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To the Graduate Council:

I am submitting herewith a dissertation written by John W. Tanner entitled "The effect of environmental temperature, electrolyte sources and dietary electrolyte balance on performance and blood parameters of weanling pigs." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

J.P. Hitchcock, Major Professor

We have read this dissertation and recommend its acceptance:

Robert A. McLean, Kelly R. Robbins, James K. Miller, Henry G. Kattesh

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

To the Graduate Council:

I am submitting herewith a dissertation written by John W. Tanner entitled "The Effect of Environmental Temperature, Electrolyte Sources and Dietary Electrolyte Balance on Performance and Blood Parameters of Weanling Pigs." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

John P. Hitchcock

J. P. Hitchcock, Major Professor

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Kelly R. Robbins

Henry S. Kattesh

Accepted for the Council

Cunninkel

Associate Vice Chancellor
and Dean of the Graduate School

THE EFFECT OF ENVIRONMENTAL TEMPERATURE, ELECTROLYTE SOURCES AND DIETARY ELECTROLYTE BALANCE ON PERFORMANCE AND BLOOD PARAMETERS OF WEANLING PIGS

A Dissertation Presented

for the

Doctor of Philosophy Degree

The University of Tennessee, Knoxville

John W. Tanner

August, 1992

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ABSTRACT

Three experiments were conducted utilizing weanling pigs to evaluate: 1) the effect of different dietary electrolyte balance (dEB) levels; 2) different dEB levels and high environmental temperature; and 3) different electrolyte sources and dEB levels on performance and blood parameters.

Experiment 1. Forty-nine crossbred weanling pigs averaging 11.8 kg were randomly assigned seven experimental diets for 21 d to determine the effect of different dEB levels on performance and blood parameters. Average daily gain, feed intake and gain/feed were not significantly affected by an increase in dEB above 224 mEq/kg of feed with the addition of either $NaHCO_3$ or $KHCO_3$. Inspection of the data indicated that initial pig weight affected response to dEB ($P<.05$) as illustrated by a greater feed intake and body weight gain of pigs fed $NaHCO_3$ versus $KHCO_3$. Blood gases were not significantly affected by treatment. Subsequent statistical analysis with electrolyte source using initial weight as a covariate indicated that supplementation of $NaHCO_3$ resulted in increased body weight gain, feed consumption, and gain/feed.

Experiment 2. Twenty-four crossbred weanling pigs averaging 17.3 kg were allotted to six dietary treatments which were blocked by initial weight. The treatments were

fed for 19 d to evaluate the effect of different dEB levels (177, 205 and 347 mEq/kg of feed) and low (19.3 to 21.9°C) and high (27.7 to 32.3°C) environmental temperatures. Pigs housed under the low temperature gained an average of 77 g more per day and consumed an average of 320 g more feed per day than pigs housed under the high temperature ($P<.05$); however, the high temperature treated pigs had improved ($P<.05$) gain/feed. Increasing the dEB level did not significantly affect performance or blood parameters. High temperature lowered performance of pigs in this experiment.

Experiment 3. Fifty-four crossbred weanling pigs averaging 12.4 kg were allotted to nine treatments for 27 d to determine the effect of electrolyte source and dEB level on performance and blood parameters. Pigs were blocked by initial weight. Average daily gain of pigs fed the higher level (417 mEq/kg) was depressed by an average of 54 g ($P<.05$). Pigs fed 417 mEq/kg tended to have a reduced intake of feed. Blood gases and plasma mineral levels were not significantly affected by electrolyte balance in this experiment. Sodium sources improved blood buffering capacity of pigs when compared to potassium sources.

TABLE OF CONTENTS

LIST OF TABLES

TABLE		PAGE
19.	Effect of Electrolyte Form and Balance on Blood Gases of Pigs - HCO_3^-, TCO_2 (Experiment 3)	61
20.	Effect of Electrolyte Form and Balance on Blood Gases of Pigs - pH, pO_2 (Experiment 3)	62
21.	Effect of Electrolyte Form and Balance on Plasma Sodium of Pigs (Experiment 3)	63
22.	Effect of Electrolyte Form and Balance on Plasma Potassium of Pigs (Experiment 3)	64
23.	Effect of Electrolyte Form and Balance on Plasma Chloride of Pigs (Experiment 3)	65

CHAPTER 1

INTRODUCTION

The mineral ions of sodium (Na), potassium (K), and chloride (Cl) are necessary to help maintain the acid-base balance of the pig. When these three minerals are fed as supplements to the diet above or below the levels already present in that diet, they make up what is known as the dietary electrolyte balance (dEB) (Na + K - Cl). Increasing the dEB above what is present in the diet provides a more alkaline diet; however, when the dEB is decreased below the normal dietary level, the diet becomes more acidic.

Inorganic anions or cations are present in the diet in part to maintain electroneutrality. The contribution of these electrolytes is calculated by using the formula: dUA $= \Sigma(Na + K + Mg + Ca) - \Sigma(Cl + P + S)$ (Patience et al., 1987b). This formula is referred to as dietary undetermined anion (Patience et al., 1987b). Dietary electrolyte balance (dEB) is a shortened form of dUA. Patience et al. (1987b) have determined that three factors are primarily responsible for the difficulty of relating dUA (dietary undetermined anion) or dEB to animal productivity. First, dUA or dEB must be independent of specific mineral effects as they influence acid-base status. Second, since the degree of mineral absorption is influenced by dietary supply, it is hard to explain in diet formulation and is further complicated by our lack of understanding of what effect, if any, unabsorbed minerals have on acid-base balance. Finally, to define the effects of the diet on acid-base status and performance we must be able to control such environmental influences as diseases, ambient temperature, water quality and possibly stress which affect mineral metabolism and acid-base status (Patience et al., 1987b). Austic (1980) stated that nutritional requirement for electrolytes must be considered in terms of the absolute minimum amount of each element allowing optimum production and in terms of electrolyte balance which is necessary for optimum physiological performance.

Therefore, the objectives of this study were: 1) to determine the effect of different dEB levels on weanling pig performance and blood parameters, 2) to determine the effect of dEB and environmental temperature on the performance and blood parameters of weanling pigs, and 3) to determine the effect of dEB levels and electrolyte sources on weanling pig performance and blood parameters.

CHAPTER 2

LITERATURE REVIEW

I. Factors Related to Dietary Electrolyte Balance

A. Growth

Sodium (Na), potassium (K), and chlorine (Cl) along with some other minerals such as magnesium (Mg), calcium (Ca), phosphorus (P), and sulfur (S) have been added to the diets of chickens and pigs to determine what effect they have on growth, blood parameters, macromineral balance and metabolic acid-base status (Adekunmisi and Robbins, 1987a,b; Utley *et al.*, 1987; Honeyfield *et al.*, 1985). Adekunmisi and Robbins (1987a) observed that growth of chicks fed low protein diets was depressed when the dietary electrolyte balance was changed by the addition of Na and K. However, when the chickens were fed a high protein diet, alteration of the electrolyte balance caused an improvement in chick growth. Photoperiod did not have any effect on the crude protein by electrolyte balance interaction, but it did alter plasma ammonia concentrations (Adekunmisi and Robbins, 1987a). In another report, it was indicated that the interaction of electrolyte balance by protein mainly resulted from some specific effect on feed intake (Adekunmisi and Robbins, 1987b). They also demonstrated that changes in dietary electrolyte balance affected kidney asparaginase activity, plasma uric acid concentration and acid-base status, but that this was independent of the effects on the growth response.

Yen *et al.* (1981) reported that pigs fed a basal diet supplemented with calcium chloride ($CaCl_2$) experienced a decrease in feed intake and a reduction in daily weight gain. This depression was determined to be caused by a metabolic acidosis in the pig which resulted from an increase in the plasma chloride (Cl^-) level. Because of the elevated plasma Cl^- levels, the body HCO_3^- concentration was reduced, shifting the pH of the body fluid toward acidosis and causing appetite suppression (Yen *et al.*, 1981). However, when an exogenous source of HCO_3^- was fed to the pigs, the growth depression and feed intake reduction occurring from the $CaCl_2$ were alleviated (Yen *et al.*, 1981). Moughan and Smith (1984) concluded that dietary electrolyte balance (Na + K -Cl) does not affect dry matter, organic matter, nitrogen or gross energy digestibility, the metabolizability of nitrogen and gross energy or urinary urea excretion. From another experiment, it was concluded that a depression in growth rate of 5-10 kg pigs was brought about by increasing either K or Cl^- alone without increasing levels of the other (Golz and Crenshaw, 1984).

Haydon *et al.* (1990) reported that an increase in daily gain and feed intake occurred in growing pigs (22 to 50 kg) when the electrolyte balance (EB) increased from 25 to 400 mEq/Kg of feed. However, feed efficiency was unaffected. In the finisher phase (50 to 105 kg) daily gain and feed intake increased up to the EB level of 250 mEq/kg, but decreased at the higher levels. Again, feed efficiency was not affected by EB (Haydon *et al.*, 1990). Blood pH, HCO_3^- and base excess increased linearly with an increase in dietary electrolyte balance from 25 to 400 mEq/kg. In addition to increased pH, HCO_3^- and base excess, total CO_2 content of the blood as well as plasma Na concentration increased with increasing EB levels (Haydon *et al.*, 1990).

In another experiment in which eight men were subjected to a control diet (80 mEq potassium (K^+)/day) followed by a diet low in K^+ (25 mEq K^+/day), body weight decreased during a 4 d exercise regimen (Costill *et al.*, 1982). These men also had a decreased plasma K concentration during the low K^+ regimen, due to hemodilution (Costill *et al.*, 1982).

In chicks fed low levels of Na from either NaCl or $NaHCO_3$, body weight increased ($P<.05$) with each .05% increase in NaCl (Damron *et al.*, 1986). Similar increases in body weight occurred in chicks fed $NaHCO_3$. Water consumption was similar for chicks receiving sodium from either source at the lower level; however, it was significantly higher at .144% $NaHCO_3$ compared to the same level of Na supplied by NaCl (Damron *et al.*, 1986).

Golz and Crenshaw (1990) reported that there was an increase in gain of .07 kg/d for pigs fed a range of Na levels from .03 to .60%. It was also demonstrated that an imbalance of dietary K and Cl^- altered pig growth by depressing it with lower levels of K and increasing levels of Cl^-, or by increasing it with higher levels of K and increasing levels of Cl^-. Furthermore, this study concluded that dEB is not appropriate in predicting optimum levels of Na, K and Cl^- for growing swine because of its limited capability of explaining the effect that one ion has on the other (Golz and Crenshaw, 1990). In another study (Golz and Crenshaw, 1991), it was determined that changes in growth caused by altered dietary K and possibly Cl^- levels are regulated by mechanisms involving renal ammonia metabolism.

B. Acid-base balance

Inorganic anions or cations are present in the diet in part to maintain electroneutrality. The contribution of these electrolytes is calculated by using the formula: dUA $= \Sigma(Na + K + Mg + Ca) - \Sigma(Cl + P + S)$ (Patience *et al.*, 1987b). This formula is referred to as dietary undetermined anion (Patience *et al.*, 1987b). Another shortened form of this formula is the dietary electrolyte balance (dEB) or (Na + K - Cl). From the results of their experiment, Patience *et al.* (1987b) demonstrated that adding Cl as $CaCl_2$ reduced blood pH (7.21 [control] vs.

7.09) (P = .0001, linear), and lowered blood bicarbonate (HCO_3^-) levels (28.1 to 22.2 mmol/L). This experiment also indicated that the pig is able to withstand a dietary alkaline load better than an acid load (Patience *et al.*, 1987b).

In chicks, Nesheim *et al.* (1964), stated that a fairly close balance of Na and K to Cl^- must be maintained in diets in which the Cl^- and sulfate (SO_4^{2-}) forms may increase dietary acidity. Excess Na supplied with a metabolizable anion can be harmful to chicks if it is not balanced with Cl^- or other anion (Nesheim *et al.*, 1964).

