forage-to-concentrate were either 60:40 or 40:60 with the forage component composed of equal parts of corn and haycrop silage. On day 84 postpartum, 17 of these cows consuming the 60% forage ration were switched to 40%, and 17 of those on the 40% were switched to 60%. Abrupt increases in concentrate caused an increased consumption of dry matter and energy, yield of milk,

percent milk protein and solids corrected milk, ruminal concentrations of propionate and total acids, and decreased concentration of butyrate and acetate-to-concentrate ratio. Increased forage had opposite effects.

In another study on abrupt changes of complete rations in early postpartum cows, no adverse effects on health, feed intake, milk production, milk constituents, or rumen environment were observed (51).

Erdman et al. (35) fed dairy cattle a prepartum ration of primarily alfalfa hay and then abruptly switched rations four days after calving (Table 2, page 16). Postpartum ration was a 40:60 complete feed of corn silage and concentrate on a dry matter basis. Sodium bicarbonate was supplemented at either 0 or 1.5% of the total ration dry matter. Results indicated that control cattle had dry matter intake and milk fat percent of 17.5 and 3.5. Values of these parameters from sodium bicarbonate treated cattle were 19.9 and 4.2. Sodium bicarbonate appeared to decrease milk production somewhat. Values in average kg daily were 35.9 and 35.2 for control and treated, respectively.

Kilmer et al. (65), in a preliminary study, fed chopped hay and concentrate (85:15) prepartum to dairy cows. The diet was then changed four days after parturition to a corn silage concentrate diet (60:40) ad libitum. The preliminary summary of results indicated that animals receiving sodium bicarbonate at .6% of the total ration peaked earlier postpartum and had significantly higher milk yields, dry matter intake as a percent of body weight, and 4% fat corrected milk ($P < .05$) than those fed the control ration.

Animal Health

Obviously, the most pronounced effect of sodium bicarbonate on today's lactating dairy cattle is stabilizing the rumen to allow a maximum of production and intake. However, the effect of sodium bicarbonate on animal health has not been extensively researched.

Kronfeld (70) reported that the addition of sodium bicarbonate to ruminant diets provides elements beneficial to the kidney in combating a high load of exogenous organic acids. Mackey (75) indicated that supplementary sodium bicarbonate at a rate of approximately .04 g per 90.9 kg of body weight may substantially prevent subacute and chronic conditions caused by lactic acid acidosis. Weinberg and Hallman (130) reported that when sodium bicarbonate was fed free-choice, the incidence of displaced abomasum decreased. Daugert and Garanch (22) added sodium bicarbonate to corn silage prior to feeding. They observed lower concentrations of ketone bodies in the blood and urine of lactating cows. Sodium bicarbonate has been found to relieve heat stress on lactating dairy cows in a tropical climate (113). Cattle in mid-lactation were fed 0, 1.8, or 2.8% sodium bicarbonate added to the grain portion of their ration. Forage consisted of 18.2 kg of corn silage and 4.6 kg pineapple bran daily. Results showed that milk production, 4% FCM, and milk fat percent tended to increase with sodium bicarbonate addition (Table 1, page 13). Means for parameters were 23.52, 23.76, and 23.86 milk yield daily, 20.54, 21.85, and 21.12 kg FCM daily, and 3.29, 3.55, and 3.32% fat for 0, 1.8, and 2.8% levels, respectively.

The addition of sodium bicarbonate to ruminant rations has also caused detrimental consequences. Milk bloat appeared to be aggravated

by inclusion of 2.2 kg sodium bicarbonate to concentrate rations of lactating cows fed either 0.9 kg of long or pelleted hay per day (30). Ojeten and Davis (93) stated that low rumen pH associated with the feeding of high concentrate diets may release carbon dioxide from the bicarbonate produced. They theorized that buffers increased the concentration of rumen bicarbonate, resulting in an increased incidence of bloat. The effects of two levels of phosphorous with or without sodium bicarbonate on the formation of phosphatic urinary calculi was investigated (52). Wether lambs were fed a corn-soybean based diet with either .28% or .55% P and 0% or 2% sodium bicarbonate. Feeding these phosphorous levels without sodium bicarbonate produced calculi in 8% and 85% of the lambs, respectively. With the inclusion of 2% sodium bicarbonate in the feed, the low phosphorous group exhibited a 58% incidence, and the high phosphorous group had an 88% incidence of urinary calculi.

# CHAPTER III

# EXPERIMENTAL PROCEDURE

## Objective

Two continuous 16-week feeding trials were conducted to evaluate 1) ruminal measurements and 2) intake and milk production responses of early postpartum Holstein cows fed corn silage and pelleted dairy concentrate with or without sodium bicarbonate. These trials were conducted from September 1978-May 1979 and from September 1979-May 1980.

## Animal Management

Sixty-two Holstein cows from The University of Tennessee, Knoxville herd were randomly assigned to respective treatments according to age three days postpartum. During the experimental period, cows were housed in individual tie stalls of a stanchion feeding barn equipped for obtaining daily feed intake. Each animal was observed individually for any abnormality in feed intake or milk production during early lactation. Cows were exercised twice daily at milking and expressions of estrous were observed during this time. Cows commencing their first lactation were classified as initial lactation cows. Similarly, cows beginning their second through seventh lactation were classified as second and later lactation cows.

## Treatment Constituents

Fresh corn silage was mixed by hand with treatment constituents prior to each feeding to assure a constant 3:1 forage-to-concentrate

ratio on an as-fed basis. Treatment I consisted of a complete ration of corn silage and commercially pelleted closed formula dairy concentrate (19% CP) mixed at an as-fed ratio of 3:1. Treatment II consisted of the same 3:1 mixture of corn silage and pelleted dairy concentrate along with feed grade sodium bicarbonate added at an as-fed rate of 0.5% of total ration. Complete mixed rations were offered ad libitum, three times daily to assure at least a 10% feed refusal. Each cow also received 5 lb of alfalfa-grass hay and, during each milking, 3 lb of pelleted dairy concentrate.

Complete mixed rations were formulated to contain approximately 13.7% CP and 70% total digestible nutrients (TDN) on a dry matter basis.

## Sample Collection and Analysis

Random samples of complete rations, alfalfa grass hay, and pelleted dairy concentrate were collected at weekly intervals, dried at 60°C for 72 hours, and ground through a 1 mm mesh screen in a Wiley Mill. Weekly feed samples were composited by four-week intervals. Proximate analyses were conducted according to AOAC (4). Acid detergent fiber (ADF) and acid insoluble lignin (AIL) were determined by the technique of Van Soest (128) except that sand was used as a filtrate in lieu of asbestos. Composite samples were analyzed for calcium and sodium using the method of Perkins and Elmer (103). Phosphorous was determined using the procedure of Fiske and Subbarow (41).

Body weights were recorded three days postpartum and at weekly intervals thereafter. Cows were milked twice daily in a standard double two-walk-through parlor equipped with stationary weigh jars. Composite morning-evening milk samples were collected at weekly

intervals and stored at -20°C. Prior to analysis, only milk samples collected during 1979-1980 were composited on successive biweekly intervals and analyzed for protein and total solids not fat (SNF). Milk fat percents were obtained monthly from the Tennessee Dairy Herd Improvement Association Central Milk Testing Laboratory.

Samples of rumen fluid via stomach tube were obtained at monthly intervals postpartum only during 1979-1980. The pH of each sample was determined immediately using a Fisher Model 600 pH meter equipped with electrode standardized with pH 7.0 phosphate buffer solution. Ruminal fluid was collected three hours after morning feeding. Before transporting, rumen fluid was sealed in plastic bags and immediately packed in crushed ice. Samples were finally stored at -20°C until volatile fatty acid (VFA) analyses could be conducted.

VFA analyses of rumen fluid were conducted on duplicate samples using the procedure of Erwin et al. (38) modified by Wilhite (131). Each frozen sample was thawed to room temperature, and 40 ml was transferred into a 45 ml test tube and centrifuged at 10°C, 10,000 g for five minutes. Five ml aliquots of supernatant was decanted and each was acidified with 1 ml of 25% metaphosphoric acid solution with 50% 2-ethylbutyric acid as an internal standard. Each acidified sample was refrigerated for an additional 30 minutes, after which the sample was centrifuged again at 10,000 g for 10 minutes. The supernatant was then decanted and frozen at -20°C to further coagulate any protein not precipitated. VFA were quantitated by gas-liquid chromotography using a Bendix 2500 gas-liquid chromatograph equipped with an Infotronics CRS-309 digital integrator. A Hamilton microliter syringe was used to

inject a .5 μl aliquot of supernatant into a 1.80 meter glass column (2.0 mm i.d.) packed with Supelco 10% SP-1200/1% $H_3PO_4$ on 80/100 mesh chromsorb WAW for separation of VFA. Peak areas of individual fatty acids were compared to similar areas from standard acid solutions and calculated to millimoles/liter using the 2-ethyl butyric acid factor.

Jugular blood samples were obtained at monthly intervals post-partum only during 1979-1980. Samples were allowed to clot for 24 hours, centrifuged at 850 g for 20 minutes, after which serum was decanted, and stored at -20°C until analyzed for $Ca^{+2}$, $Mg^{+2}$, and $Na^{+1}$ using the procedure developed by Perkin and Elmer (103). Monthly samples were composited, and serum phosphorus was determined using modifications to the methods established by Fiske and Subbarow (41). To 1 ml of serum, 4 mls of 10% Trichloro-acetic acid were added to precipitate proteins, and the sample was centrifuged. Five-tenths ml of molybdate II and .5 ml of ANSA were then added to the supernatant. Samples were allowed to stand for 15 minutes and analyzed on the Beckman DU-21 spectrophotometer (660 Å).

Statistical Analysis

The General Linear Model procedure of the Statistical Analysis System (SAS) was utilized in data analysis (50). Multivariate and univariate analyses were used to determine if discrete variables significantly affected dependent production variables. Treatment, stage, year, and cow were the discrete variables in the analysis of variance for the following model:

$$Y_{ijkl} = u + t_i + s_j + y_k + c_l + (t * s)_{ij} + (t * y)_{ik} + (s * y)_{jk} + (t * s * y)_{ijk} + e_{ijkl}$$

where:

$Y_{ijkl}$ = the estimate of dependent production variables: milk yield, milk fat, 4.0% fat corrected milk (FCM), dry matter intake per hundred pounds of body weight, total dry matter intake per hundred pounds of body weight, milk protein, total solids, SNF, serum calcium, serum phosphorus and serum magnesium, serum sodium, rumen volatile fatty acids, and rumen pH;

$u$ = theoretical population mean;

$t_l$ = treatment, i = 1-2;

$s_j$ = stage, j = 1-2;

$y_k$ = year, k = 1-2;

$c$ = cow within treatment;

$e_{ijkl}$ = random error.

Cow within treatment was used as the error term for the source treatment. When differences existed ($P < .05$) as indicated by F tests, mean separation was conducted with the Student-Neuman-Keuls test (114).

Dependent variables milk yield, milk fat, FCM, dry matter intake, and total dry matter intake were fitted to a nonlinear regression against lactation week using weekly observed values as a polynomial to describe the curve of each treatment. The following equation was utilized:

$$Y_i = a + b_1 \text{ (week)} + b_2 \text{ (week)}^2 + b_3 \text{ (week)}^3 + b_4 \text{ (week)}^4$$

where:

$Y_i$ = the estimate value of the dependent production variable for each week;

a = the intercept value for each dependent variable at week 0;

week = week number;

$b_1$, $b_2$, $b_3$, $b_4$ = the regression coefficients for each dependent variable on the independent variable = week, $\text{week}^2$, $\text{week}^3$, $\text{week}^4$.

## CHAPTER IV

## RESULTS AND DISCUSSION

Animal health appeared to be unaffected by the addition of sodium bicarbonate to complete rations with hay. Sixty-three cows were assigned to this study, and 62 finished. One cow died during the seventh week of the experiment due to undiagnosable reasons. She received the complete ration with sodium bicarbonate, and her data were not utilized. Furthermore, over the entire experimental periods, only five cases of diarrhea were observed in cows consuming sodium bicarbonate.

No significant differences were observed between treatments for rations on total dry matter intake (Table 5). In this present study, total dry matter intake has been defined as the total intake of feed from the complete mixed ration and alfalfa-grass hay on a dry matter basis. These trends may be indicative of swift ration adaptation in both groups. Ration adaptation in early lactation might be enhanced by consumption of alfalfa hay. Mertens (81) reported that the buffering capacity of haylage is quite variable in pH ranges of 4-6. When ensiled for haylage, legumes such as alfalfa have buffering capacities of 64 meq HCl/100 g forage, while grass like timothy has a buffering capacity of 22.0 meq/HCl/100 g forage. Buffering capacities of these species undoubtedly follow similar trends when offered as dry hay.

The dynamics of forage intake during early lactation have been discussed (129). Initial lactation cows of both ration treatments tended to consume more ration and total dry matter than those on second

Table 5. Least-square means and standard error of various parameters for sodium bicarbonate experiment of 1978-1980

| | Treatment[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | | | | | | II | | | | | |
| | Yr 1 | | Yr 2 | | Combined | | Yr 1 | | Yr 2 | | Combined | |
| Parameter | $\bar{X}$ | S.E.[b] | $\bar{X}$ | S.E. | $\bar{X}$ | S.E. | $\bar{X}$ | S.E. | $\bar{X}$ | S.E. | $\bar{X}$ | S.E. |
| Milk Yield (lb/d) | | | | | | | | | | | | |
| Initial lactation[c] | 62.46 | 4.17 | 55.62 | 2.60 | 58.03 | 2.21 | 57.15 | 4.17 | 54.90 | 2.73 | 55.74 | 1.66 |
| Second and later lactations[d] | 69.48 | 2.95 | 62.73 | 5.00 | 68.13 | 3.41 | 65.84 | 3.07 | 70.37 | 5.00 | 66.81 | 2.19 |
| All lactations | 67.14 | 2.50 | 57.14 | 2.61 | 62.76 | 2.15 | 62.77 | 2.58 | 58.47 | 2.70 | 60.91 | 1.68 |
| Milkfat (%) | | | | | | | | | | | | |
| Initial lactation | 3.14 | .13 | 3.28 | .06 | 3.23 | .06 | 3.19 | .13 | 3.37 | .06 | 3.30 | .5 |
| Second and later lactations | 3.43 | .09 | 3.19 | .12 | 3.38 | .07 | 3.57 | .10 | 3.50 | .12 | 3.55 | .01 |
| All lactations | 3.33 | .08 | 3.26 | .05 | 3.30 | .05 | 3.43 | .08 | 3.40 | .06 | 3.42 | .06 |
| 4.0% Fat-Corrected (lb/d) | | | | | | | | | | | | |
| Initial lactation | 54.45 | 3.73 | 49.66 | 2.51 | 51.35 | 2.03 | 50.09 | 3.73 | 49.72 | 2.63 | 49.86 | 1.33 |
| Second and later lactations | 63.46 | 2.64 | 55.32 | 4.80 | 61.83 | 3.17 | 61.46 | 2.76 | 65.31 | 4.80 | 62.29 | 2.11 |
| All lactations | 60.46 | 2.40 | 50.87 | 2.52 | 56.26 | 2.03 | 57.45 | 2.17 | 53.32 | 2.62 | 55.66 | 1.66 |
| Ration Dry Matter Intake (% of body weight) | | | | | | | | | | | | |
| Initial lactation | 2.01 | .14 | 2.26 | .09 | 2.17 | .07 | 2.14 | .14 | 2.35 | .09 | 2.27 | .08 |
| Second and later lactations | 1.94 | .10 | 2.27 | .17 | 2.00 | .09 | 2.14 | .10 | 1.92 | .17 | 2.09 | .1 |
| All lactations | 1.96 | .08 | 2.26 | .08 | 2.09 | .06 | 2.14 | .08 | 2.25 | .08 | 2.19 | .06 |

Table 5. (Continued)

| Parameter | Treatment[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | | | | | | II | | | | | |
| | Yr 1 | | Yr 2 | | Combined | | Yr 1 | | Yr 2 | | Combined | |
| | $\bar{X}$ | S.E.[b] | $\bar{X}$ | S.E. | $\bar{X}$ | S. E. | $\bar{X}$ | S. E. | $\bar{X}$ | S. E. | $\bar{X}$ | S. E. |
| Total Dry Matter Intake[e] (% of body weight) | | | | | | | | | | | | |
| Initial lactation | 2.38 | .14 | 2.63 | .09 | 2.54 | .07 | 2.52 | .14 | 2.75 | .09 | 2.67 | .08 |
| Second and later lactations | 2.25 | .10 | 2.63 | .17 | 2.33 | .09 | 2.46 | .10 | 2.23 | .17 | 2.41 | .1 |
| All lactations | 2.30 | .08 | 2.63 | .09 | 2.44 | .06 | 2.40 | .08 | 2.63 | .09 | 2.55 | .07 |

[a]Treatment I = complete mixed ration of 3 parts corn silage and 1 part commercial dairy pellet (16% CP) as fed basis.
Treatment II = complete mixed ration of 3 parts corn silage and 1 part commercial dairy pellet (16% CP) with 0.5% sodium bicarbonate on an as fed basis.

[b]Standard error.

[c]Initial lactation = first lactation.

[d]Second and later lactations = second and subsequent lactations.

[e]Total dry matter intake = hay + ration dry matter intake.

or later lactations. Ration dry matter intake in this study has been defined as the total intake of feed only from the complete ration on a dry matter basis. Cows receiving complete rations with sodium bicarbonate consumed slightly more ration dry matter and total ration dry matter as a percent of body weight (Table 5). These differences were not significant. Ration dry matter intake of combined data over all lactations was 2.09 vs. 2.19% of body weight for control and buffered diets, respectively. Total dry matter intake as a percent of body weight was 2.44% for control and 2.55% for treated when all lactations were considered; again, differences were not significant. However, other researchers discovered significant increases in dry matter intake both as a percent of body weight (17,66) and as kg of diet consumed (16,27,36).

Cows consuming buffered rations appeared to have postpartum peaks in dry matter intake earlier than controls (Figures 1 and 2). This observation confirms earlier work (36,66). Earlier postpartum peaks in dry matter intake of cows on buffered rations might be indicative of ration adaptation. Thus, the lag between peak milk production and peak dry matter intake may have been narrowed. Similar results with sheep and beef cattle have been reported (121).

Two explanations have been offered for these trends. The free acid content of silage could have been partially neutralized with the addition of sodium bicarbonate. McLeod et al. (80) experienced a 9.7-20% increase in dry matter intake when cattle were fed corn silage in this manner. Emmanuel et al. (34) reported that bicarbonate supplements enhanced cellulose digestion. It has been suggested that

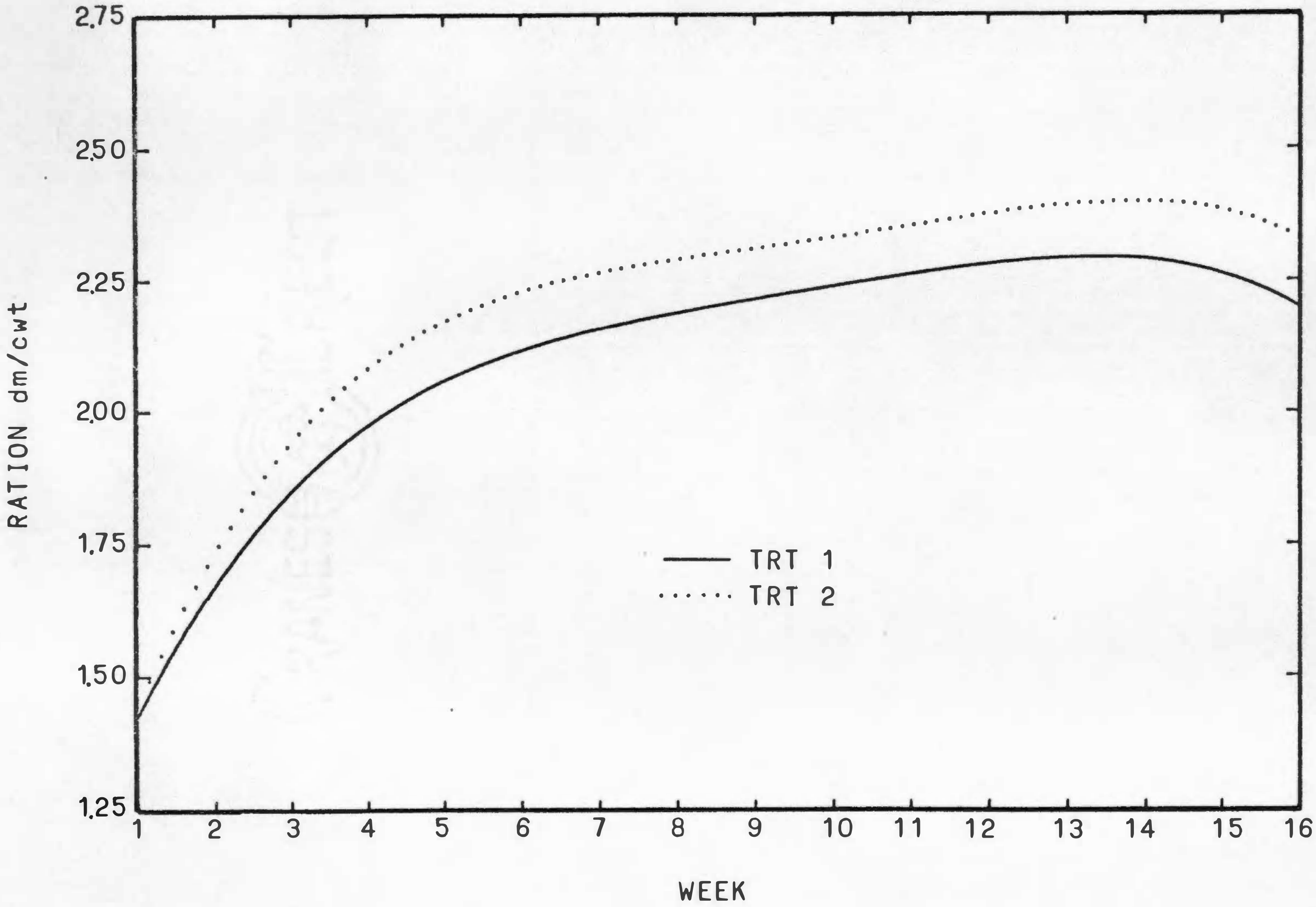


Figure 1. Quartic regression curve for ration dry matter intake.