In pigs there was a response to oral HCO_3^- supplementation, since both HCO_3^- and base excess were significantly increased (Patience *et al.*, 1986). It was concluded that changes in venous blood measures are indicative of altered acid-base status since the response to HCO_3^- occurred in an acidotic state compared to control values which reflected a normal venous acid-base status. The levels of Na fed in the diet were not sufficient to alter plasma Na levels because they apparently did not overwhelm Na regulatory systems (Patience *et al.*, 1986). From the results of a second experiment in this study, it was determined that kidney excretion of base is closely related to dietary HCO_3^- level. The energy digestibility of the pigs diet in this experiment was not enhanced but was decreased by the dietary addition of potassium bicarbonate ($KHCO_3$). This study, therefore, demonstrated that supplementary $NaHCO_3$ or $KHCO_3$ changed the acid-base status of the normal, healthy pig by inducing renal compensation to maintain blood pH and plasma Na (Patience *et al.*, 1986). Patience *et al.* (1987c), also demonstrated that homeostatic mechanisms, on a short-term basis, can be overcome by heavy supplementation of Na or K as 2.6% $NaHCO_3$ or 3.0% $KHCO_3$, in the diet.

In a study by Andren and Persson (1983), in which 1-3 d old piglets were either infected with enteropathogenic *Escherichia coli* or had spontaneous cases of diarrhea, it was determined that very young piglets are more susceptible to changes in acid-base balance because of a decrease in the serum buffering capacity due to a low serum protein content. Also, the greatest differences between the healthy and diseased pigs were illustrated in base excess, hematocrit and K^+ values which serve as good indicators of the acid-base status, water balance and the prognosis of the individual diseased pig (Andren and Persson, 1983).

Honeyfield *et al.* (1985), demonstrated that as dietary Na increased from .03% to .18%, growing pig performance improved quadratically. However, changes in dietary Cl^- did not affect performance. With an increase in dietary Na, hemoglobin decreased. This agreed with earlier work which demonstrated that low Na diets resulted in hemoconcentration in pigs (Honeyfield *et al.*, 1985). Base excess, an indicator of the total buffering capacity of the blood, was negative when pigs were fed .03% dietary Na. This indicated either acid in the blood or removal of base (Honeyfield *et al.*, 1985). From this study, it was concluded that Na and Cl should be added separately to a pig's diet, in addition to mineralized salt (Honeyfield *et al.*, 1985). According to Patience *et al.* (1987a) the relationship between dietary electrolyte balance and acid-base status in swine appears to be directly or indirectly related to growth and feed intake. As dEB was reduced from a basal level of 175 mEq/Kg, blood pH and HCO_3^- concentrations dropped, indicating a metabolic acidosis. As dEB was increased from a basal level of 175 mEq/kg of feed to 341 mEq/kg, daily gain and feed consumption did not change (Patience *et al.*, 1987a).

The addition of $NaHCO_3$ to diets for yearling horses did not affect average daily gain, respiration rate, venous partial pressure of CO_2 and oxygen, serum K, Cl^-, Ca, P, urea nitrogen or protein levels (Deuel *et al.*, 1985). However, horses receiving HCO_3^- ($NaHCO_3$) had a higher urine pH, lower fecal pH, higher packed cell volume, lower blood pH and lower serum glucose concentrations the day after a meal than horses not receiving the buffer (Deuel *et al.*, 1985).

Holtenius (1990) reported that food-deprived goats given a KCl load maintained their plasma Na and Cl^-

concentrations, while the concentration of plasma K increased. The deficiency of Na in the blood occurring in food-deprived ruminants is mostly caused by a decreased K intake (Holtenius, 1990). Lactating dairy cows fed diets with added dietary Na or KCl salts had lower blood partial pressure of CO_2 (pCO_2) and HCO_3^- than normal, which was indicative of respiratory alkalosis (Schneider *et al.*, 1988).

According to Honeyfield and Froseth (1985), young pigs (average 8.5 kilograms) had an increase in rate and efficiency of gain as the percentage of Na in the diet increased from .02 to .18%. As dietary levels of Cl^- increased from .10 to .33% the hemoglobin concentration decreased quadratically. The .02% level of dietary Na caused a negative base excess (BE) which indicated either a removal of base or presence of acid in the blood. Pigs fed the highest level of Cl^- had a negative BE, lower HCO_3^- and higher plasma K than those fed either .10 or .22% (Honeyfield and Froseth, 1985).

Ducks and chickens fed different levels of Na in the diet did not consume any more or less feed regardless of level; however, the low Na level depressed weight gain compared to the normal or high Na levels (Radke *et al.*, 1984). With the high Na diet both chickens and ducks had a reduced concentration of aldosterone, but when the low Na diets were fed, the aldosterone concentration dramatically increased, probably increasing renal and extrarenal Na retention. Therefore, this study demonstrated that alteration of aldosterone secretions mediate homeostatic adaptations in electrolyte balance during a deficiency or excess of Na (Radke *et al.*, 1984).

Keshavarz (1991) observed that an increased level of calcium sulfate (gypsum) in the diets of laying hens reduced blood HCO_3^- and base excess probably because of its increased acidity with an increased dietary content of gypsum. Weight gain was significantly reduced in hens when all of the supplemental calcium came from gypsum. The blood HCO_3^-, BE and body weight reductions were lessened when part of the supplemental calcium was obtained from oyster shell, rather than gypsum, partly due to longer retention of the oyster shell in the digestive system (Keshavarz, 1991).

Patience (1990) pointed out that acid-base parameters in the blood will change only when the total acid or alkaline load cannot be compensated for by the lungs and kidney. Two types of acid generated by normal metabolic processes are volatile (example: CO_2) and fixed (example: sulfuric and phosphoric). If either of these two types of acid are present in excess or are deficient, they can alter normal acid-base status. Body metabolism and diet contribute to a net acid load which is revealed in a urine pH that is normally below 7.0 (Patience, 1990).

Patience and Wolynetz (1990), in three experiments, concluded that with a decrease in dUA (dietary undetermined anion) (Σ(Na + K + Mg + Ca) - Σ(Cl + P + S)) provided by an increasing level of dietary Cl^-, growth rate of pigs declined. As the Cl^- level increased, the acidity of the diet also increased causing a depression of feed intake as well as a decline in blood pH, HCO_3^- and base excess. Pigs fed increasing levels of dietary Cl^- in the second experiment had elevated levels of plasma Cl^- with lowered plasma Na levels (Patience and Wolynetz, 1990). In experiment three, there was no effect on plasma K, but increasing Cl^- level in the diet decreased plasma Na and increased plasma Cl^- concentrations. These changes in the third experiment were due to Cl^- and were independent of dUA (Patience and Wolynetz, 1990).

C. Environmental temperature

From another study on the dietary electrolyte balance (dEB) of the pig, it was reported that a dEB of 250 mEq/kg appears to promote optimum growth (Utley *et al.*, 1987). In this experiment the pigs were exposed to three maximum ambient temperatures, 35.6, 32.2, and 23.9°C, on three days of blood sampling, d 7, d 21, and d 35, respectively. The upper critical temperature for pigs in this experiment was 32.2°C. Since the highest ambient temperature occurred on d 7, most of the significant effects on blood gases were produced at this time. When pigs are subjected to high temperature they increase their respiration rate by panting more, thus exhaling more carbon dioxide (CO_2). This changes the acid base status of the animal, creating a respiratory alkalosis (Utley *et al.*, 1987). As the dEB increased from 250 to 400 mEq/kg for the Na based diets, the blood pH tended to be numerically lower, whereas the opposite trend occurred in the K fed pigs (Utley *et al.*, 1987). These data suggest that as the ambient temperature rises above the pig's upper critical temperature, the acid-base status of the pig would be more difficult to maintain (Utley *et al.*, 1987). Lopez *et al.* (1991a) reported a reduction in gain and feed intake when the pigs were subjected to a hot environment versus one that is within a pig's thermoneutral comfort zone. For every 1°C increase above 20°C, pigs gained 17.6 g/d less and consumed 43.5 g/d less feed than the thermoneutral pigs (Lopez *et al.*, 1991a).

Bottje and Harrison (1985a) found that cockerels subjected to high heat (37°C) for 90 min exhibited polypnea. Infusing the birds with $NaHCO_3$ increased their blood pH during a 90 min thermoneutral period as well as the heat stress period. A $CaCl_2$ infusion caused the blood pH to decrease during both periods (Bottje and Harrison, 1985a). Birds infused with the $NaHCO_3$ during the heat stress period exhibited a metabolic alkalosis, that overrode the normal respiratory alkalosis, as indicated by an unchanged level of blood HCO_3^-. However, the blood HCO_3^- decreased ($P<.05$) in birds treated with $CaCl_2$ compared with tap water (TW) or carbonated water (CW) (Bottje and Harrison, 1985a). The decrease in the blood HCO_3^- of the $CaCl_2$-infused birds indicated an overriding metabolic acidosis during heat stress (Bottje and Harrison, 1985a). In another study, Bottje and Harrison (1985b) reported that heat stressed cockerels had lower daily gains, feed intake and feed efficiency than cockerels subjected to moderated cyclic temperatures. It was demonstrated that birds infused with CW had improved daily gains, possibly due to an improved blood acid-base balance (Bottje and Harrison, 1985b). Teeter *et al.* (1985) reported that broilers subjected to 32°C (heat stress) gained 53% less weight ($P<.01$) and consumed 48% less feed ($P<.01$) than birds at more normal growing temperatures. The heat stressed birds also exhibited alkalosis caused by a loss of CO_2 due to excessive panting (Teeter *et al.*, 1985).

Lopez *et al.* (1991b) found that pigs subjected to a hot (22 to 35°C) environment versus a thermoneutral (18 to 22°C) environment gained less weight and consumed less feed, but did not differ in feed conversion. The animals in the hot environment also had lower blood pH, pCO_2 and partial pressure of oxygen (pO_2) (Lopez *et al.*, 1991b). Ross and Spears (1992) reported a quadratic response of feed consumption and feed to gain in cattle given four different levels of dEB (0, 150, 300 and 450 mEq/kg), although daily gains were unaffected. The plasma Cl^- content of these cattle decreased linearly to d 42 as dEB increased, while plasma Na and K decreased with 150 and 300 mEq/kg, but increased at 450 mEq/kg. Therefore, it was concluded that dEB affected systemic acid-base balance (Ross and Spears, 1992). Optimum performance was noted for pigs fed a dietary electrolyte balance between 100 and 300 mEq/kg (Na + K - Cl) (Austic *et al*., 1983).

II. Effects of Electrolytes and pH on Nutrient Digestibility

In one study, increasing dEB from -50 to 400 mEq/kg linearly increased the disappearance or digestibility of nitrogen (N), energy and dry matter (DM) from the small intestine (Haydon and West, 1990). However, over the entire gastrointestinal (GI) tract, there were no differences in the digestibility of these nutrients. Blood HCO_3^-, pH and base excess increased linearly with increasing dietary electrolyte balance levels. Blood CO_2 and oxygen concentrations were not affected by increasing dEB levels; however, there was a linear ($P<.001$) increase in total CO_2 concentration as dEB increased (Haydon and West, 1990).

Straw *et al*. (1991) demonstrated that pigs fed increasing pH levels (6.0 to 6.7) had reduced daily gains and feed intake in two trials, in the first 3 wk, when fed dietary P as either dicalcium phosphate (DCP) or defluorinated rock phosphate (DFP). Dietary pH by P source interaction also reduced feed intake in the first 3 wk. The reduction in feed intake and growth rate occurred over the whole study, except that only feed intake was reduced during wk 4 to 6 (Straw *et al.*, 1991). A dietary pH of 5.4 and 6.7 caused a higher Cl^- concentration ($P<.007$) in pigs than did a dietary pH of 6.0. Dry matter values in the stomach were reduced for pigs fed DFP versus DCP diets. Also, colon pH values were lower in pigs fed DFP diets compared to those fed DCP diets (Straw *et al.*, 1991).