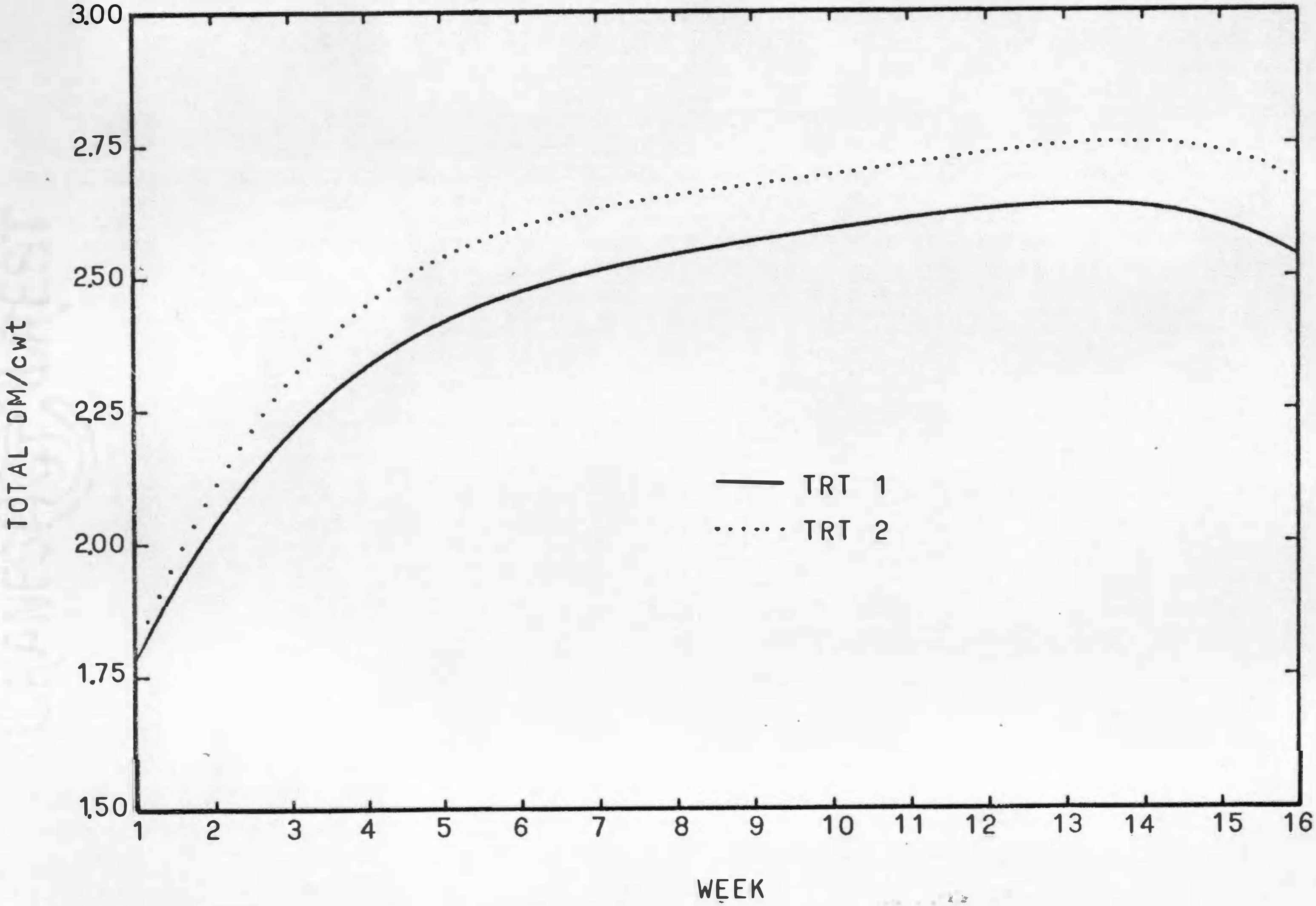


Figure 2. Quartic regression curve for total dry matter intake.

increased rate of cellulose digestion allows higher rates of feed consumption (80). Ration palatability has at times decreased when sodium bicarbonate was incorporated into dairy rations. No significant changes in ration intake in this study indicate animal acceptance was not affected by incorporation of sodium bicarbonate into diets.

Means of daily milk yield over the entire experiment can be found in Table 5, page 40. No significant treatment effects were observed ($P \geq .05$). However, based on combined data, it appears that cows consuming buffered ration produced slightly less milk. The average decrease for daily milk yield was 2.29, 1.32, and 1.85 lb/d for initial, second and later lactations, and all lactations. Similar studies of cows fed sodium bicarbonate in mid-lactation (30,31,32,83,112) and early lactation (37,124) showed similar results. However, two recent studies with cows in early lactation indicate that sodium bicarbonate significantly increased milk production (36,66).

There appeared to be no differences between treatments for time required to reach peak lactation (Figure 3). Similar results were observed by Chase et al. (17). These trends are in opposition to those indicating that dairy cows consuming sodium bicarbonate in complete rations reach peak lactation earlier (36,67) and at a higher level of milk production (36) than controls.

Flatt et al. (42) reported that high producing dairy cattle are often unable to consume enough energy in early lactation to prevent the loss of body energy. The utilization of body energy influences the efficiency of milk yield (90). In attaining highest peak production, the complete ration must be of sufficient energy to optimize milk yield

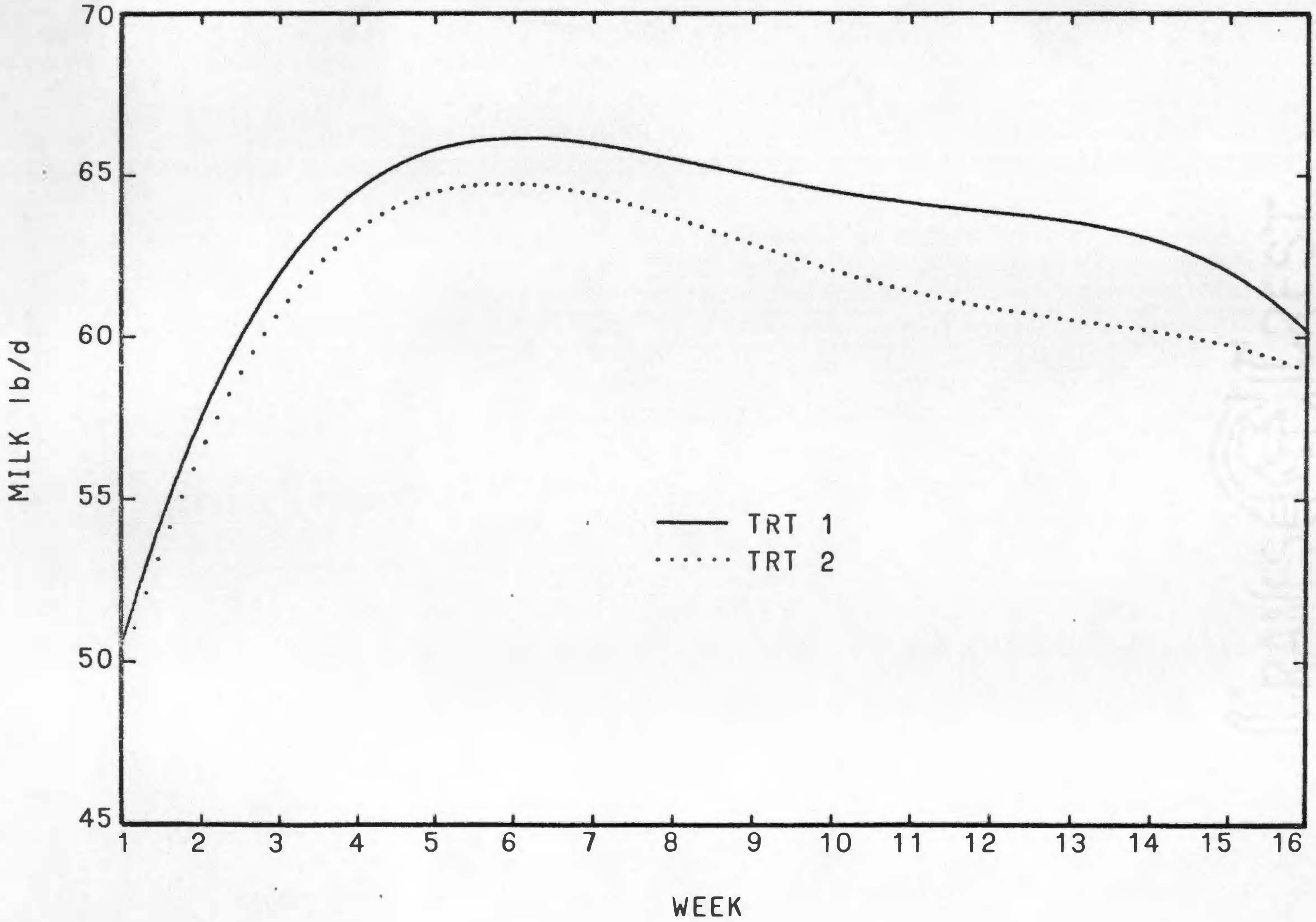


Figure 3. Quartic regression curve of milk production.

through lactation (19). Diets utilized in this experiment were formulated to meet the 1978 NRC energy requirements of early lactation-high producing dairy cows.

Olds et al. (92) reported that it is possible to influence total milk production for an entire lactation by regulating persistency in the first 120 days of lactation. Persistency is influenced by age, genotype, and feeding programs. Thus, any factors providing stimuli to milk yield during early lactation would enhance total milk production throughout the entire lactation (37).

Sodium bicarbonate had no significant effects on milk fat test of consuming buffered rations; however, in every classification milk fat was always slightly higher in the sodium bicarbonate fed animals (Table 5, page 40). Over all lactations, milk fat percent of control cows was 0.12 lb less than treated (3.30 vs. 3.42). Quartic regression curves indicating milk fat test of both treatments over both experimental periods can be found in Figure 4. Recent studies similar to this work showed similar results (36,66). Chase et al. (17) observed significant increases in milk fat percent when sodium bicarbonate was added at 0 or 1.6% of the complete ration dry matter. Erdman (37) found that sodium bicarbonate at 1% of ration dry matter significantly increased milk fat when fed to cows in early lactation. Studies using sodium bicarbonate in mid-lactation and over a complete lactation showed significant increases in milk fat test when cows consumed 216.2-454 g/d (27,30,31,83, 110,112). Provided the mixture of sodium bicarbonate was uniform throughout the complete ration, an average of 127 g/d of buffer was consumed by cows in this study (as fed). The quartic regression curve

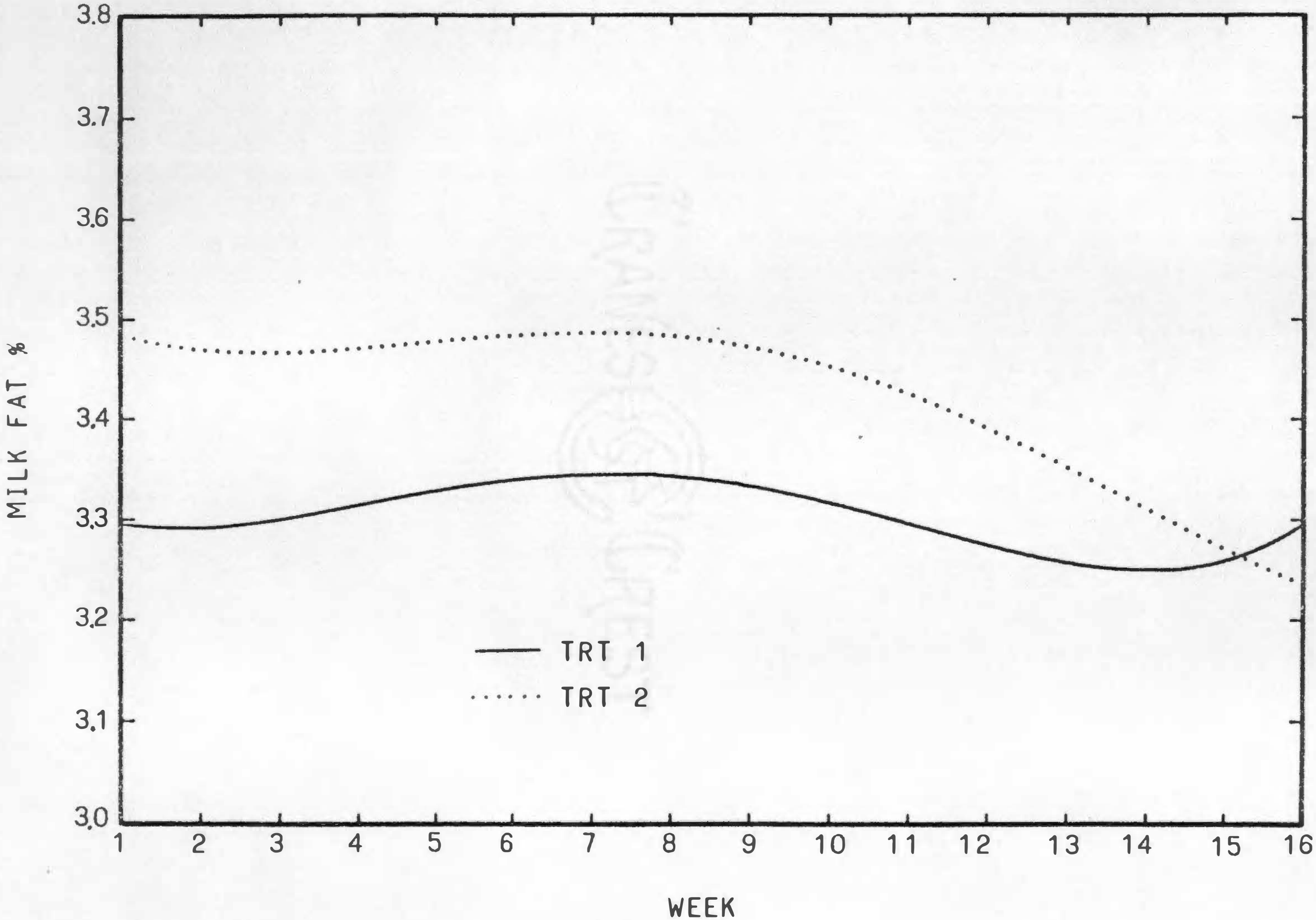


Figure 4. Quartic regression curve for milk fat.

indicating sodium bicarbonate intake over both experimental periods can be found in Figure 5.

NRC (90) reported that fat depression may occur when rations contain less than 21% ADF as fed to dairy cows. Lofgren and Warner (73) reported that 17.5% ADF would maintain a 3.3% milk fat test. The ADF values in this study were 18.38% vs. 21.28% for control and buffered rations during 1978-1979 (Table 6) and 20.07% vs. 19.36% for control and buffered rations during 1979-1980 (Table 7).

Species of forage may play an important role in the effect of sodium bicarbonate on milk fat test. Loften and Mertens (74) showed an improved milk fat percent when alfalfa at 35% NDF and sodium bicarbonate at .75% of the total ration were fed to cows. Muller (89) reported that improved performance with this diet was due to improved fiber digestion in the rumen and a more favorable environment for fiber digestion.
Milk fat production (g/kg) was significantly increased ($P < .01$) when sodium bicarbonate was added at a rate of 4% of the concentrate fed to Damascus dairy goats (46). However, milk production was not changed ($P > .05$).

Sodium bicarbonate did not exhibit any significant effect on 4% fat corrected milk (Table 5, page 40). Quartic regression curves indicating intake of sodium bicarbonate on both treatments over both experimental periods can be found in Figure 6. The lack of significant increase in feed intake or milk fat test of cows consuming the buffered diet might explain this trend. Donker and Marx (27) observed significant increases in FCM in cows consuming sodium bicarbonate ($P < .05$). They suggested that sodium bicarbonate enhanced efficiency of TDN

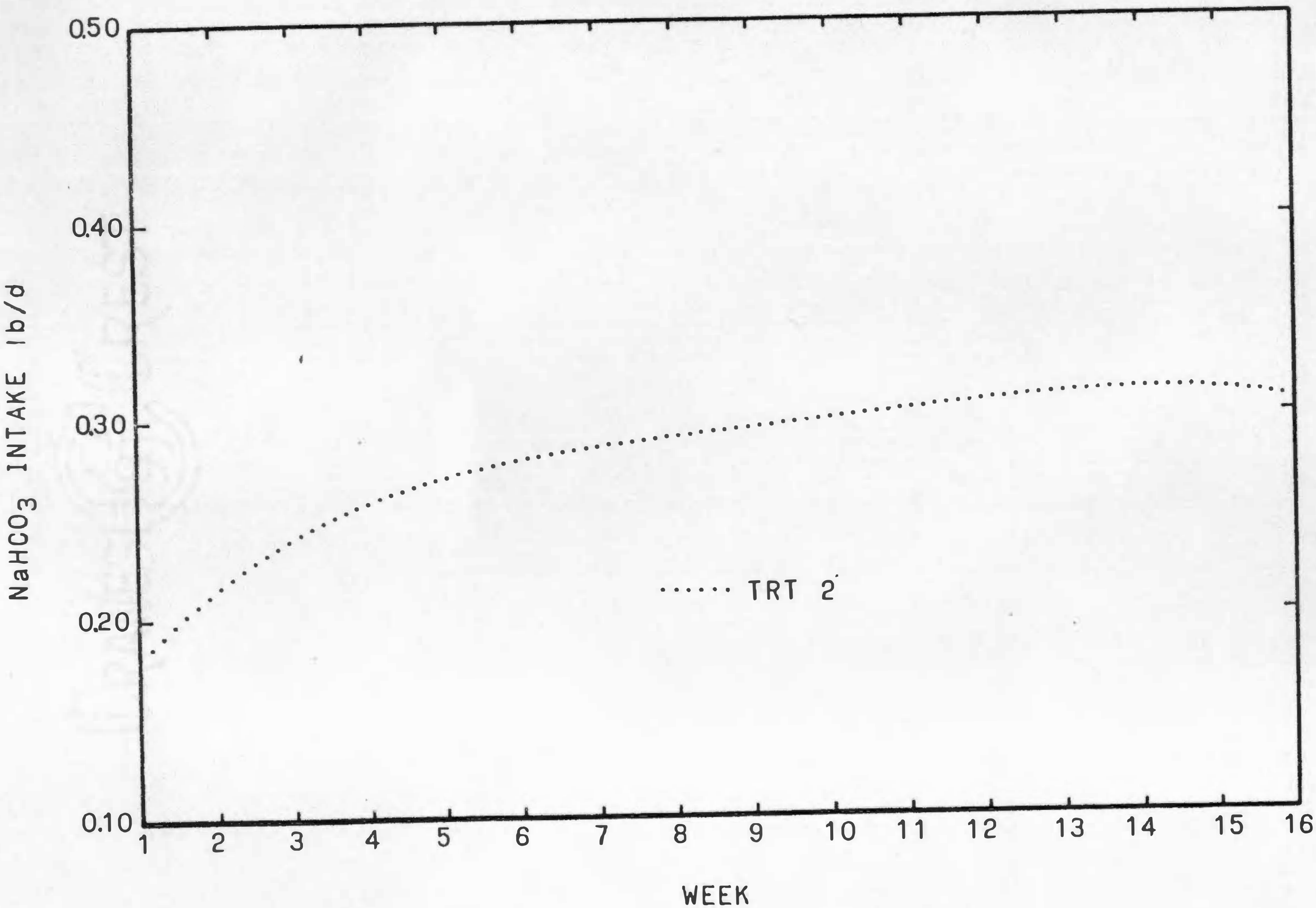


Figure 5. Quartic regression curve for sodium bicarbonate intake.

Table 6. Means of proximate fractions of complete rations, 1978-1979

| Fraction | Complete Ration[a] I | II |
|---|---|---|
| Dry matter (%) | 52.87 | 50.58 |
| % of dry matter | | |
| Crude protein | 12.50 | 11.07 |
| Acid detergent fiber | 18.38 | 21.28 |
| Acid insoluble lignin | 2.41 | 2.51 |
| Calcium | .59 | .59 |
| Phosphorus | .45 | .40 |
| Sodium | .14 | .32 |

[a]Treatment I = 3 parts corn silage and 1 part pelleted dairy concentrate (on as fed basis).

Treatment II = 3 parts corn silage and 1 part pelleted dairy concentrate plus sodium bicarbonate added at a rate of five-tenths percent (as fed basis).

Table 7. Means and standard error of proximate fractions of complete rations and treatment constituents 1979-1980

| | Complete Ration[a] | | | | Pelleted Dairy Concentrate | | Mixed Alfalfa - Grass Hay | |
|---|---|---|---|---|---|---|---|---|
| | I | | II | | | | | |
| Fraction | $\bar{X}$ | S.E.[b] | $\bar{X}$ | S.E. | $\bar{X}$ | S.E. | $\bar{X}$ | S.E. |
| Dry matter (%) | 46.28 | .51 | 44.94 | .56 | 90.20 | .24 | 88.77 | .50 |
| % of dry matter | | | | | | | | |
| Crude protein | 14.15 | .18 | 14.96 | .48 | 18.60 | .33 | 15.32 | .49 |
| Acid detergent fiber | 20.07 | .34 | 19.36 | .38 | 13.92 | .51 | 39.47 | 1.10 |
| Acid insoluble lignin | 3.10 | .07 | 2.97 | .07 | 3.28 | .17 | 8.15 | .28 |
| Ash | 6.68 | .17 | 6.83 | .14 | 10.70 | .55 | 8.43 | .29 |
| Calcium | .74 | .04 | .77 | .03 | 1.63 | .19 | .88 | .05 |
| Phosphorus | .42 | .05 | .44 | .06 | .73 | .03 | .32 | .02 |
| Sodium | .22 | .02 | .45 | .04 | .51 | .04 | .03 | .002 |

[a]Treatment I = 3 parts corn silage and 1 part pelleted dairy concentrate (on as fed basis).
Treatment II = 3 parts corn silage and 1 part pelleted dairy concentrate with sodium bicarbonate added at a rate of .5% (as fed basis).

[b]Standard error.