III. Relationship between Dietary Electrolytes and Leg Disorders in Chickens

Incidence of twisted legs at 21 d in chickens was reduced by .44% dietary Cl^-; however, it tended to increase with increasing dietary electrolyte balance levels (Hulan *et al.*, 1987). With an increase in dietary levels of Na, K, and Ca there was a decrease in incidence of tibial dyschondroplasia. With a reduction in body weight of chicks fed high K or Ca, there was a reduction in the incidence of tibial dyschondroplasia which may have been caused by the loss in weight (Hulan *et al.*, 1987). An increase in the Cl^- content of the diet increased total chick growth over the whole trial (0 to 35 days) independently of dietary cation level. Excess Na with high

K (1.4%) caused a significant reduction in body weight gain and poorer feed efficiency (Hulan *et al.*, 1986). Another experiment suggested that the effect of anion-cation balance and dietary electrolyte balance on growth were highly dependent on the dietary level of Ca (Hulan *et al.*, 1987). This study also demonstrated that an increase in dietary Cl^- probably caused a metabolic acidosis resulting in an increased occurrence of tibial dyschondroplasia. Increasing the Na and K levels in the diet probably caused a metabolic alkalosis which blocked the effect of high dietary Cl^- on tibial dyschondroplasia (Hulan *et al.*, 1986). When dietary Na and Ca were high (1.38% Ca and .30% Na), decreased K caused a reduction in the incidence of tibial dyschondroplasia (Hulan *et al.*, 1986).

IV. Effect of Single Electrolytes and Electrolyte Balance on Performance of Chickens

Young chickens can endure a wide range of dietary electrolyte balances if Na, K, and Cl^- concentrations remain within the limits of minimum requirements and toxic concentrations (Karunajeewa and Barr, 1988). At a dEB of 205 mEq/kg, including potassium carbonate in the diet at 5.79 g/kg reduced feed efficiency and daily gain; however, the inclusion of potassium sulfate at 8.34 g/kg in the diet caused an increase in the daily gain and feed efficiency. This interaction between K source and dEB may have been due to the chicken's requirement for inorganic sulfate and a possible toxicity of excess potassium carbonate (Karunajeewa and Barr, 1988).

As dietary electrolyte balance increased from 180 to 344 mEq/kg with a Na cation source, there was a tendency for improvement in growth rate at 42 days of age (Johnson and Karunajeewa, 1985). With K as the cation source there was a reduction in live weight gain over the same dEB range. Total dietary cation-anion balance (dUA) as a measure of electrolyte influence was not supported by this study because birds fed a diet with added ammonium chloride (NH_4Cl) (dUA = 327 mEq/kg, dEB = -29 mEq/kg) and a diet supplemented with calcium phosphate (Ca_2HPO_4) (dUA = 327 mEq/kg, dEB = 180 mEq/kg) had reduced daily gains and feed intakes when fed NH_4Cl (Johnson and Karunajeewa, 1985). Ammonium chloride supplementation caused a marked acidosis demonstrated by lower (P<.01) pH, partial pressure of CO_2 and HCO_3^- on d 22. An optimum electrolyte balance for growth of broilers was reported as a range of 200 to 350 mEq/kg of feed (Johnson and Karunajeewa, 1985). In another study, diets containing 8.2 g/kg or more of inorganic P caused a depression in broiler chicken performance (Karunajeewa *et al.*, 1986). Depression in performance of broilers occurred more in the starter phase, with lowered weight gains and poorer feed efficiency, than in the finisher phase with only reduced weight gains (Karunajeewa *et al.*, 1986). Austic *et al.* (1977) reported that growth and feed efficiency of chickens were lower when dietary K was increased but were improved when additional Cl^- was fed with the K.

Parsons *et al.* (1984) concluded that an impaired dietary electrolyte balance did not explain an increased weight loss in chickens fed a low protein diet with added monensin (coccidiostat for chickens). Dietary electrolyte balance decreased from 278 to 172 mEq/kg as crude protein decreased from 24 to 16 percent. Supplementation of .3% K to the 16% crude protein diet (dEB = 249 mEq/kg) had no effect on the weight loss caused by the monensin (Parsons *et al.*, 1984).

V. Electrolyte Responses in Cattle

Szenci *et al.* (1982) indicated that short-term (1 d) acute acidosis induced by oral administration of a large dose of sucrose to dairy cows did not change the acid-base status of Caesarean-derived calves. However, when repeated doses of sucrose were fed for 4 to 7 d to the dams, their calves were either born with metabolic acidosis or developed it shortly after birth. Two of three calves with the metabolic acidosis died soon after birth, probably due to an exhausted *in utero* buffer system (Szenci *et al.*, 1982). Reece (1984) indicated that with a small increase in the blood pH of cattle, there is a decrease in plasma K concentration. Since plasma concentration of HCO_3^- was reduced toward the end of the 15 wk study, the Cl^- concentration in the plasma increased in order to maintain electrical neutrality (Reece, 1984).

An acidic diet, one with supplemental NH_4Cl, caused a reduction in concentrate intake ($P<.05$) resulting in a lower ($P<.05$) DM intake in dairy heifers when compared to two diets buffered by $NaHCO_3$ or $KHCO_3$ (McKinnon *et al.*, 1990). There was a greater consumption of silage, total DM and concentrate for heifers fed $KHCO_3$ than those fed $NaHCO_3$. In another trial, cows fed the buffered diets had significantly higher rumen pH levels than those fed the NH_4Cl diet (McKinnon *et al.*, 1990). Supplementation of $NaHCO_3$ or $KHCO_3$ to the diet elevated blood pH in cows, but not in heifers, when compared to NH_4Cl or control diets. Ammonium chloride supplementation reduced HCO_3^- levels. Concentrations of electrolytes in the serum were not affected by treatment (McKinnon *et al.*, 1990). Supplementation of the diet with buffers did not improve the systemic acid-base status (McKinnon *et al.*, 1990).

Goff *et al.* (1991) stated that six of 23 cows fed a cationic diet (high in Na) developed milk fever; however, only 1 of 24 cows fed an anionic (Cl^-) diet had milk fever. This was a significant reduction which probably occurred because of a reduction in the cation balance of the diet brought about by the anions. Thus, the tissue response to parathyroid hormone increased releasing more Ca into the

(Izquierdo and Czarnecki-Maulden, 1991). Kienzle *et al.* (1991) found that $CaCl_2$, phosphoric acid and ammonium helped to acidify the urine of cats when fed in the diet.

VII. Minerals and Trace Elements

Ching *et al.* (1989) stated that cats fed diets supplemented with NH_4Cl had significant reductions in blood pH, urine pH and blood HCO_3^-. Ammonium chloride treated cats had higher blood ionized Ca concentrations than control cats; however, total plasma Ca was not different. Plasma Na and K of treated cats were not different from control cats, but Cl^- concentration, urinary Cl^- excretion and average daily intake of Cl^- were significantly higher in treated versus control cats (Ching *et al.*, 1989). Long-term acidification of the diet with 1.5% NH_4Cl resulted in chronic metabolic acidosis and lower, or negative, Ca and K balance (Ching *et al.*, 1989).

Dow *et al.* (1990) reported that K deficiency plus dietary acidification caused a more severe hypocalcemia than K deficiency alone. In addition, K depletion caused metabolic acidosis which was increased by dietary acidification with NH_4Cl. Supplementing K in the diet partially corrected the renal dysfunction that was caused by K deficiency and dietary acidification (Dow *et al.*, 1990).

CHAPTER 3

ABSTRACT

Three experiments were conducted utilizing weanling pigs to evaluate: 1) the effect of different dietary electrolyte balance (dEB) levels; 2) different dEB levels and high environmental temperature; and 3) different electrolyte sources and dEB levels on performance and blood parameters.

Experiment 1. Forty-nine crossbred weanling pigs averaging 11.8 kg were randomly assigned seven experimental diets for 21 d to determine the effect of different dEB levels on performance and blood parameters. Average daily gain, feed intake and gain/feed were not significantly affected by an increase in dEB above 224 mEq/kg of feed with the addition of either $NaHCO_3$ or $KHCO_3$. Inspection of the data indicated that initial pig weight affected response to dEB ($P<.05$) as illustrated by a greater feed intake and body weight gain of pigs fed $NaHCO_3$ versus $KHCO_3$. Blood gases were not significantly affected by treatment. Subsequent statistical analysis with electrolyte source using initial weight as a covariate indicated that supplementation of $NaHCO_3$ resulted in increased body weight gain, feed consumption, and gain/feed.

Experiment 2. Twenty-four crossbred weanling pigs averaging 17.3 kg were allotted to six dietary treatments

which were blocked by initial weight. The treatments were fed for 19 d to evaluate the effect of different dEB levels (177, 205 and 347 mEq/kg of feed) and low (19.3 to 21.9°C) and high (27.7 to 32.3°C) environmental temperatures. Pigs housed under the low temperature gained an average of 77 g more per day and consumed an average of 320 g more feed per day than pigs housed under the high temperature ($P<.05$); however, the high temperature treated pigs had improved ($P<.05$) gain/feed. Increasing the dEB level did not significantly affect performance or blood parameters. High temperature lowered performance of pigs in this experiment.

Experiment 3. Fifty-four crossbred weanling pigs averaging 12.4 kg were allotted to nine treatments for 27 d to determine the effect of electrolyte source and dEB level on performance and blood parameters. Pigs were blocked by initial weight. Average daily gain of pigs fed the higher level (417 mEq/kg) was depressed by an average of 54 g ($P<.05$). Pigs fed 417 mEq/kg tended to have a reduced intake of feed. Blood gases and plasma mineral levels were not significantly affected by electrolyte balance in this experiment. Sodium sources improved blood buffering capacity of pigs when compared to potassium sources.

CHAPTER 4

MATERIALS AND METHODS

Experiment 1

I. Experimental Animals and Treatments

Forty-nine crossbred (Landrace X Hampshire X Duroc) weanling pigs initially averaging 43 d of age and 11.8 kg in weight were randomly allotted to seven dietary treatments. Average daily temperatures ranged from 19.6°C to 21.5°C.Compositions of diets used in this experiment are presented in Table 1. The corn-soybean meal diets were formulated to meet or exceed NRC (1988) recommendations for 10 to 20 kg pigs. The addition of calcium chloride ($CaCl_2$) decreased the dietary electrolyte balance (dEB) to 224 mEq/kg. The dEB was raised to 324 or 304, 435 or 390, and 555 or 481 mEq/kg with the addition of either sodium bicarbonate ($NaHCO_3$) or potassium bicarbonate ($KHCO_3$) respectively. Chemical analyses of the diets indicated that the variation between calculated and analyzed dEB levels was mostly due to soybean meal. The analyzed dEB levels were 224 mEq/kg (Diet B-125), 324 mEq/kg (Diet Na1-200), 304 mEq/kg (Diet K1-200), 435 mEq/kg (Diet Na2-275), 390 mEq/kg (Diet K2-275), 555 mEq/kg (Diet Na3-350), and 481 mEq/kg (Diet K3-350). The differences between calculated and analyzed dEB levels were similar to those reported by Adekumnisi and Robbins (1987a) and Patience *et al.* (1987a). The diets were fed for a 3 wk period to

TABLE 1. DIET COMPOSITION FOR EXPERIMENT 1

Diet[1]	B	Na1	K1	Na2	K2	Na3	K3
Corn	67.8	67.8	67.8	67.8	67.8	67.8	67.8
Soybean meal 48	25.2	25.2	25.2	25.2	25.2	25.2	25.2
Dicalcium phosphate	1.37	1.37	1.37	1.37	1.37	1.37	1.37
Limestone	.46	.46	.46	.46	.46	.46	.46
Dextrose	3.69	3.06	2.94	2.43	2.19	1.80	1.44
Sodium bicarbonate ($NaHCO_3$)	--	.63	--	1.26	--	1.89	--
Potassium bicarbonate ($KHCO_3$)	--	--	.751	--	1.502	--	2.252
Calcium chloride ($CaCl_2$)	.33	.33	.33	.33	.33	.33	.33
VTM[2]	.60	.60	.60	.60	.60	.60	.60
Salt	.30	.30	.30	.30	.30	.30	.30
Antibiotic[3]	.25	.25	.25	.25	.25	.25	.25

[1]B designates a basal 18% crude protein diet containing an electrolyte balance of 224 mEq/kg; Na1, Na2, Na3 designate diets containing electrolyte balances of 324, 435, and 555 mEq/kg, respectively, achieved by variable addition of $NaHCO_3$; K1, K2, K3 designate diets containing electrolyte balances of 304, 390, and 481 mEq/kg, respectively, achieved by variable addition of $KHCO_3$.