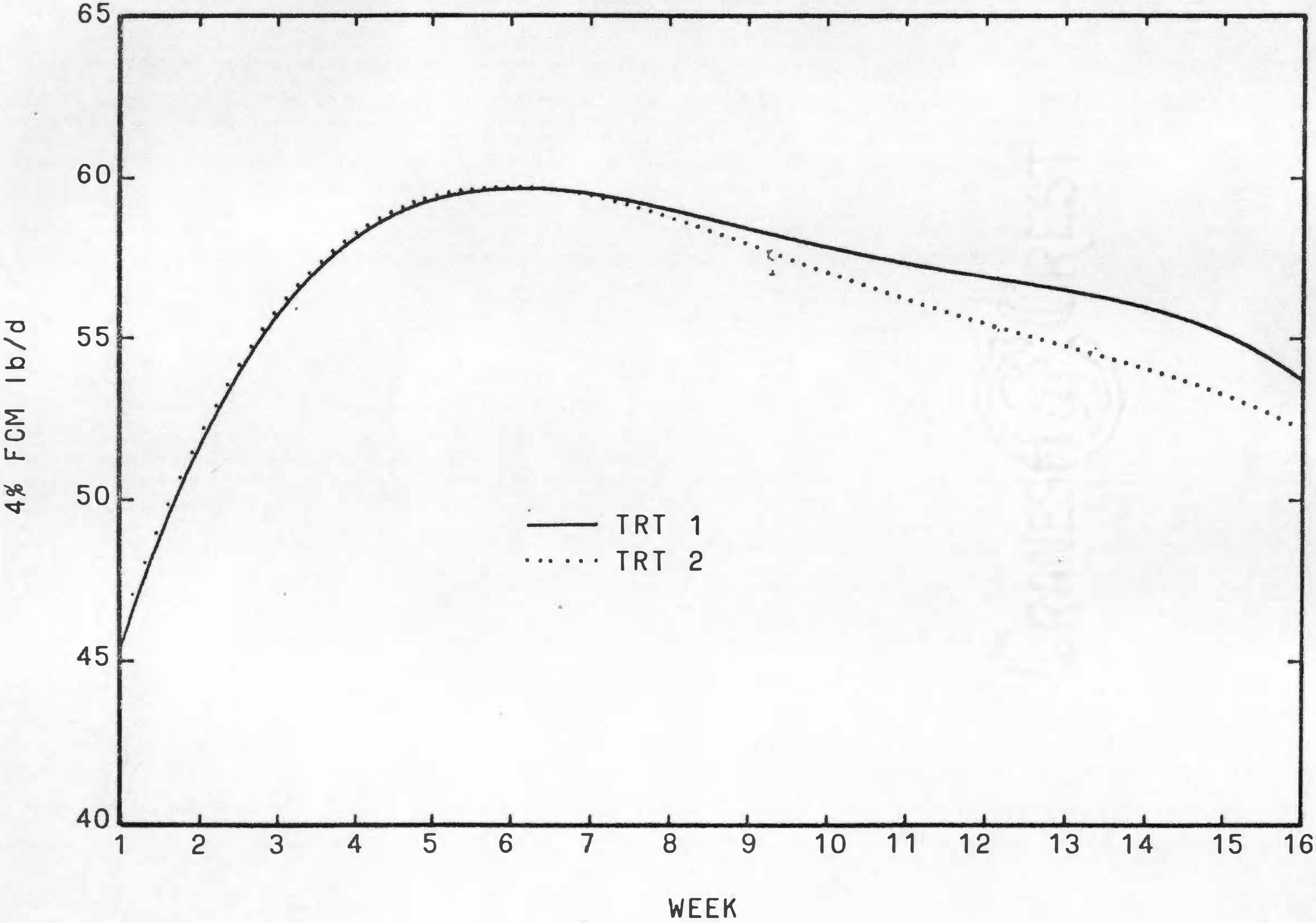


Figure 6. Quartic regression curve for 4% fat corrected milk.

utilization through increased feed intake. Similar results were observed by others (36,66,110,112).

Any increase in FCM in early lactation would require a substantial amount of energy (90). Maximum TDN intake occurs during the eighth week postpartum, whereas maximum TDN output occurs during the third week postpartum (102). It appears that in this study very few dairy cows in early lactation consumed enough energy to both maintain energy balance and produce high levels of 4% FCM.

The small, nonsignificant shift to a more propionic production as observed in this study would be indicative of a lower milk fat percent (Table 8). McCullough (79) reported that a molar percentage of propionic acid about 20 resulted in a consistent decrease in milk fat. The molar percent of propionate in this study was 22.48 for control ration and 23.50 for sodium bicarbonate ration. However, no significant change in milk fat test was seen in this report. Davis (26) reported that a linear increase in milk fat content exists as the acetate-to-propionate ratio increases from values of 1 up to approximately 2.2. Above a ratio of 2.2, there is little change in fat percent. Therefore, supplements which increase acetate-to-propionate ratio would have their greatest effect on milk fat when added to basal diets yielding fermentation ratios of less than 2.0.

Differences in concentrations of VFA were nonsignificant ($P > .05$) between treatments (Table 8). Molar percent VFA were unaltered by sodium bicarbonate in similar studies (30,36,37,66,111).

Acetate-to-propionate ratios were 2.85 vs. 2.66 for the control and treated groups, respectively (Table 8). Means were nonsignificant

Table 8. Least-square means and standard error of volatile fatty acids (VFA) in Holstein cows, 1979-1980

| | Treatment[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | I | | | | II | | | |
| | Micromoles/ml | | Molar Percent | | Micromoles/ml | | Molar Percent | |
| VFA | $\bar{X}$ | SE[b] | $\bar{X}$ | SE | $\bar{X}$ | SE | $\bar{X}$ | SE |
| Acetate | 51.90 | 1.81 | 59.49 | .80 | 57.21 | 1.89 | 59.06 | .84 |
| Propionate | 19.88 | 1.17 | 22.48 | .81 | 23.33 | 1.23 | 23.50 | .84 |
| Isobutyrate | 0.79 | 1.06 | .09 | .06 | .94 | .06 | .96 | .06 |
| Butyrate | 12.07 | 0.63 | 13.71 | .51 | 13.00 | .66 | 13.38 | .54 |
| Isovalerate | 1.37 | .08 | 1.61 | .11 | 1.31 | .09 | 1.34 | .11 |
| Valerate | 1.61 | .15 | 1.82 | .11 | 1.78 | .16 | 1.75 | .12 |
| Acetate:propionate ratio | 2.85 | .12 | 2.85 | .12 | 2.66 | .13 | 2.66 | .13 |
| Total VFA | 87.63 | 3.06 | 100 | 0.0 | 97.56 | 3.21 | 100 | 0.0 |

[a]Treatment I = Complete mixed ration of 3 parts corn silage and 1 part commercial dairy pellet (16% C.P.) on as fed basis.

Treatment II = Complete mixed ration of 3 parts corn silage and 1 part commercial dairy pellet (16% C.P.) plus 0.5% sodium bicarbonate on as fed basis.

[b]Standard error.

(P > .05). However, sodium bicarbonate has widened the acetate-to-propionate ratio, thus changing the rumen fermentation to one favoring acetate (36,37,39,57,111,112). A shift in fermentation to favor acetate by intraruminal infusion of 2.5% sodium bicarbonate significantly increased (P < .05) dilution rate and decreased the molar concentration of propionate (49). When mixed buffers were included in the diet at 0, 5.7, and 11.4% of the diet (dry matter), significant increases in the proportion of acetic acid in the rumen liquor and decreases in propionic acid were observed. Rumen dilution rate was also increased (120). Total VFA's in this study were slightly higher in cows consuming the buffered ration (Table 8). Least-square means values were 87.63 mm/ml vs. 97.56 mm/ml for control and sodium bicarbonate treatments, respectively. Values favoring the buffered ration may indicate no rumen dilution occurred.

Sodium bicarbonate tended to increase the amount of total VFA produced (Table 8). Significant increases were reported by Thompson et al. (120) but disputed by others (36,37,39,66,67). Rodgers et al. (104) fed Holstein steers either a high concentrate or high roughage diet and intraruminally infused 9 liters of water containing .36 or .72 kg of sodium bicarbonate. Their results indicated a decrease in total rumen VFA during periods of sodium bicarbonate infusion. Bauman et al. (12) found that there appears to be a high positive correlation between both the concentration of rumen volatile fatty acids and their production. Production rates were not measured in this study.

No significant differences could be attributed to treatment for changes in rumen pH (Table 9). This trend has been reported by other

Table 9. Least-square means and standard error of rumen pH of Holstein cows, 1979-1980

| | Treatment[a] | | | |
|---|---|---|---|---|
| | I | | II | |
| Month | $\bar{X}$ | SE[b] | $\bar{X}$ | SE |
| 1 | 6.53 | .14 | 6.36 | .13 |
| 2 | 6.53 | .14 | 6.34 | .13 |
| 3 | 6.37 | .07 | 6.41 | .08 |
| 4 | 6.36 | .08 | 6.15 | .08 |
| Overall | 6.45 | .06 | 6.31 | .05 |

[a]Treatment I = a complete ration of 3 parts corn silage and 1 part commercial dairy pellet on an as fed basis.

Treatment II = a complete ration of 3 parts corn silage and 1 1 part commercial dairy pellet with .5% sodium bicarbonate on an as fed basis.

[b]Standard error.

researchers (32,36,66,111). However, significant increases in rumen pH have been observed (30,39,57,112). A significant linear increase in rumen pH of cows consuming sodium bicarbonate might be indicative of ration adaptation. However, these trends were not observed in this study.

Lactating cows were fed complete rations of 50% corn silage:50% concentrate from day 1 to 112 postpartum and were changed to 60:40 corn silage-to-concentrate on day 113 (111). These diets contained 0, .4, .8, and 1.6% sodium bicarbonate as a percent of total ration dry matter. Rumen pH and total VFA concentrations (mm/ml) displayed a significant quadratic effect. Rumen pH was 6.33, 6.46, 6.49, and 6.45, and VFA concentrations were 96.2, 91.9, 90.2, and 99.7, respectively. No significant differences were observed between these four levels of buffer for individual VFA's.

No significant differences could be attributed to treatment when percent milk protein, total solids, or SNF were considered (Table 10). These trends have been confirmed by those feeding cows sodium bicarbonate with barley based diets (86). Typical ranges for milk protein and SNF of Holstein cows in early mid-lactation were 3.0-3.7 and 8.43-9.07 (47,125). Bath (10) reported that milk from cows fed fat depressing rations usually have slightly higher milk protein. Although protein values in this study are slightly higher than the usual range, differences were probably not due to ration. Neither of the rations fed caused milk fat depression. Miller et al. (83) reported no significant changes in percent solid-not-fat when the concentrate was supplemented with 381 g of sodium bicarbonate. Sodium bicarbonate fed at a rate of

Table 10. Least-square means and standard error of milk constituents from Holstein cows, 1979-1980

| | Treatment[a] | | | |
|---|---|---|---|---|
| | I | | II | |
| Parameter | $\bar{X}$ | S.E.[b] | $\bar{X}$ | S.E. |
| Milk protein | 3.95 | .07 | 3.98 | .08 |
| Total solids | 12.13 | .14 | 11.93 | .15 |
| Solid-not-fat | 8.87 | .14 | 8.53 | .15 |

[a]Treatment I = a complete mixed ration of 3 parts corn silage and 1 part dairy pellet (16%) on an as fed basis.

Treatment II = a complete mixed ration of 3 parts corn silage and 1 part dairy pellet (16%) with 0.5% sodium bicarbonate on an as fed basis.

[b]Standard error.

either 0 or 4% in the concentrate with two levels of roughage significantly increased ($P < .05$) total solids in dairy goats (46).

Huber and Bowman (54) reported that increases in the energy level of dairy cattle rations usually resulted in increased SNF and protein. Sodium bicarbonate plays an important role in protein synthesis in the rumen (121). However, its effect on milk protein synthesis is unknown. Changes in milk composition with advancing lactation and dietary composition have been reported (11,21,106,109).

Serum values for minerals can be found in Table 11. No significant differences could be attributed to treatment for changes in serum sodium, magnesium, phosphorus, or calcium. Similar reports were reported by others (36,37,67). However, Kilmer et al. (66) reported that sodium bicarbonate significantly increased ($P < .05$) phosphorus in the eighth week and calcium in the second week of their study when rations were supplemented with sodium bicarbonate postpartum. They suggested that bicarbonate influenced calcium uptake in the gut which changed both gut acidity and pH.

Typical mineral values in bovine serum are 11.08, 6.05, 2.05, and 326.6 mg/100 ml for calcium, phosphorus, magnesium, and sodium, respectively (58). One explanation why there were no changes in this study could be that the sodium bicarbonate added to complete rations was too low a level to produce metabolic changes. Kronfeld et al. (71) fed early postpartum dairy cows sodium bicarbonate in complete rations at 0, .4, .8, and 1.6% of ration dry matter. There was no major difference in blood sodium, calcium, and phosphorus between diets. However, sodium bicarbonate did cause a linear decrease in magnesium and calcium.

Table 11. Least-square means and standard error of blood serum parameters in Holstein cows, 1979-1980

| | Treatment[a] | | | |
|---|---|---|---|---|
| | I | | II | |
| Parameter | $\bar{X}$ | S.E.[b] | $\bar{X}$ | S.E. |
| | mg/100 ml | | | |
| Calcium | 9.44 | .21 | 10.09 | .22 |
| Phosphorus | 5.25 | .14 | 5.40 | .15 |
| Magnesium | 2.22 | .06 | 2.14 | .07 |
| Sodium | 403.13 | 6.74 | 405.37 | 6.99 |

[a]Treatment I = Complete ration consisting of 3 parts corn silage and 1 part commercial dairy pellet (16%).

Treatment II = Complete ration consisting of 3 part corn silage and 1 part commercial dairy pellet (16%) with .05% sodium bicarbonate.

[b]Standard error.

Differences in serum mineral composition are primarily due to days in lactation, pregnancy (13,43,44,59,66,107,117), or season of year (44,59,117) rather than ration composition (13,95).

# CHAPTER V

## SUMMARY AND CONCLUSIONS

Two experiments were conducted to evaluate the effect sodium bicarbonate had on feed intake, milk production, and rumen measurements of dairy cows in early lactation. The following results were obtained:

1. Sodium bicarbonate was not effective in significantly increasing daily milk production of cows consuming this buffer in complete rations.
2. Sodium bicarbonate nonsignificantly increased milk fat percent in every lactation stage considered. Milk fat percent was increased .7% in initial lactation cows, .17% in second and later lactation cows, and .12% in all lactation cows when least-square means were evaluated.
3. Ration dry matter intake and total dry matter intake were nonsignificantly increased in every lactation stage considered from combined data. Consumption on a percent body weight increased over all lactations when combined means considered were .1% in ration dry matter intake and .11% in total dry matter intake.
4. Fat corrected milk was nonsignificantly decreased in combined data in all and initial lactations but nonsignificantly increased .46 lb/d in combined data for second and later lactations.

5. VFA were not effected significantly by sodium bicarbonate in complete rations.
6. Sodium bicarbonate nonsignificantly increased milk protein .03% but decreased total solids .20% and solids-not-fat .34%.
7. Sodium bicarbonate had no significant effect on minerals in blood serum.

The following conclusions were made:

1. Dietary sodium bicarbonate had no significant effect on intake, ration adjustment, milk production and composition, blood serum, or rumen parameters.
2. The data indicate that incorporation of .5% sodium bicarbonate to complete rations was neither beneficial nor harmful.
3. Sodium bicarbonate added to complete rations of 75% corn silage and 25% commercial dairy pellets at the rate of .5% on an as-fed basis is not adequate in increasing intake production or rumen parameters.
4. Optimum levels of sodium bicarbonate for maximum animal response are unknown.

# LIST OF REFERENCES

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1. Adams, R. S. 1978. Buffers in dairy cattle rations. Proc. 13th and Pacific Northwest Animal Nutrition Conf., p. 99.

2. Annison, E. G. and R. Bickerstaffe. 1974. Glucose and fatty acid metabolism in cows producing milk of low fat content. J. Agric. Sci. 82:87.

3. Ash, R. W. and A. Dobson. 1963. The effect of absorption on the acidity of rumen contents. J. Physiol. 169:39.

4. Association of Official Analytical Chemists. 1965. Official methods of analysis. 19th ed. W. Horwitz, ed. AOAC, Washington, D.C.

5. Bailey, C. B. 1961. Saliva secretion and its relation in feeding cattle 3. The rate of secretion of mixed saliva in the cow during eating with an estimate of the magnitude of the total daily secretion of mixed saliva. Brit. J. Nutr. 15:443.

6. Bailey, C. B. and C. C. Balch. 1961. Saliva secretion and its relation to feeding in cattle 1. The composition and rate of parotid saliva in a small steer. Brit. J. Nutr. 15:371.

7. Baker, D. H. and P. C. Harrison. 1979. Sodium Bicarbonate in Poultry and Swine Nutrition. National Feed Ingredients Association. West Des Moines, Iowa.

8. Bartley, E. E. 1976. Bovine saliva: Production and function. In M. S. Weinberg and A. L. Sheffner, eds. Buffers in Ruminant Physiology and Metabolism. Church and Dwight Co., Inc., New York.

9. Bates, R. G. 1966. Acids, bases and buffers. Ann. N.Y. Acad. Sci. 133:25.

10. Bath, D. L. 1982. Reducing fat in milk and dairy products by feeding. J. Dairy Sci. 65:450.

11. Bath, I. H. and J. A. F. Rook. 1965. The evaluation of cattle foods and diets in terms of the ruminal concentration of volatile fatty acids II. Roughages and succulents. J. Agric. Sci. 64:67.

12. Bauman, D. E., C. L. Davis, and H. F. Bucholtz. 1971. Propionate production in the rumen of cows fed either a control or high grain, low fiber diet. J. Dairy Sci. 54:1282.

13. Belyea, R. L., C. E. Coppock, and G. B. Lake. 1975. Effects of silage diets on health, reproduction, and blood metabolites of dairy cattle. J. Dairy Sci. 58:1336.

14. Bhattacharya, A. N. and R. G. Warner. 1968. Voluntary feed intake of pelleted diets for cattle, sheep and rabbits as affected by different alkali supplements. J. Anim. Sci. 27:1418.

15. Billups, N. F. 1981. American Drug Index. J. B. Lippincott Co., Philadelphia.

16. Bull, L. S., R. W. Hemken, J. O. Leary, and R. H. Hatton. 1978. Influence of silo type and addition of sodium bicarbonate to the ration performance of lactating dairy cows. J. Dairy Sci. 61 (Suppl. 1):136.

17. Chase, L. E., W. Chalupa, R. W. Hemken, L. D. Muller, D. S. Kronfeld, G. T. Lane, C. J. Sniffen, and T. J. Snyder. 1981. Milk production responses to 0, .4, .8 and 1.6 sodium bicarbonate. J. Dairy Sci. 64 (Suppl. 1):134.

18. Christensen, H. N. 1963. Body Fluids and Tbeir Neutrality. Oxford University Press, New York.

19. Clark, J. H. and C. L. Davis. 1980. Some aspects of feeding high producing dairy cows. J. Dairy Sci. 63:873.

20. Counotte, G. H. M., A. T. Van't Klooster, J. Vander Kuilen, and R. A. Prins. 1979. An analysis of the buffer system in the rumen of dairy cattle. J. Anim. Sci. 49:1536.

21. Cowan, E. D., J. Oliver, and R. C. Elliott. 1970. The effects of dietary roughage content on some by-products of rumen fermentation and on milk composition of cows fed with complete diets throughout lactation. Rhod. J. Agric. Res. 8:23.

22. Daugert, R. and A. Garanch. 1974. The effect of sodium bicarbonate in the rumen and some biochemical indices of the blood and urine of lactating cows. Raksti Latvi Lauksaimn Akad 78:12-19. Cited in Muller, L. D. and L. H. Kilmer. 1979. Sodium Bicarbonate in Dairy Nutrition. National Feed Ingredient Association, West Des Moines, Iowa.

23. Davenport, H. W. 1974. The ABC of Acid-Base Chemistry. 6th Ed., University of Chicago Press, Chicago.

24. Davis, C. L., R. E. Brown, and D. C. Beitz. 1964. Effect of feeding high-grain restricted roughage rations with and without bicarbonates on the fat content of milk produced and proportions of volatile fatty acids in the rumen. J. Dairy Sci. 47:1217.

25. Davis, C. L. and R. E. Brown. 1970. Low fat milk syndromes. In A. T. Phillipson, ed. Physiology of Digestion and Metabolism in the Ruminant. Oriel Press, New Castle upon Tyne.

26. Davis, C. L. 1979. The use of buffers in rations of lactating dairy cows. In W. H. Hale and P. Meinhardt, eds. Regulation of Acid Base Balance. Church and Dwight Co., Inc., Piscataway, New Jersey.

27. Donker, J. D. and G. D. Marx. 1980. Sodium bicarbonate in diets for milking Holstein cows. J. Dairy Sci. 63:931.

28. Dunn, B. H., R. J. Emerick, and L. B. Embry. 1979. Sodium bentonite and sodium bicarbonate in high concentrate diets for lambs and steers. J. Anim. Sci. 48:765.

29. Emerick, R. J. 1976. Buffering acidic and high concentrate ruminant diets. In M. S. Weinberg and A. L. Sheffner, eds. Buffers in Ruminant Physiology and Metabolism. Church and Dwight Co., Inc., New York.

30. Emery, R. S. and L. D. Brown. 1961. Effect of feeding sodium and potassium bicarbonate on milk fat, rumen pH and volatile fatty acid production. J. Dairy Sci. 44:1899.

31. Emery, R. S., L. D. Brown, and J. W. Thomas. 1964. Effect of sodium and calcium carbonates on milk fat production and composition of milk, blood and rumen contents of cows fed grain ad libitum with restricted roughage. J. Dairy Sci. 47:1325.

32. Emery, R. S., L. D. Brown, and J. E. Bell. 1965. Correlation of milk fat with dietary and metabolic factors in cows fed restricted roughage rations supplemented with magnesium oxide or sodium bicarbonate. J. Dairy Sci. 48:1647.

33. Emery, R. S. 1976. High energy feeds for milk production. In M. S. Weinberg and A. L. Sheffner, eds. Buffers in Ruminant Physiology and Metabolism. Church and Dwight Co., Inc., New York.

34. Emmanuel, Bijan, M. J. Lawlor, and D. M. McAleese. 1969. The rumen buffering system of sheep fed pelleted roughage-concentrate rations. Brit. J. Nutr. 23:805.