[2]Vitamin-trace mineral premix provided the following quantities per kg of diet: 10,371 USP Vitamin A; 1,881 ICU Vitamin D3; 18.86 IU Vitamin E; 7.54 mg riboflavin; 22.63 mg d-calcium Pantothenate; 37.7 mg niacin; 9.43 μg Vitamin B_{12}; 3.77 mg Vitamin K menadione sodium bisulfite complex (MSBC); 377 mg choline chloride; 154 mg Zn; 103 mg Fe; 68.6 mg Mn; 10.3 mg Cu; .685 mg I; .086 mg Se.

[3]Antibiotic: ASP250 added at 1.502 lbs/600 lbs (.25% of the diet); ASP250 supplied 100 grams chlortetracycline, 100 grams sulfamethazine and 50 grams of penicillin.

TABLE 1 (CONT.) DIET COMPOSITION FOR EXPERIMENT 1

Diets	B	Na1	K1	Na2	K2	Na3	K3
Lab analysis:							
as-fed basis:							
Crude protein, %	18.41	18.20	17.98	18.92	18.58	18.39	18.92
Sodium, Na^+, %	.146	.350	.145	.681	.146	.877	.189
Potassium, K^+, %	.996	1.024	1.300	1.030	1.621	1.049	1.887
Chloride, Cl^-, %	.333	.319	.324	.442	.314	.334	.299

evaluate the effect of 4 different dEB levels on the performance and blood parameters of weanling pigs.

II. Facilities

Animals were individually housed in expanded metal pens measuring 76 cm in length X 60 cm in width X 57 cm in height. Animals were given *ad libitum* access to feed and water. Feed was added twice daily in individual self feeders and water was supplied using nipple waterers.

III. Dates and Sample Collection

Pigs in experiment one were weighed on a weekly basis. Buckets for storing feed for each pig were weighed at the beginning and end of each week. Feed samples were obtained for crude protein (CP) and dry matter (DM) analyses, (AOAC, 1990). Sodium (Na), K and Cl analyses of diets (Table 1) were performed using the procedures as outlined in Appendices A and B.

Individual blood plasma samples were analyzed for Na, and K using a Model IL 551 aa/ae spectrophotometer after appropriate dilutions were made. Blood samples were obtained from the anterior vena cava on d 0, and on d 14 for blood gas analysis using an automated blood pH-gas analyzer (Model IL 1312) at a temperature of 38.6° C and standardized at a hemoglobin concentration of 15.0 g/dL.

IV. Statistical Analysis

The data were analyzed by the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, 1985). The model for this completely randomized design was:

$$Y_{ij} = \mu + t_i + e_{ij}$$

where: Y_{ij} = the dependent variables average daily gain, feed efficiency, feed consumption, blood gases, and plasma minerals

μ = the overall theoretical mean

t_i = treatment mean which is made up of different dietary electrolyte balance (dEB) levels (Na + K - Cl in mEq/kg of feed) obtained with the addition of sodium or potassium bicarbonate (fixed)

e_{ij} = random error

In addition to this model, orthogonal (single-degree of freedom) comparisons were made to evaluate the effect of initial weight as a covariate and its treatment interaction on performance of the pigs. The model for this was:

$$Y_{ij} = \mu + t_i + b*(x_{ij} - x \text{ mean}) + t_i*b_i(x_i - x \text{ mean}) + e_{ij}$$

Where Y_{ij} = the dependent variables average daily gain, feed efficiency, and feed consumption

μ = the overall theoretical mean

t_i = treatment mean which is made up of different dEB levels obtained with the addition of sodium or potassium bicarbonate (fixed)

$b*(x_{ij}$ - x mean) = regression of initial weight on treatment mean

$t_i*b_i(x_i$ - x mean) = initial weight by treatment interaction

b_i = differential regression coefficient for measuring differences among treatments

e_{ij} = random error

Means were tested for significance using the overall error mean square.

Experiment 2

I. Experimental Animals and Treatments

Twenty-four crossbred (Landrace X Hampshire X Duroc) weanling pigs averaging 55 d of age and 17.3 kg in weight, were allotted to six dietary treatments. Pigs were blocked by initial weight, and sex was evenly distributed within treatments. Four pigs were fed each of three levels of dEB (177, 205, and 347 mEq/kg of feed) at a temperature range of 19.3 to 21.9° C (T1), while four other pigs were fed each of the same levels at a temperature range of 27.7 to 32.3°C (T2). Heat was provided by ceramic floor heaters. With the addition of $CaCl_2$ to an 18% crude protein corn-soybean meal diet the dEB was lowered to 177 mEq/kg. The dEB was raised to 205 and 347 mEq/kg with the addition of $NaHCO_3$. Chemical analyses of the diets indicated that the variation between calculated and analyzed dEB levels was mostly due to soybean meal. The analyzed dEB levels were 177 mEq/kg (A-150), 205 mEq/kg (B-250), and 347 mEq/kg (C-350). The differences between calculated and analyzed dEB levels were similar to those reported by Adekunmisi and Robbins (1987a). Composition of diets used in this experiment are presented in Table 2. The diets were fed for 19 d to evaluate the effect of dEB levels and high environmental temperature on weanling pig performance and blood parameters. Facilities were similar to those in experiment 1.

TABLE 2. DIET COMPOSITION FOR EXPERIMENT 2

Diet[1]	A	B	C
Corn	70.19	70.19	70.19
Soybean meal 48	24.81	24.81	24.81
Dicalcium phosphate	1.34	1.34	1.34
Limestone	.791	.791	.791
Dextrose	1.031	1.653	.813
Sodium bicarbonate ($NaHCO_3$)	---	.066	.906
Calcium chloride ($CaCl_2$)	.688	---	---
VTM[2]	.600	.600	.600
Salt	.300	.300	.300
Antibiotic[3]	.250	.250	.250

[1]A designates a diet containing an electrolyte balance of 177 mEq/kg; B designates a diet containing an electrolyte balance of 205 mEq/kg; C designates a diet containing an electrolyte balance of 347 mEq/kg.

[2]Vitamin-trace mineral premix provided the following quantities per kg of diet: 10,371 USP Vitamin A; 1,881 ICU Vitamin D_3; 18.86 IU Vitamin E; 7.54 mg riboflavin; 22.63 mg d-calcium Pantothenate; 37.7 mg niacin; 9.43 μg Vitamin B_{12}; 3.77 mg Vitamin K (MSBC); 377 mg choline chloride; 154 mg Zn; 103 mg Fe; 68.6 mg Mn; 10.3 mg Cu; .685 mg I; .086 mg Se.

[3]Antibiotic: ASP250 added at 1.29 lbs/515 lbs (.25% of the diet), ASP250 supplied 100 grams chlortetracycline, 100 grams sulfamethazine and 50 grams of penicillin.

TABLE 2 (CONT). DIET COMPOSITION FOR EXPERIMENT 2

Diet	A	B	C
Lab analysis:			
As-fed basis:			
Crude protein, %	18.09	17.77	16.87
Sodium, Na^+, %	.170	.142	.424
Potassium, K^+, %	.907	.834	.851
Chloride, Cl^-, %	.457	.250	.196

II. Dates and Sample Collection

The pigs were weighed on a weekly basis. Buckets for storing feed for each pig were weighed at the beginning and end of each week. Feed samples were obtained for crude protein (CP) and dry matter (DM) analyses (AOAC, 1990). Sodium (Na), potassium (K) and chloride (Cl) analyses of diets (Table 2) and plasma were performed using the procedure described in Appendices A and B.

Individual blood plasma samples were analyzed for Na, and K using a Model IL 551 aa/ae spectrophotometer, after appropriate dilutions were made. Blood samples were obtained from the anterior vena cava on d 0, on d 14, and on d 19 for blood gas analysis using an automated blood pH-gas analyzer (Model IL 1312) at a temperature of 38.6° C and standardized at a hemoglobin concentration of 15.0 g/dL.

III. Statistical Analysis

The data were analyzed by the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, 1985). The model for this randomized complete block design was:

$$Y_{ijkl} = \mu + B_i + \delta_{(i)k} + T_j + e_{(ijk)l}$$

where: Y_{ijkl} = the dependent variables average daily gain, feed efficiency, feed consumption, blood gases, and plasma minerals

μ = the overall theoretical mean

B_i = effect of the $i^{\underline{th}}$ block or initial weight of the pigs

$\delta_{(i)k}$ = the $K^{\underline{th}}$ restriction error within initial weight and completely confounded with initial weight

T_j = effect of the $j^{\underline{th}}$ treatment mean (fixed), made up of two temperature ranges and three dietary electrolyte balance levels

$e_{(ijk)l}$ = effect of the $l^{\underline{th}}$ random error associated with the $ij^{\underline{th}}$ experimental unit and subjected to the $K^{\underline{th}}$ restriction on the $i^{\underline{th}}$ block (initial weight)

In addition to this model, the treatment was partitioned into its two components, temperature range and dEB level, and their interaction using the following model:

$$Y_{ijklm} = \mu + B_i + \delta_{(i)k} + t_j + l_l + tl_{jl} + e_{(ijkl)m}$$

where Y_{ijklm} = the dependent variables average daily gain, feed efficiency, feed consumption, blood gases, hematocrits, hemoglobins, and plasma minerals

μ = the overall theoretical mean

B_i = effect of the i^{th} block or initial weight of the pigs

$\delta_{(i)k}$ = the k^{th} restriction error within initial weight and completely confounded with initial weight

t_j = the effect of the j^{th} temperature range (random)

l_l = the effect of the l^{th} level of dietary electrolyte balance (fixed)

tl_{jl} = interaction effect of the j^{th} temperature range with the l^{th} dietary electrolyte balance level

$e_{(ijkl)m}$ = effect of the m^{th} random error associated with the ijl^{th} experimental unit and subjected to the k^{th} restriction on the i^{th} block (initial weight)

Means for both models were separated by the Student Newman Kuels (SNK) mean separation procedures and least squared means. Means were tested for significance using the overall error mean square.

Experiment 3

I. Experimental Animals and Treatments

Fifty-four crossbred (Landrace X Hampshire X Duroc) weanling pigs, averaging 49 d of age and 12.4 kg in weight, were allotted to nine dietary treatments. The average room temperature in this experiment was 29.9°C. Heat was provided by ceramic floor heaters. Pigs were blocked by initial weight. Six pigs were fed each of the nine 18% crude protein corn-soybean meal diets, a negative control and eight others consisting of a factorial arrangement of two dietary electrolyte balance (dEB) levels (319 or 417 mEq/kg) and four electrolyte sources ($NaHCO_3$, Na_2CO_3, $KHCO_3$, and K_2CO_3). Chemical analyses of the diets indicated that the variation between calculated and analyzed dEB levels was mostly due to soybean meal. The analyzed dEB levels were 312, 311, 328, and 327 mEq/kg for the 250 mEq/kg dEB level, 448, 417, 361, and 442 mEq/kg for the 350 mEq/kg dEB level, and 254 mEq/kg for the 184 mEq/kg negative control. The differences between calculated and analyzed dEB levels were similar to those reported by Adekunmisi and Robbins (1987a). The diets were fed for 27 d to evaluate the effect of dEB levels and electrolyte sources on weanling pig performance and blood parameters. Composition of diets used in this experiment are presented in Table 3. Facilities were similar to those in experiment 1.