35. Erdman, R. A., R. L. Bolts, R. W. Hemken, and L. S. Bull. 1978. The effect of buffers on performance and pH parameters in lactating cows. J. Dairy Sci. 61 (Suppl. 1):172.

36. Erdman, R. A., R. L. Bolts, R. W. Hemken, and L. S. Bull. 1980. Effect of dietary sodium bicarbonate and magnesium oxide on production and physiology in early lactation. J. Dairy Sci. 63:923.

37. Erdman, R. A. 1980. Effect of sodium bicarbonate and magnesium oxide for early lactating dairy cows. Ph.D. Thesis, University of Kentucky, Lexington, Kentucky.

38. Erwin, E. S., G. J. Marco, and E. M. Emergy. 1961. Volatile fatty analysis of blood and rumen fluid by gas chromotography. J. Dairy Sci. 44:1768.

39. Esdale, W. J. and L. D. Satter. 1972. Manipulation of ruminal fermentations IV. Effect of altering ruminal pH on volatile fatty acid production. J. Dairy Sci. 55:964.

40. Fell, M., M. Kay, E. R. Orskov, R. Boyne, and J. T. Walker. 1972. The role of ingested animal hairs and plant spicules in the pathogenesis of rumenitis. Res. in Vet. Sci. 13:30.

41. Fiske, C. H. and Y. Subbarow. 1925. The colorimetric determination of phosphorous. J. Biol. Chem. 66:375.

42. Flatt, W. P., C. E. Coppock, and L. A. Moore. 1965. Energy balance studies with lactating non-pregnant dairy cows consuming rations with varying hay to grain ratios. Proc. Third Sym. on Energy Metab., Troon, Scotland European Assoc. Anim. Prod. Publ. 11:121.

43. Forar, F. L., R. L. Kincaid, R. L. Preston, and J. K. Hillers. 1980. Variation in levels of inorganic phosphorus in plasma and milk of cows with age, milk production, month of lactation, season of calving and dietary phosphorus. J. Dairy Sci. 63 (Suppl. 1):146.

44. Fraering, E., J. D. Roussel, S. S. Nicholson, and C. L. Seger. 1977. Factors affecting serum constituents of Louisiana dairy cattle. J. Dairy Sci. 60 (Suppl. 1):204.

45. Guyton, A. C. 1976. Textbook of Medical Physiology. W. B. Saunders Company, Philadelphia.

46. Hadjipanayioutou, M. 1982. Effect of sodium bicarbonate and roughage on milk yield and milk composition of goats and on rumen fermentation of sheep. J. Dairy Sci. 65:59.

47. Haenlein, G. F. W., L. H. Schultz, and L. H. Hausen. 1968. Relation of milk depressing rations and subclinical mastitis on milk protein. J. Dairy Sci. 51:535.

48. Hall, M. W. and E. E. Thomas. 1981. Effect of selected dietary buffers upon utilization of concentrate or roughage based cattle diets I. Laboratory studies. J. Anim. Sci. 53 (Suppl. 1):403.

49. Harrison, D. G., D. E. Beever, D. J. Thomson, and D. F. Osbourn. 1975. Manipulation of rumen fermentation in sheep by increasing the rate of flow of water from the rumen. J. Agric. Sci. 85:93.

50. Helwig, J. T. and K. A. Council, eds. 1979. SAS User's Guide. SAS Institute, Inc.

51. Hernandex-Urdaneta, A., C. E. Coppock, R. E. McDowell, D. Granola, and N. E. Smith. 1975. Changes in forage concentrate ratio of complete feeds for dairy cattle. J. Dairy Sci. 59:695.

52. Hoar, D. W., R. J. Emerick, and L. B. Embry. 1969. Ovine phosphate urolithiasis as related to the phosphorus and calcium contents and acid-base-forming effects of all concentrates diets. J. Anim. Sci. 29:647.

53. Houpt, T. R. 1977. Water, electrolytes, and acid base balance. In M. J. Swenson, ed. Dukes Physiology of Domestic Animals, 9th Ed. Cornell University Press, Ithaca, New York.

54. Huber, J. T. and R. L. Bowman. 1966. Nutritional factors affecting the solids-not-fat content of milk. J. Dairy Sci. 49:816.

55. Huntington, G. B., R. J. Emerick, and L. B. Embry. 1977. Sodium bentonite or sodium bicarbonate as aids in feeding high concentrate diets to lambs. J. Anim. Sci. 46:804.

56. Jorgensen, N. A. and L. H. Schultz. 1965. Ration effects on rumen acids, ketogenesis and milk composition II. Restricted roughage feeding. J. Dairy Sci. 48:1040.

57. Ibbetson, R. W. and F. W. Boren. 1976. Sodium bicarbonate levels for lactating cows receiving flaked grain rations. Dairy Sci. Investigations. Kans. Agr. Expt. Sta. Rpt. 275.

58. Kaneko, J. J. 1973. Standard values of domestic animals. In H. M. Stahr, ed. Analytical Toxicology Methods Manual. 2nd Ed. Iowa State University Press, Ames, Iowa.

59. Kappel, L. C., R. H. Ingraham, and E. B. Morgan. 1981. Effect of season and days post calving on blood constituents. J. Anim. Sci. 53 (Suppl. 1):183.

60. Kaufmann, H., H. Hagemeister, and G. Kirksen. 1980. Adaptation to changes in dietary composition, level and frequency of feeding. In Y. Ruckenbusch and P. Thiveld. Digestive Physiology and Metabolism in Ruminants. AVI Publishing Company, Westport, Connecticut.

61. Kay, R. N. B. 1960. The rate of flow and composition of various salivary secretions in sheep and calves. J. Physiol. 150:515.

62. Kay, R. N. B. and P. N. Hobson. 1963. Reviews of the progress of dairy science. J. Dairy Res. 30:261.

63. Kay, M. B., F. Fell, and R. Boyne. 1969. The relationship between the acidity of the rumen contents and rumenitis in calves fed on barley. Res. in Vet. Sci. 10:181.

64. Kellaway, R. C., D. J. Thompson, D. E. Beever, and D. F. Osbourn. 1977. Effects of NaCl and $NaHCO_3$ on food intake, growth rate and acid-base balance in calves. J. Agric. Sci. 88:81.

65. Kilmer, L. H., L. D. Muller, and P. J. Wagnsness. 1979. Addition of sodium bicarbonate to rations of pre- and post-partum dairy cows. Progress Report, Department of Dairy and Animal Science, The Pennsylvania State University, University Park, Pennsylvania.

66. Kilmer, L. H., L. D. Muller, and P. J. Wagnsness. 1980. Addition of sodium bicarbonate to rations of pre- and post-partum dairy cows. J. Dairy Sci. 63:2026.

67. Kilmer, L. H., L. D. Muller, and T. J. Snyder. 1981. Addition of sodium bicarbonate to rations of post-partum dairy cows: physiological and metabolic effects. J. Dairy Sci. 64:2357.

68. Kromann, R. P. 1976. Buffering capacity as influenced by dietary physical characteristics. <u>In</u> M. S. Weinberg and A. L. Sheffner, eds. Buffers in Ruminant Physiology and Metabolism. Church and Dwight Co., Inc., New York.

69. Kronfeld, D. S. 1976. Metabolic and respiratory adjustments of acid-base balance and the burden of exogenous acids in ruminants. <u>In</u> M. S. Weinberg and A. L. Sheffner, eds. Buffers in Ruminant Physiology and Metabolism. Church and Dwight Co., Inc., New York.

70. Kronfeld, D. S. 1979. Sodium, osmolarity and hydration. <u>In</u> W. H. Hale and P. Meinhardt. Regulation of Acid Base Balance. Church and Dwight Co., Inc., Piscataway, New Jersey.

71. Kronfeld, D. S., W. Chalupa, L. F. Chase, R. Harmon, R. W. Hemken, L. D. Muller, C. J. Sniffen, and T. J. Snyder. 1981. Blood and urine responses of lactating cows to 0, .4, .8 and 1.6% sodium bicarbonate. J. Dairy Sci. 64 (Suppl. 1):134.

72. Latham, M. J., J. D. Sutton, and M. E. Sharpe. 1974. Fermentation and microorganisms in the rumen and the content of fat in the milk of cows given low roughage rations. J. Dairy Sci. 57:803.

73. Lofgren, P. A. and R. G. Warner. 1970. Influence of various fiber sources and fractions on milk fat percentage. J. Dairy Sci. 53:296.

74. Loften, J. R. and D. R. Mertens. 1979. The effect of sodium bicarbonate, forage source and NDF level on feed intake, milk production and milk constituents. J. Dairy Sci. 62 (Suppl. 1):141.

75. Mackey, D. R. 1979. Lactic acidosis in the feedlot. In W. H. Hale and P. Meinhardt, eds. Regulation of Acid Base Balance. Church and Dwight Co., Inc., Piscataway, New Jersey.

76. Macleod, G. K., D. G. Grieve, and I. McMillan. 1980. Forage: concentrate ratios for first lactation dairy cows. J. Dairy Sci. 63 (Suppl. 1):126.

77. Masoro, E. J. and P. D. Siegel. 1977. Acid-base regulation. W. B. Saunders Co., Philadelphia.

78. Maynard, L. A., J. K. Loosli, H. F. Hintz, and R. G. Warner. 1979. Animal Nutrition. 7th Ed. McGraw-Hill Book Company, New York.

79. McCullough, M. E. 1966. Relationships between rumen fluid volatile fatty acids and milk fat percentages and feed intake. J. Dairy Sci. 49:896.

80. McLeod, D. S., R. J. Wilkins, and W. F. Raymond. 1970. The voluntary intake by sheep and cattle of silages differing in free acid content. J. Agric. Sci. 75:311.

81. Mertens, D. 1979. Effect of buffers upon fiber digestion. In W. H. Hale and P. Meinhardt, eds. Regulation of Acid Base Balance. Church and Dwight Co., Inc., Piscataway, New Jersey.

82. Miller, R. W., D. R. Waldo, L. A. Moore, and R. W. Hemken. 1964. Effect of buffers to dairy cows on high concentrate rations. J. Anim. Sci. 23:885.

83. Miller, R. W., R. W. Hemken, D. R. Waldo, M. Okamoto, and L. A. Moore. 1965. Effect of feeding buffers to dairy cows fed a high concentrate, low roughage ration. J. Dairy Sci. 48:1455.

84. Miller, W. J. and G. D. O'Dell. 1969. Nutritional problems of using maximum forage or maximum concentrates in dairy rations. J. Dairy Sci. 52:1144.

85. Moseley, J. E., C. E. Coppock, and G. B. Lake. 1976. Abrupt changes in forage-concentrate ratios of complete feeds fed *ad libitum* to dairy cows. J. Dairy Sci. 59:1471.

86. Moss, B. R., S. G. Prier, and R. J. Parker. 1978. The use of high levels of barley and sodium bicarbonate with barley in lactating dairy cow rations. Proc. 29th Ann. Montana Nutrit. Conf., p. 60.

87. Muller, L. D., L. V. Schaffer, L. C. Ham, and M. J. Owens. 1977. Cafeteria style free choice mineral feeder for lactating dairy cows. J. Dairy Sci. 60:1574.