TABLE 3. DIET COMPOSITION FOR EXPERIMENT 3

Diet[1] Ingredients, %	Na1	Na2	K1	K2	Na3	Na4	K3	K4	B
Corn	70.19	70.19	70.19	70.19	70.19	70.19	70.19	70.19	70.19
Soybean meal 48	24.81	24.81	24.81	24.81	24.81	24.81	24.81	24.81	24.81
Dicalcium phosphate	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34
Limestone	.79	.79	.79	.79	.79	.79	.79	.79	.79
Dextrose	1.12	1.32	1.01	1.22	.28	.79	.01	.52	1.67
Sodium bicarbonate ($NaHCO_3$)	.553	--	--	--	1.394	--	--	--	--
Sodium carbonate (Na_2CO_3)	--	.349	--	--	--	.879	--	--	--
Potassium bicarbonate ($KHCO_3$)	--	--	.66	--	--	--	1.661	--	--
Potassium carbonate (K_2CO_3)	--	--	--	.455	--	--	--	1.146	--
VTM[2]	.60	.60	.60	.60	.60	.60	.60	.60	.60
Salt	.35	.35	.35	.35	.35	.35	.35	.35	.35
Antibiotic[3]	.25	.25	.25	.25	.25	.25	.25	.25	.25

[1]Na1, Na2, Na3, Na4 designate diets containing electrolyte balances of 312, 311, 448 and 417 mEq/kg, respectively, provided by addition of $NaHCO_3$, Na_2CO_3, $NaHCO_3$, and Na_2CO_3, respectively. K1, K2, K3, K4 designate diets containing electrolyte balances of 328, 327, 361, 442 mEq/kg, respectively, provided by addition of $KHCO_3$, K_2CO_3, $KHCO_3$, and K_2CO_3, respectively. B designates a basal 18% crude protein diet containing an electrolyte balance of 254 mEq/kg.

[2]Vitamin-trace mineral premix provided the following quantities per kg of diet: 10,371 USP vitamin A; 1,886 ICU vitamin D_3; 18.86 IU vitamin E; 7.54 mg riboflavin; 22.63 mg d-calcium Pantothenate; 37.7 mg niacin; 9.43 Ìg vitamin B_{12}; 3.77 mg vitamin K menadione sodium bisulfite complex (MSBC); 377 mg choline chloride; 154 mg Zn; 103 mg Fe; 68.6 mg Mn; 10.3 mg Cu; .685 mg I; .086 mg Se.

[3]Antibiotic: ASP250 added at 1.79 lbs/714 lbs (.25% of feed), ASP250 supplied 100 grams chlortetracycline, 100 grams sulfamethazine and 50 grams of penicillin.

TABLE 3 (CONT). DIET COMPOSITION FOR EXPERIMENT 3

Diet	Na1	Na2	K1	K2	Na3	Na4	K3	K4	B
Lab analysis:									
as-fed basis:									
Crude protein, %	16.24	17.21	16.84	17.47	16.87	18.01	15.63	18.04	16.58
Sodium, Na, %	.328	.382	.235	.154	.661	.546	.171	.219	.221
Potassium, K, %	.848	.863	1.126	1.20	.870	.901	1.313	1.623	.889
Chloride, Cl, %	.167	.270	.221	.168	.221	.181	.173	.244	.246

II. Dates and Sample Collection

The pigs were weighed on a weekly basis. Buckets for storing feed for each individual pig were weighed at the beginning and end of each week. Feed samples were obtained for crude protein (CP) and dry matter (DM) analyses (AOAC, 1990). Sodium, K, and Cl^- analyses of diets (Table 3) and plasma were performed using the procedure as described in Appendices A and B.

Individual blood plasma samples were analyzed for Na, and K using a Model IL 551 aa/ae spectrophotometer, after appropriate dilutions were made. Blood samples were obtained from the anterior vena cava on d 14 and on d 27 for blood gas analysis using an automated blood pH-gas analyzer (Model IL 1312) at a temperature of 38.6° C and standardized at a hemoglobin concentration of 15.0 g/dL.

III. Statistical Analysis

The data were analyzed by the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, 1985). The data analyzed with the GLM only include the factorial arrangement of two levels and four sources because the negative control treatment was similar to the other eight. The model for this randomized complete block design was:

$$Y_{ijklm} = \mu + B_i + \delta_{(i)k} + l_j + f_l + lf_{jl} + e_{(ijkl)m}$$

Where: Y_{ijklm} = the dependent variables average daily gain, feed efficiency, feed consumption, blood gases, and plasma minerals

μ = the overall theoretical mean

B_i = effect of the i^{th} block or initial weight of the pigs

$\delta_{(i)k}$ = the k^{th} restriction error within initial weight and completely confounded with initial weight

l_j = the effect of the j^{th} level of dietary electrolyte balance (fixed)

f_l = the effect of the l^{th} form of electrolyte (fixed)

lf_{jl} = interaction effect of the j^{th} dietary electrolyte balance level with the l^{th} form of electrolyte (fixed)

$e_{(ijkl)m}$ = effect of the m^{th} random error associated with the ijl^{th} experimental unit and subjected to the k^{th} restriction on the i^{th} block (initial weight)

Means for this model were separated by the Student Newman Keuls (SNK) mean separation procedure. Means were tested for significance using the overall error mean square.

CHAPTER 5

RESULTS

Experiment 1

Increasing dietary electrolyte balance above 224 mEq/kg by the addition of either sodium or potassium bicarbonate had no significant effect on either gain, feed intake, or gain/feed (Table 4). There was a consistent tendency for feed consumption and average daily gain to decline as electrolyte balance increased in each of wk 1-3 and overall, but this effect was not significant. In this experiment pigs were randomly allotted to treatments. Inspection of data indicated that initial pig weight affected response to electrolyte balance. Subsequent statistical analysis with electrolyte source and initial pig weight used as a covariate (Table 5) indicated pigs fed diets containing sodium bicarbonate consumed more feed, gained more body weight and were more feed efficient than pigs fed diets containing potassium bicarbonate. As a result, subsequent experiments were conducted as randomized complete block designs to account for the variation introduced by initial body weight. Blood gases and plasma minerals were not significantly affected by electrolyte source or dEB level (Tables 6, 7, and 8).

TABLE 4. EFFECT OF ELECTROLYTE BALANCE ON PERFORMANCE OF PIGS (EXPERIMENT 1)

Diet[1,2]	B	Na1	K1	Na2	K2	Na3	K3	SEM[3]
ADG, g								
Week 1	356	382	336	325	341	304	246	45.2
Week 2	876	813	857	853	859	840	786	54.2
Week 3	766	819	744	727	712	711	774	50.5
Overall	666	671	646	635	637	619	602	35.6
ADFI, g								
Week 1	705	731	710	631	686	663	608	54.5
Week 2	1,438	1,310	1,357	1,294	1,410	1,300	1,211	68.1
Week 3	1,840	1,739	1,862	1,699	1,752	1,732	1,681	81.0
Overall	1,327	1,260	1,310	1,209	1,283	1,232	1,166	51.3
G/F								
Week 1	.50	.52	.49	.51	.49	.45	.40	.05
Week 2	.61	.62	.64	.66	.60	.65	.65	.03
Week 3	.42	.47	.40	.43	.41	.41	.47	.03
Overall	.51	.53	.50	.53	.49	.50	.52	.02

[1]B designates a basal 18% crude protein diet containing an electrolyte balance of 224 mEq/kg; Na1, Na2, Na3 designate diets containing electrolyte balances of 324, 435, and 555 mEq/kg, respectively, achieved by variable addition of $NaHCO_3$; K1, K2, K3 designate diets containing electrolyte balances of 304, 390, and 481 mEq/kg, respectively, achieved by variable addition of $KHCO_3$.

[2]Seven pigs per diet.

[3]SEM equals standard error of the mean.

TABLE 4 (CONT). EFFECT OF ELECTROLYTE BALANCE ON PERFORMANCE OF PIGS (EXPERIMENT 1)

Initial weight by treatment contrasts	p values									
	ADG Week				ADFI Week			G/F Week		
	1	2	3	overall	2	3	overall	1	2	Overall
2&4&6 vs 3&5&7	.0049	.0003		.0002	.0100	.0216	.0123	.0172		
4 vs 6	.0359		.0326	.0148				.0264		.0173
3 vs 5&7	.0292	.0103		.0112				.0072	.0224	.0050
5 vs 7		.0161		.0110				.0303	.0428	.0032

TABLE 5. EFFECTS OF ELECTROLYTE SOURCE ON PERFORMANCE OF PIGS (EXPERIMENT 1)[1]

Electrolyte sources:[2]	Sodium bicarbonate	Potassium bicarbonate	SEM
ADG, g			
Week 1	337[a]	308[b]	22.86
Week 2	835[a]	834[b]	22.10
Week 3	752	743	28.04
Overall	642[a]	628[b]	16.13
ADFI, g			
Week a	675	668	31.09
Week 2	1,301[a]	1,326[b]	32.08
Week 3	1,723[a]	1,765[b]	40.59
Overall	1,234[a]	1,253[b]	29.60
G/F			
Week 1	.49[a]	.46[b]	.03
Week 2	.64	.63	.02
Week 3	.44	.43	.01
Overall	.52	.50	.01

[1]Initial weight used as a covariate to determine differences.

[2]Twenty-one pigs per source.

[a,b]Means within a row lacking a common superscript letter differ ($P<.05$).

TABLE 6. EFFECT OF ELECTROLYTE BALANCE ON BLOOD GASES OF PIGS - pH, pO_2, BE (EXPERIMENT 1)

Diets[1,2]	B	Na1	K1	Na2	K2	Na3	K3	SEM
pH								
Day 0	7.43	7.38	7.42	7.46	7.51	7.47	7.43	.02
Day 14	7.29	7.33	7.34	7.34	7.34	7.28	7.34	.02
Partial pressure of oxygen (pO_2), mmHg								
Day 0	82	57	71	88	90	90	72	9.06
Day 14	52	58	54	65	63	47	57	7.47
Base excess (BE), mmol/L[3]								
Day 0	2.7	2.7	4.3	4.1	5.6	4.9	3.1	.77
Day 14	1.1	2.4	3.6	2.8	3.3	2.8	3.9	.93

[1]B designates a basal 18% crude protein diet containing an electrolyte balance of 224 mEq/kg; Na1, Na2, Na3 designate diets containing electrolyte balances of 324, 435, and 555 mEq/kg, respectively, achieved by variable addition of $NaHCO_3$; K1, K2, K3 designate diets containing electrolyte balances of 304, 390, and 481 mEq/kg, respectively, achieved by variable addition of $KHCO_3$.

[2]Seven pigs per diet.

[3]Base excess in mmol/liter; base excess is the quantity of extra base above normal (principally bicarbonate ions) after exclusion of the hemoglobin content.

TABLE 7. EFFECT OF ELECTROLYTE BALANCE ON BLOOD GASES OF PIGS - pCO_2, HCO_3^-, TCO_2 (EXPERIMENT 1)

Diet[1,2]	B	Na1	K1	Na2	K2	Na3	K3	SEM
Partial pressure of carbon dioxide (pCO_2), mmHg								
Day 0	40	46	45	38	34	37	41	2.07
Day 14	62	56	58	56	54	67	57	4.04
Bicarbonate concentration (HCO_3^-), mmol/L								
Day 0	26	27	28	26	27	27	26	.70
Day 14	28	29	30	29	28	31	30	1.15
Total concentration of carbon dioxide (TCO_2), mmol/L								
Day 0	27	29	29	27	28	28	27	.73
Day 14	30	30	32	30	30	33	32	1.23

[1]B designates a basal 18% crude protein diet containing an electrolyte balance of 224 mEq/kg; Na1, Na2, Na3 designate diets containing electrolyte balances of 324, 435, and 555 mEq/kg, respectively, achieved by variable addition of $NaHCO_3$; K1, K2, K3 designate diets containing electrolyte balances of 304, 390, and 481 mEq/kg, respectively, achieved by variable addition of $KHCO_3$.

[2]Seven pigs per diet.

TABLE 8. EFFECT OF ELECTROLYTE BALANCE ON PLASMA MINERALS OF PIGS (EXPERIMENT 1)

Diet[1,2]	B	Na1	K1	Na2	K2	Na3	K3	SEM
Sodium, mEq/L								
Day 0	150	148	149	150	150	150	148	1.02
Day 7	147	146	147	147	148	146	147	1.62
Day 14	151	149	151	149	152	151	152	1.52
Day 21	161	160	157	166	156	158	155	3.68
Potassium, mEq/L								
Day 0	6.3	6.2	5.7	5.6	5.6	5.8	6.0	.22
Day 7	6.0	6.1	5.4	5.9	6.0	6.0	5.5	.21
Day 14	5.4^{ab}	5.5^{ab}	4.9^{b}	5.5^{ab}	6.1^{a}	5.6^{ab}	5.5^{ab}	.20
Day 21	6.1	5.8	6.1	5.9	5.4	5.9	6.0	.24
Chloride, mEq/L								
Day 0	94	95	94	95	95	94	94	1.26
Day 7	92	92	89	89	92	92	90	1.19
Day 14	90	90	88	88	90	88	89	1.16
Day 21	89	89	87	89	86	88	87	.87

[1]B designates a basal 18% crude protein diet containing an electrolyte balance of 224 mEq/kg; Na1, Na2, Na3 designate diets containing electrolyte balances of 324, 435, and 555 mEq/kg, respectively, achieved by variable addition of $NaHCO_3$; K1, K2, K3 designate diets containing electrolyte balances of 304, 390, and 481 mEq/kg, respectively, achieved by variable addition of $KHCO_3$.

[2]Seven pigs per diet.

[a,b]Means within a row lacking a common superscript letter differ ($P<.05$).

Experiment 2

Pigs housed under the lower temperature consumed an average of 320 g more feed per day, and gained an average of 77 g more per day than pigs housed under the higher temperature; however, pigs housed under the higher temperature had improved gain/feed (Table 9). Pigs housed under the higher temperature exhibited a respiratory alkalosis as demonstrated by a lower partial pressure of CO_2 and a higher pH (Table 10 and 11). The combination of lower feed consumption, lower weight gain, and respiratory alkalosis in pigs housed under the higher temperature indicate that high temperature can cause a depression in performance of weaned pigs. Partial pressure of O_2 and plasma minerals were not significantly affected by either temperature or dEB levels (Tables 12 and 13). There was no response to increasing dEB level in this experiment in pigs housed in either temperature range. Therefore, a subsequent experiment was conducted as a randomized complete block design to determine if dEB level and electrolyte source influenced pig growth and feed consumption with pigs housed under high temperature.

TABLE 9. EFFECT OF TEMPERATURE AND ELECTROLYTE BALANCE ON PERFORMANCE OF PIGS (EXPERIMENT 2)

Temperature Item	19.3 to 21.9°C											
	ADG, g				ADFI, g				G/F			
	Week 1	Week 2	Week 3	Overall	Week 1	Week 2	Week 3	Overall	Week 1	Week 2	Week 3	Overall
dEB level[1,2]												
A	414	1,106	1,015	805	1,026	1,823	2,135	1,550	.41	.61	.49	.52
B	360	1,104	977	775	1,088	1,919	2,364	1,655	.33	.57	.41	.47
C	416	1,037	856	749	1,076	1,922	2,208	1,624	.39	.54	.39	.46
Mean[3]	397	1,082[a]	949	776	1,063	1,888[a]	2,236	1,610	.38	.57	.43	.48
SEM[4]	39.64	69.30	76.60	27.61	26.86	68.77	173.25	55.55	.04	.03	.05	.02
Temperature	27.7 to 32.3°C											
dEB level[1,2]												
A	505	763	959	719	1,099	1,628	1,106	1,296	.46	.47	.83	.55
B	498	843	800	705	1,054	1,653	1,075	1,280	.48	.50	.76	.55
C	547	925	500	674	1,122	1,696	989	1,298	.49	.55	.52	.52
Mean[3]	517	844[b]	753	699	1,092	1,659[b]	1,057	1,291	.48	.51	.70	.54
SEM[4]	42.36	119.00	220.86	54.99	34.53	130.00	107.50	74.94	.04	.06	.19	.03

[1]A designates a diet containing an electrolyte balance of 177 mEq/kg; B designates a diet containing an electrolyte balance of 205 mEq/kg; C designates a diet containing an electrolyte balance of 347 mEq/kg.
[2]Four pigs per level within the temperature range.
[3]Mean of animals across levels, within temperatures.
[4]SEM equals standard error of the mean.
[a,b]Means within a column lacking a common superscript letter differ ($P<.05$).

TABLE 10. EFFECT OF TEMPERATURE AND ELECTROLYTE BALANCE ON BLOOD GASES OF PIGS - pCO_2, HCO_3^-, TCO_2 (EXPERIMENT 2)

Temperature	19.3 to 21.9°C								
Item	Partial pressure of carbon dioxide (pCO_2), mmHg			Bicarbonate concentration (HCO_3^-), mmol/L			Total concentration of carbon dioxide (TCO_2), mmol/L		
	Day 0	Day 14	Day 19	Day 0	Day 14	Day 19	Day 0	Day 14	Day 19
dEB level[1,2]									
A	53	82	--	28	29	--	30	32	--
B	60	81	--	27	29	--	29	32	--
C	54	71	--	28	28	--	30	30	--
Mean[3]	56	78[a]	--	28	29	--	30	31	--
SEM	4.11	6.83	--	.79	1.22	--	.91	1.32	--
Temperature	27.7 to 32.3°C								
A	49	67	60	27	28	28	29	30	30
B	50	53	64	28	26	29	29	28	31
C	49	72	61	28	29	28	30	31	30
Mean[3]	49	64[b]	62	28	28	28	29	30	30
SEM	4.15	5.46	4.04	1.04	.85	.69	1.06	.92	.69

[1]A designates a diet containing an electrolyte balance of 177 mEq/kg; B designates a diet containing an electrolyte balance of 205 mEq/kg; C designates a diet containing an electrolyte balance of 347 mEq/kg.
[2]Four pigs per level within the temperature range.
[3]Mean of animals across levels, within temperature.
[a,b]Means within a column lacking a common superscript letter differ ($P<.05$).

TABLE 11. EFFECT OF TEMPERATURE AND ELECTROLYTE BALANCE ON BLOOD GASES OF PIGS - pH, BE (EXPERIMENT 2)

Temperature	19.3 to 21.9°C					
dEB level[1,2]	pH			Base excess (BE)[3]		
	Day 0	Day 14	Day 19	Day 0	Day 14	Day 19
A	7.35	7.16	--	2.8	-.7	--
B	7.27	7.17	--	.3	-.5	--
C	7.33	7.23	--	2.2	.1	--
Mean[4]	7.32	7.19[a]	--	1.8	-.4	--
SEM	.03	.04	--	.49	1.31	--
Temperature	27.7 to 32.3°C					
A	7.36	7.23	7.28	2.5	-.4	.4
B	7.36	7.32	7.26	2.7	-1.0	.4
C	7.37	7.22	7.26	3.2	-.5	.1
Mean[4]	7.36	7.26[b]	7.27	2.8	-.6	.3
SEM	.04	.03	.03	1.28	.94	1.06

[1]A designates a diet containing an electrolyte balance of 177 mEq/kg; B designates a diet containing an electrolyte balance of 205 mEq/kg; C designates a diet containing an electrolyte balance of 347 mEq/kg.
[2]Four pigs per level within the temperature range.
[3]Base excess in mmol/Liter; the quantity of extra base above normal (principally bicarbonate ions) after exclusion of the hemoglobin content.
[4]Mean of animals across levels, within temperatures.
[a,b]Means within a column lacking a common superscript letter differ ($P<.05$).

TABLE 12. EFFECT OF TEMPERATURE AND ELECTROLYTE BALANCE ON THE PARTIAL PRESSURE OF OXYGEN IN PIGS (EXPERIMENT 2)

Temperature	19.3 to 21.9°C				27.7 to 32.3°C			
dEB level[1,2] Item	A	B	C	SEM	A	B	C	SEM
partial pressure of oxygen, mmHg								
Day 0	53	42	57	10.89	42	70	53	12.84
Day 14[3]	44[a]	43[a]	59[b]	7.40	48[c]	81[d]	48[c]	7.25
Day 19	--	--	--	--	43	43	48	4.53

[1]A designates a diet containing an electrolyte balance of 177 mEq/kg; B designates a diet containing an electrolyte balance of 205 mEq/kg; C designates a diet containing an electrolyte balance of 347 mEq/kg.

[2]Four pigs per level within temperature range.

[3]Partial pressure of oxygen tended (P = .0985) to be higher for pigs housed at the higher temperature.

[a,b,c,d]Means within a row within temperature range lacking a common superscript letter differ ($P<.05$)

TABLE 13. EFFECT OF TEMPERATURE AND ELECTROLYTE BALANCE ON PLASMA MINERALS OF PIGS (EXPERIMENT 2)

Temperature	19.3 to 21.9°C				27.7 to 32.3°C			
dEB level[1,2] Item	A	B	C	SEM	A	B	C	SEM
Sodium, mEq/L								
Day 0	127	127	124	1.55	129	128	127	1.80
Day 7	131	130	128	1.23	126	128	131	1.52
Day 14	142	143	143	1.23	141	143	142	1.49
Day 19	---	---	---	---	125	127	125	2.24
Potassium, mEq/L								
Day 0	5.5	5.3	5.0	.15	5.9	4.9	5.7	.34
Day 7	5.2	5.0	5.0	.28	5.2	5.2	6.0	.32
Day 14	6.7	6.3	6.3	.29	6.2	6.0	6.1	.26
Day 19	---	---	---	---	5.4	5.3	5.5	.18
Chloride, mEq/L								
Day 0	89	95	88	2.94	90	90	89	1.47
Day 7	88	90	90	1.05	88	87	92	1.89
Day 14	94	91	88	2.00	90	93	92	2.73
Day 19	---	---	---	---	94	92	94	1.14

[1]A designates a diet containing an electrolyte balance of 177 mEq/kg; B designates a diet containing an electrolyte balance of 205 mEq/kg; C designates a diet containing an electrolyte balance of 347 mEq/kg.
[2]Four pigs per level within temperature range.

Experiment 3

With a dEB of 417 mEq/kg of feed, body weight gain of pigs fed under high temperature was depressed ($P<.05$) by an average of 54 g/d (Table 14). Even though dEB level did not significantly affect feed intake, there was a tendency for a reduced intake at the higher level (Table 15). Gain/feed was unaffected by dEB level (Table 16). In this experiment, pigs fed either $NaHCO_3$ or Na_2CO_3 tended to have a higher blood buffering capacity than those pigs fed either $KHCO_3$ or K_2CO_3 (Table 19) as illustrated by a greater HCO_3^- and TCO_2. Dietary electrolyte balance level did not have an effect on either blood gases or plasma mineral levels (Tables 17, 18, 20, 21, 22, and 23).