88. Muller, L. D. and L. H. Kilmer. 1979. Sodium Bicarbonate in Dairy Nutrition. National Feed Ingredient Association, West Des Moines, Iowa.

89. Muller, L. D. 1982. Feeding buffers to lactating dairy cows. Proc. 37th Ann. Distillers Feed Research Council Conf., p. 41.

90. National Research Council. 1978. Nutrient requirements for dairy cattle. National Academy of Sciences, Washington, D.C.

91. Nicholson, J. W. G., H. M. Cunningham, and D. W. Friend. 1963. The addition of buffers to ruminant rations IV. The effect of additions of sodium bicarbonate, sodium propionate, limestone and cod liver oil on intra-rumen environments. Can. J. Anim. Sci. 43: 309.

92. Olds, D., T. Cooper, and F. H. Thrift. 1979. Effect of days open on economic aspects of current lactation. J. Dairy Sci. 63:1167.

93. Oltjen, R. R. and R. E. Davis. 1965. Factors affecting the characteristics of cattle fed all-concentrate rations. J. Anim. Sci. 24:198.

94. Osol, A. and R. Pratt. 1973. The United States Dsspensatory, 27th Ed. J. B. Lippincott Co., Philadelphia.

95. Parker, B. N. J. and R. W. Blowery. 1976. Investigation into the relationship of selected blood components to nutrition and fertility of dairy cows under commercial farm conditions. Vet. Rec. 98:394.

96. Patton, W. R. 1970. Ruminant and microbial physio-chemical responses to abrupt rations as influenced by chemical or biological means. Ph.D. Thesis, Oregon State Univ. Dept. of Animal Sci., Corvallis, Oregon. Cited by R. H. Diven. 1975. Bicarbonates in ruminant nutrition and physiology. Feedstuffs 47:32:23.

97. Pauling, L. 1947. General Chemistry. Freeman and Co., San Francisco, California.

98. Phillipson, A. T. and J. L. Mangan. 1959. Bloat in cattle XVI. Bovine saliva: The chemical composition of the parotid, submaxillary and residual secretions. New Zealand J. Agric. Res. 2:990.

99. Putman, P. A., D. A. Yarns, and R. E. Davis. 1966. Feed intake and salivary secretion by steers. J. Anim. Sci. 25:817.

100. Quintero, J. A. 1979. Acid base balance. Warren H. Green, Inc., St. Louis, Missouri.

101. Ralston, A. T. and W. R. Patton. 1976. Controlled ruminant responses to abrupt ration changes. In M. S. Weinberg and A. L. Sheffner, eds. Buffers in Ruminant Physiology and Metabolism. Church and Dwight Co., Inc., New York.

102. Reid, J. T., P. W. Moe, and H. F. Tyrrell. 1966. Re-evaluation of nutrient allowance for high-producing cows energy and protein requirements for milk production. J. Dairy Sci. 49:215.

103. Revision of Analytical Methods for Atomic Absorption. Spectrophotometry. 1958. Perkins-Elmer Co.

104. Rodgers, J. A., B. C. Marks, C. L. Davis, and J. H. Clark. 1979. Alteration of rumen fermentation in steers by increasing rumen fluid dilution rate with mineral salts. J. Dairy Sci. 62:1599.

105. Ronning, M. and R. C. Laben. 1966. Response of lactating cows to free choice feeding of milled diets from 10 to 100% concentrates. J. Dairy Sci. 49:1080.

106. Rook, J. A. and R. C. Campling. 1965. Effect of stage and number of lactation on the yield and composition of cows milk. J. Dairy Res. 32:45.

107. Rowlands, G. J., R. Manston, R. M. Pocock, and S. M. Dew. 1975. Relationships between stage of lactation and pregnancy and blood composition in a herd of dairy cows and the influences of seasonal changes in management on these relationships. J. Dairy Res. 42:349.

108. Scott, D. 1975. Changes in mineral, water and acid-base balance associated with feeding and diet. In I. W. McDonald and A. C. I. Warner, eds. Digestion and Metabolism in the Ruminant. University of New England Publishing Unit, Armidale, NSW, Australia.

109. Schmidt, G. H. 1971. Biology of Lactation. W. H. Freeman Company, San Francisco, California.

110. Schultz, L. H., N. A. Jorgensen, and R. A. Pendleton. 1965. Effect of addition of sodium bicarbonate to pelleted rations which depress milk fat percentage. J. Dairy Sci. 48:808.

111. Synder, T. J., W. Chalupa, L. E. Chase, R. W. Hemken, D. S. Kronfeld, L. D. Muller, L. Mann, and C. J. Sniffen. 1981. Rumen and fecal responses of lactating cows to 0, .4, .8 and 1.6% sodium bicarbonate. J. Dairy Sci. 64 (Suppl. 1):134.

112. Stanley, R. W., N. Kanjanipibul, K. Mortia, and S. M. Ishizake. 1972. Effect of feeding buffered concentrate rations on the performance and metabolism of dairy cattle in a subtropical environment. J. Dairy Sci. 55:959.

113. Stanley, R. W. and L. Kung. 1978. An evaluation of two levels of sodium bicarbonate feeding for lactating animals in a hot climate. J. Dairy Sci. 61 (Suppl. 1):188.

114. Steel, R. G. D. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Company, Inc.

115. Stewart, P. A. 1981. How to Understand Acid-Base. Elsevier North Holland, Inc., New York.

116. Stout, J. D., L. J. Bush, and R. D. Morrison. 1972. Palatability of buffered concentrate mixtures for dairy cows. J. Dairy Sci. 55:130.

117. Stout, W. L., D. C. Kradel, G. A. Jung, and C. G. Smiley. 1976. Blood compositions of well managed high-producing Holstein cows in Pennsylvania. Pa. Agric. Exp. Sta. Prog. Rpt. 358.

118. Teh, T. H., R. W. Hemken, L. M. Mann, and R. H. Hatton. 1981. Palatability of concentrates containing sodium bicarbonate for dairy cows. J. Anim. Sci. 53 (Suppl. 1):438.

119. Thomas, J. W. and R. S. Emery. 1969. Additive nature of sodium bicarbonate and magnesium oxide on milk fat concentrations of milking cows fed restricted roughage rations. J. Dairy Sci. 52: 1762.

120. Thompson, D. J., D. E. Beever, M. J. Latham, M. S. Sharpe, and R. A. Terry. 1978. The effect of inclusion of mineral salts in the diet on dilution rate, the pattern of rumen fermentation and composition of the rumen microflora. J. Agric. Sci. 91:1.

121. Trenkle, A. H. 1979. Sodium Bicarbonate in Beef Nutrition. National Feed Ingredients Association, West Des Moines, Iowa.

122. Turner, A. W. and V. Elizabeth Hodgetts. 1955. Buffering systems in the rumen of sheep. Aust. J. Agric. Res. 6:125.

123. Van Campen, Darrell. 1976. Effects of buffers on ruminal acids. In M. S. Weinberg and A. L. Sheffner, eds. Buffers in Ruminant Physiology and Metabolism. Church and Dwight Co., Inc., New York.

124. Vandenmark, L. L., M. R. Stokes, L. S. Bull, and C. K. Walker. 1981. Effect of buffers on performance by early post-partum cows fed diets based on hay crop silage. J. Dairy Sci. 64 (Suppl. 1): 135.

125. Varman, P. N. and L. H. Schultz. 1968. Blood lipid changes in cows in different rations depressing milk fat test. J. Dairy Sci. 51:1597.

126. Van Soest, P. J. and N. N. Allen. 1959. Studies on the relationship between rumen acids and fat metabolism of ruminants fed on restricted roughage rations. J. Dairy Sci. 42:1977.

127. Van Soest, P. J. 1963. Ruminant fat metabolism with particular reference to factors affecting low milk fat and feed efficiency: A review. J. Dairy Sci. 46:204.

128. Van Soest, P. J. 1963. The use of detergents in the analysis of fibrous feed II. A rapid method for the determination of fiber and lignin. J. Assoc. Official Agr. Chemists 46:829.

129. Wagnsness, P. J. and L. D. Muller. 1981. Maximum forage for dairy cows: A review. J. Dairy Sci. 64:1.

130. Weinberg, M. S. and L. C. Hallman, Jr. 1977. The role of buffers in ruminant digestion and physiology. Proc. 32nd Kansas Formula Feed Conf., p. 11.

131. Wilhite, J. V. 1980. Performance and ruminal parameters in beef steers fed whole shelled corn rations with sodium diacetate or rumensin. M. S. Thesis, The University of Tennessee, Knoxville.

132. Windholz, M., ed. 1976. The Merck Index, 9th Ed. Merck and Co., Inc., Rahway, New Jersey.

133. Winters, R. W., K. Engel, and R. B. Dell. 1969. Acid Base Physiology in Medicine, 2nd Ed. London Co., Cleveland, Ohio.

APPENDIX

Table A-1. Intercept and regression coefficients for production parameter curves of Holstein cows

| Parameter | Treatment[a] | Intercept | $B_1$[b] | $B_2$[b] | $B_3$[b] | $B_4$[b] |
|---|---|---|---|---|---|---|
| Milk yield | I | 40.53779690 | 11.86218389 | -1.93891931 | .13188468 | -.00326576 |
| | II | 40.37068452 | 11.15639399 | -1.75992803 | .11146464 | -.00253223 |
| Milk fat | I | 3.31777344 | -.03493566 | .01398300 | -.00156383 | .0000513 |
| | II | 3.51672436 | -.04481101 | .01266445 | -.00121325 | .00003302 |
| 4% fat corrected milk | I | 36.52243797 | 10.47492358 | -1.65967225 | .10838719 | -.00258605 |
| | II | 37.56414941 | 9.87277692 | -1.50715635 | .09190810 | -.00204394 |
| Ration dry matter intake | I | 1.08447597 | .38965413 | -.05546711 | .00378507 | -.00009804 |
| | II | 1.03414669 | .47180116 | -.06937328 | .00469437 | -.00011783 |
| Total dry matter intake | I | 1.44668999 | .38714246 | -.05482166 | .00370900 | -.000095541 |
| | II | 1.39630342 | .47394769 | -.06966207 | .00469763 | -.00011762 |
| Sodium bicarbonate intake | II | .13177423 | .05545458 | -.00784535 | .00053259 | -.00001352 |

[a]Refer to Tables 6 and 7, pages 51-52, for ration composition.

[b]$B_1$ = Linear regression coefficient for week.
$B_2$ = Quadradic regression coefficient for week.
$B_3$ = Cubic regression coefficient for week.
$B_4$ = Quartic regression coefficient for week.

VITA

Brian C. Bogart, son of Clarence and Alice Bogart, was born in Buffalo, New York on April 7, 1955. He lived in Cheektowaga, New York while attending elementary and high schools. He graduated from Canisius High School, Buffalo, New York, in June of 1973. His formal animal science training began in January of 1975 at the State University of New York Agricultural and Technical College, Alfred, New York, where he received the degree of Associate in Applied Science in Agricultural Science on May 28, 1977. To continue his training, he entered Murray State University, Murray, Kentucky, and the degree of Bachelor of Science with a major in Animal Science and a minor in Chemistry was bestowed on him on May 13, 1978. He then entered graduate school at The University of Tennessee, Knoxville to study Dairy Nutrition and received the degree of Master of Science in Animal Science in August 1982. He is a member of the American Society of Animal Science and the American Dairy Science Association.