TABLE 14. EFFECT OF ELECTROLYTE FORM AND BALANCE ON AVERAGE DAILY GAIN OF PIGS (EXPERIMENT 3)

Diet[1]:	Na1	Na2	K1	K2	
Item		L[2]			SEM[3]
ADG, g					
Week 1	663	577	585	664	19
Week 2	660	719	603	615	18
Week 3	722	677	636	679	17
Week 4	708	775	765	759	16
Overall	688	684	643	676	9
Diet:	Na3	Na4	K3	K4	
		H[2]			
Week 1	611	636	548	629	24
Week 2	585	586	608	549	28
Week 3	544	599	539	556	26
Week 4	693	805	799	699	32
Overall	605	647	617	605	19

Mean of level across forms	Week 1		Week 2		Week 3		Week 4		Overall	
	L	H	L	H	L	H	L	H	L	H
	622	606	649^a	582^b	679^a	560^b	752	749	673^a	619^b

[1]Six pigs per form within level.
[2]L designates the average electrolyte balance of Na1, Na2, K1, and K2 which is equal to 319 mEq/kg; H designates the average electrolyte balance of Na3, Na4, K3, and K4 which is equal to 417 mEq/kg.
[3]SEM equals standard error of the mean.
[a,b]Means within week lacking a common superscript letter differ ($P<.05$).

TABLE 15. EFFECT OF ELECTROLYTE FORM AND BALANCE ON AVERAGE DAILY FEED INTAKE OF PIGS (EXPERIMENT 3)

Diet[1]: Item	Na1	Na2	K1	K2	SEM
		L[2]			
ADFI, g					
Week 1	971	907	947	982	19
Week 2	1,417	1,358	1,288	1,437	34
Week 3	1,492	1,573	1,482	1,599	36
Week 4	1,775	1,779	1,823	1,922	38
Overall	1,400	1,390	1,369	1,469	21
Diet:	Na3	Na4	K3	K4	
		H[2]			
Week 1	919	948	830	964	25
Week 2	1,376	1,357	1,278	1,330	54
Week 3	1,382	1,361	1,349	1,374	59
Week 4	1,657	1,712	1,553	1,751	74
Overall	1,321	1,332	1,241	1,340	45
Mean across	week 1	week 2	week 3	week 4	Overall
forms within L	952	1,375	1,537[a]	1,852	1,407
level H	915	1,335	1,367[b]	1,668	1,309

[1]Six pigs per form within level.
[2]L designates the average electrolyte balance of Na1, Na2, K1, and K2, which is equal to 319 mEq/kg; H designates the average electrolyte balance of Na3, Na4, K3, and K4, which is equal to 417 mEq/kg.
[a,b]Means within a column lacking a common superscript letter differ ($P<.05$).

TABLE 16. EFFECT OF ELECTROLYTE FORM AND BALANCE ON GAIN PER FEED OF PIGS (EXPERIMENT 3)

Diet[1]: Item		Na1	Na2	L[2] K1	K2	SEM
G/F						
Week 1		.69	.64	.63	.68	.02
Week 2		.47	.53	.47	.44	.01
Week 3		.48	.43	.43	.43	.01
Week 4		.40	.44	.42	.40	.01
Overall		.49	.49	.47	.46	.01
Diet:		Na3	Na4	H[2] K3	K4	
Week 1		.66	.67	.65	.65	.01
Week 2		.42	.43	.49	.42	.02
Week 3		.40	.45	.41	.41	.02
Week 4		.42	.47	.53	.41	.02
Overall		.46	.49	.50	.45	.01
Mean across forms within level		week 1	week 2	week 3	week 4	Overall
	L	.66	.48	.44	.42[a]	.48
	H	.66	.44	.42	.46[b]	.48
G/F						
Week 4[3]		.41[b]	.46[a,b]	.48[a]	.41[b]	.02

[1]Six pigs per form within level.
[2]L designates the average electrolyte balance of Na1, Na2, K1, and K2 which is equal to 319 mEq/kg; H designates the average electrolyte balance of Na3, Na4, K3, and K4 which is equal to 417 mEq/kg.
[3]Mean of 12 pigs across dietary electrolyte balance levels.
[a,b]Means within a column lacking a common superscript letter differ ($P<.05$); means within a row lacking a common superscript letter differ ($P<.05$).

TABLE 17. EFFECT OF ELECTROLYTE FORM AND BALANCE ON BLOOD GASES OF PIGS - HCO_3^-, BE (EXPERIMENT 3)

Diet: Item	Na1	Na2	K1	K2	SEM
		L[1]			
Bicarbonate concentration (HCO_3^-), mmol/L					
Day 14	29	29	28	29	.42
Day 27	31	30	29	30	.32
Base excess (BE), mmol/L[2]					
Day 14	2.5	1.8	1.7	2.9	.35
Day 27	3.3	2.1	2.5	2.2	.37
Diet:	Na3	Na4	K3	K4	
		H[1]			
Bicarbonate concentration mmol/L					
Day 14	29	31	29	30	.40
Day 27	31	32	30	29	.34
Base excess, mmol/L					
Day 14	3.2	4.2	2.9	3.2	.41
Day 27	4.1	3.4	2.1	2.0	.36
Mean across forms[3] within level			L	H	
	HCO_3^-	Day 14	29	30	
		Day 27	30	31	
	BE	Day 14	2.2^a	3.4^b	
		Day 27	2.5	2.9	

[1]L designates the average electrolyte balance of Na1, Na2, K1, and K2 which is equal to 319 mEq/kg; H designates the average electrolyte balance of Na3, Na4, K3, and K4 which is equal to 417 mEq/kg.

[2]Base excess is the quantity of extra base above normal (principally bicarbonate ions) after exclusion of the hemoglobin content.

[3]Mean of 24 animals.

a,bMeans within a row lacking a common superscript letter differ (P<.05).

TABLE 18. EFFECT OF ELECTROLYTE FORM AND BALANCE ON BLOOD GASES OF PIGS - pCO_2, TCO_2 (EXPERIMENT 3)

Diet[1]: Item	Na1	Na2	K1	K2	SEM
		L[2]			
Partial pressure of carbon dioxide (pCO_2), mm Hg					
Day 14	59	65	60	58	2.07
Day 27	67	70	62	69	2.15
Total concentration of carbon dioxide (TCO_2), mmol/L					
Day 14	31	31	30	31	.46
Day 27	33	32	31	32	.35
Diet:	Na3	Na4	K3	K4	
		H[2]			
Partial pressure of carbon dioxide (pCO_2), mm Hg					
Day 14	53	61	58	65	2.23
Day 27	63	71	68	61	1.49
Total concentration of carbon dioxide (TCO_2), mmol/L					
Day 14	30	32	31	32	.43
Day 27	33	34	32	30	.40

[1]Six pigs per form within level.
[2]L designates the average electrolyte balance of Na1, Na2, K1, and K2 which is equal to 319 mEq/kg; H designates the average electrolyte balance of Na3, Na4, K3, and K4 which is equal to 417 mEq/kg.

TABLE 19. EFFECT OF ELECTROLYTE FORM AND BALANCE ON BLOOD GASES OF PIGS - HCO_3^-, TCO_2 (EXPERIMENT 3)

Electrolyte form[1]: Item	$NaHCO_3 + Na_2CO_3$	$KHCO_3 + K_2CO_3$	SEM
Bicarbonate concentration, mmol/L			
Day 27	30.9[a]	29.5[b]	.33
Total concentration of carbon dioxide, mmol/L			
Day 27	33.0[a]	31.3[b]	.35

[1]Twenty-four animals per mean.
[a,b]Means within a row lacking a common superscript letter differ ($P<.05$).

TABLE 20. EFFECT OF ELECTROLYTE FORM AND BALANCE ON BLOOD GASES OF PIGS - pH, pO_2 (EXPERIMENT 3)

Diet[1]: Item	Na1	Na2	K1	K2	SEM
		L[2]			
pH					
Day 14	7.31	7.28	7.29	7.32	.01
Day 27	7.28	7.25	7.29	7.26	.01
Partial pressure of oxygen (pO_2), mmHg					
Day 14	53	50	51	56	3.81
Day 27	52	47	51	50	3.57
Diet:	Na3	Na4	K3	K4	
		H[2]			
pH					
Day 14	7.35	7.32	7.31	7.29	.01
Day 27	7.30	7.26	7.26	7.29	.01
Partial pressure of oxygen (pO_2), mmHg					
Day 14	60	59	55	41	4.03
Day 27	42	41	46	51	1.99

[1]Six pigs per form within level.
[2]L designates the average electrolyte balance of Na1, Na2, K1, and K2 which is equal to 319 mEq/kg; H designates the average electrolyte balance of Na3, Na4, K3, and K4 which is equal to 417 mEq/kg.

TABLE 21. EFFECT OF ELECTROLYTE FORM AND BALANCE ON PLASMA SODIUM OF PIGS (EXPERIMENT 3)

Diet[1]: Item		Na1	Na2		K1	K2	SEM
				L[2]			
Sodium (Na), mEq/L							
Day 7		157	155		151	155	2.63
Day 14		157	159		159	157	.87
Day 21		155	154		159	155	.70
Day 27		158	154		154	156	.74
Diet:		Na3	Na4		K3	K4	
				H[2]			
Day 7		155	156		163	155	2.25
Day 14		158	156		157	158	.71
Day 21		158	155		156	157	.43
Day 27		156	154		156	161	1.67
		$NaHCO_3$	Na_2CO_3		$KHCO_3$	K_2CO_3	
Mean across levels within form	Day 21	157[ab]	155[a]		158[b]	156[ab]	

[1]Six pigs per form within level.
[2]L designates the average electrolyte balance of Na1, Na2, K1, and K2 which is equal to 319 mEq/kg; H designates the average electrolyte balance of Na3, Na4, K3, and K4 which is equal to 417 mEq/kg.
[a,b]Means within a row lacking a common superscript letter differ (P<.05).

TABLE 22. EFFECT OF ELECTROLYTE FORM AND BALANCE ON PLASMA POTASSIUM OF PIGS (EXPERIMENT 3)

Diet[1]: Item	Na1	Na2	K1	K2	SEM
		L[2]			
Potassium (K), mEq/L					
Day 7	7.0	6.7	6.7	6.5	.19
Day 14	5.5	5.2	5.7	5.7	.12
Day 21	7.8	8.0	8.3	8.1	.14
Day 27	6.0	5.7	6.2	6.2	.13
Diet:	Na3	Na4	K3	K4	
		H[2]			
Day 7	6.7	6.5	7.1	7.3	.16
Day 14	4.9	5.6	5.7	5.4	.11
Day 21	7.9	8.3	8.5	8.6	.13
Day 27	5.7	5.5	5.9	5.3	.17

[1]Six pigs per form within level.
[2]L designates the average electrolyte balance of Na1, Na2, K1, and K2 which is equal to 319 mEq/kg; H designates the average electrolyte balance of Na3, Na4, K3, and K4 which is equal to 417 mEq/kg.

TABLE 23. EFFECT OF ELECTROLYTE FORM AND BALANCE ON PLASMA CHLORIDE OF PIGS (EXPERIMENT 3)

Diet[1]: Item	Na1	Na2	K1	K2	SEM
		L^2			
Chloride (Cl), mEq/L					
Day 7	89	97	92	87	2.33
Day 14	90	89	89	88	.60
Day 21	88	89	90	88	.49
Day 27	92	90	91	92	.78
Diet:	Na3	Na4	K3	K4	
		H^2			
Day 7	88	92	94	90	1.52
Day 14	90	86	89	90	.78
Day 21	89	90	92	90	.50
Day 27	91	89	91	92	.80

[1]Six pigs per form within level.
[2]L designates the average electrolyte balance of Na1, Na2, K1, and K2 which is equal to 319 mEq/kg; H designates the average electrolyte balance of Na3, Na4, K3, and K4 which is equal to 417 mEq/kg.

CHAPTER 6

DISCUSSION

The thermoneutral comfort zone, or zone of thermoneutrality (Pond and Maner, 1974) is a range of environmental temperatures in which no extra heat production by the body is required for maintenance of body temperature. In this zone the metabolic rate of the animal is at a minimum. Regulation of body temperature in this range is maintained constant by peripheral vasoconstriction or vasodilation, hair erection and postural changes, and by sweating (physical control of heat balance). The point where the environmental temperature falls below the zone of thermoneutrality is referred to as the critical temperature. An increase in metabolic rate at this point is necessary to maintain body temperature. The point above the zone of thermoneutrality, known as the point of hyperthermal rise, also requires an increase in the metabolic rate of the animal to maintain body temperature, by expelling excess heat production (Pond and Maner, 1974).

In experiment 1 of this study, pigs were housed under temperatures within their zone of thermoneutrality (26 to 33°C) (Holmes and Close, 1977) and fed diets with different electrolyte balance levels. There was no significant effect of increasing dEB on either gain, feed intake, or gain/feed. Results from this experiment are similar to those of Haydon *et al*. (1990) who reported that daily gain tended to increase with an increase in dEB from 25 to 250 mEq/kg; however, as dEB increased from 250 to 400 mEq/kg, gains tended to decline. Patience *et al.* (1987a) reported no differences in feed intake or average daily gains when pigs were fed a dEB varying from 0 to 341 mEq/kg. Honeyfield *et al.* (1985) demonstrated that as dietary Na increased from .03 to .18%, there was a quadratic improvement in growing pig performance. Including initial weight and electrolyte source in the analysis of this experiment indicated that pigs fed diets containing $NaHCO_3$ consumed more feed, gained more body weight, and were more feed efficient than pigs fed diets containing $KHCO_3$. Subsequent experiments were conducted with a block on initial weight to account for variation attributed to initial body weight.

The second experiment of this study looked at the effect of increasing dEB on the performance of weanling pigs. In addition, the pigs were subjected to two temperature ranges, 19.3 to 21.9°C and 27.7 to 32.3°C. Pigs housed under high temperatures lose weight and consume less feed as a result of their inefficiency of body heat dissipation (Pond and Maner, 1974). When pigs are subjected to high temperatures, their respiration rate increases resulting in the exhalation of CO_2. This causes the pH in the blood to increase producing a respiratory alkalosis. Once the pH in the blood becomes elevated by increased exhalation of CO_2, it can be reduced by the excretion of HCO_3^- by the kidney. The acidity of the blood is also regulated by Cl^- shift. When the pH of the blood is too high (too basic) there is an influx of Cl^- into the cell and an efflux of HCO_3^- out of the cell, thus reducing the pH. An efflux of hydrogen ions (H^+) from the cell can cause an influx of Na^+ into the cell. The sodium influx helps to increase the intracellular pH. Both of these processes help to maintain intracellular pH. Coupled with the Cl^- shift is an efflux of CO_2 from the cell when HCO_3^- is brought into the cell. Within the cell HCO_3^- combines with H^+ forming CO_2 and H_2O as illustrated by the following reaction: $CO_2 + H_2O \leftrightharpoons H_2CO_3 \leftrightharpoons H^+ + HCO_3^-$. This process is regulated by the enzyme carbonic anhydrase. Since $NaHCO_3$ or $KHCO_3$ supply HCO_3^- as a metabolizable anion, the level of HCO_3^- could be increased. If this were to occur as it appeared to in experiment 2, the above reaction could go from right to left increasing levels of CO_2 and thus decreasing intracellular pH. This in turn could have decreased the respiratory alkalosis caused by the higher temperature in this experiment.

Pigs housed under the lower temperature gained an average of 77 g more per day and consumed an average of 320 g more feed per day than pigs housed under the higher temperature. This is similar to those results of Lopez *et al*. (1991a) who reported that pigs housed in a hot, diurnal temperature (H; 22.5 to 35°C) gained 16.3% more slowly ($P<.001$; .77 vs .92 kg/d) than pigs housed in a constant, thermoneutral environment. Bottje and Harrison (1985b) reported decreased gains, feed intake, and feed efficiency in heat stressed cockerels compared to cockerels subjected to moderate (25 to 29°C) cyclic (day-night) temperatures. In addition, Lopez *et al.* (1991b) reported that pigs housed in a hot environment consume less feed than those housed in a thermoneutral environment. The pigs in experiment 2 housed under the higher temperature exhibited a respiratory alkalosis as demonstrated by a higher pH and a lower partial pressure of CO_2. As subjectively evaluated their respiration rate appeared to increase.

One way that an animal such as the pig attempts to compensate for respiratory alkalosis, as exhibited in experiment 2, is by increasing the excretion of fixed bases such as Na, K, magnesium, and calcium ions and HCO_3^- into the urine, causing an increase in the urine pH (Curtis, 1983). If this excretion continues to occur at a high level, the pig can become deficient in these electrolytes. Even though the dEB level in the diet did not significantly affect performance of pigs fed under the high temperature in experiment 2, a diet with supplemental $NaHCO_3$ or $KHCO_3$ could help the pig by providing needed Na, K, or HCO_3^- which may have been excreted by the kidney in the urine in this experiment.

From experiment 1, it was demonstrated that with the influence of initial body weight, pigs fed diets supplemented with $NaHCO_3$ gained more weight, consumed more feed and were more feed efficient than those pigs fed diets supplemented with $KHCO_3$. In the third experiment in this study, diets containing different electrolyte sources and different electrolyte balance levels were fed to pigs housed in a hot environment to see what effect there would be on weanling pig performance and blood parameters. Pigs consuming diets with a dEB of 319 mEq/kg of feed gained an average of 54 g/d more than pigs consuming diets with a dEB of 417 mEq/kg of feed. This result is supported by the findings of Haydon *et al.* (1990) who reported that daily gain tended to decrease at dEB levels above 250 mEq/kg of feed. In experiment 3, pigs fed diets supplemented with either $NaHCO_3$ or Na_2CO_3 tended to have a higher blood buffering capacity than those fed diets with supplemental $KHCO_3$ or K_2CO_3 as demonstrated by a greater TCO_2 and HCO_3^-. This is in agreement with Utley *et al.* (1987). The bicarbonate ion is one of the buffers that helps to regulate and maintain intracellular pH by its involvement in the Cl^- shift.

The buffering capacity of the pig's blood in experiment 3 may have been improved more with sodium salts than potassium salts due possibly to a greater physiological need for Na versus K.

From this study it can be concluded that, when housed under high temperatures (27.7 to 32.3°C), pigs gain less weight and consume less feed resulting in a lowered performance. Feeding these pigs a dEB of 319 mEq/kg or less helped to restore pig performance. In addition, the buffering capacity of the pig's blood was increased by supplementing their diets with sodium salts such as $NaHCO_3$ and Na_2CO_3 compared to potassium salts such as $KHCO_3$ and K_2CO_3.

CHAPTER 7

SUMMARY

Three experiments were conducted utilizing weanling pigs to evaluate: 1) the effect of different dietary electrolyte balance (dEB) levels; 2) different dEB levels and high environmental temperature; and 3) different electrolyte sources and dEB levels on performance and blood parameters.

Experiment 1. Forty-nine crossbred weanling pigs averaging 11.8 kg were randomly assigned seven experimental diets for 21 d to determine the effect of different dEB levels on performance and blood parameters. Average daily gain, feed intake and gain/feed were not significantly affected by an increase in dEB above 224 mEq/kg of feed with the addition of either $NaHCO_3$ or $KHCO_3$. Inspection of the data indicated that initial pig weight affected response to dEB ($P<.05$) as illustrated by a greater feed intake and body weight gain of pigs fed $NaHCO_3$ versus $KHCO_3$. Blood gases were not significantly affected by treatment. Subsequent statistical analysis with electrolyte source using initial weight as a covariate, indicated that supplementation of $NaHCO_3$ resulted in increased body weight gain, feed consumption, and gain/feed.

Experiment 2. Twenty-four crossbred weanling pigs averaging 17.3 kg were allotted to six dietary treatments

which were blocked by initial weight. The treatments were fed for 19 d to evaluate the effect of different dEB levels (177, 205 and 347 mEq/kg of feed) and low (19.3 to 21.9°C) and high (27.7 to 32.3°C) environmental temperatures. Pigs housed under the low temperature gained an average of 77 g more per day and consumed an average of 320 g more feed per day than pigs housed under the high temperature (P<.05); however, the high temperature treated pigs had improved (P<.05) gain/feed. Increasing the dEB level did not significantly affect performance or blood parameters. High temperature lowered performance of pigs in this experiment.

Experiment 3. Fifty-four crossbred weanling pigs averaging 12.4 kg were allotted to nine treatments for 27 d to determine the effect of electrolyte source and dEB level on performance and blood parameters. Pigs were blocked by initial weight. Average daily gain of pigs fed the higher level (417 mEq/kg) was depressed by an average of 54 g (P<.05). Pigs fed 417 mEq/kg tended to have a reduced intake of feed. Blood gases and plasma mineral levels were not significantly affected by electrolyte balance in this experiment. Sodium sources improved blood buffering capacity of pigs when compared to potassium sources.

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APPENDICES

APPENDIX A

Sodium and potassium analyses of diets were performed using the procedure below:

1) Weigh out a .50 g representative subsample of feed into a preweighed 250 mL Erlenmyer flask.
2) Add 30 mL of reagent grade nitric acid (15.7N) plus 1 mL (mL) of reagent grade sulfuric acid (36N).
3) Let the mixture boil until 1 or 2 mL of solution is left in the beaker.
4) Allow the samples to cool and then add 12 mL of 30% H_2O_2 (hydrogen peroxide).
5) Let this mixture boil until 1 or 2 mL of solution is left. Add 25 mL of Millipore water (14-18 mega ohms [Mohm] resistivity) to the initial weight of the flask for the initial dilution.
6) Further dilute the samples, if necessary, so that they can be analyzed with the use of a Model IL 551 atomic absorption spectrophotometer (Instrumentation Laboratory, Inc., 1978). Standards were obtained from appropriate dilutions of 1,000 ppm Fisher sodium and potassium standards.

APPENDIX B

Chloride analysis of diets and plasma samples was performed using the following procedure:

1) Weigh out a 1.00 g representative subsample of feed into a preweighed 250 mL Erlenmyer flask. To this add 9.00 g of 1N HNO_3 (nitric acid), made from 64 mL of reagent grade HNO_3 added to a 1 L flask and filled to volume with Millipore H_2O (14-18 Mohm resistivity), to extract the chloride from the feed.

2) The 10 g mix of feed and nitric acid is then shaken vigorously with a mechanical wrist action shaker for 1 h.

3) After the mixture is shaken for 1 h, it is transferred to a 15 mL centrifuge tube. The remaining contents of the 250 mL flask are then washed into the centrifuge tube with 3 mL of 1N HNO_3.

4) The centrifuge tube with the feed-acid mix is then placed into a tabletop centrifuge (IEC Clinical Centrifuge) and spun at 4200 g for 20 min.

5) After the 20 min spin, the samples are removed from the centrifuge and the supernatant is transferred to a 100 mL beaker, one beaker per sample.

6) Once the samples were in the beakers, an Orion chloride specific ion combination electrode, model 96-17B, connected to an Orion pH ion analyzer (EA920) was used to measure change in millivolts (mV) from the start of titration to the titration endpoint. The samples are titrated with 0.0282 N $AgNO_3$(silver nitrate) made from 4.7903 g of reagent grade $AgNO_3$ dissolved in 1 L of Millipore H_2O (14-18 Mohm resistivity).

7) Once a rapid increase in mV reading (60-80 mV vs 5-10 mV) occurs, addition of $AgNO_3$ is stopped and the mL of $AgNO_3$ added to reach titration endpoint is recorded. NOTE: During the titration the solution in the beaker is stirred with a magnetic stirring bar with the beaker sitting on a Corning PC-351 hot plate-stirrer.

8) The concentration of Cl^- in the feed sample was then calculated using the equation obtained from a standard curve. A blank was subtracted from the mL of titrant used. The standards for the standard curve were 100, 200, 300, 400, and 500 ppm obtained from appropriate dilutions of a 1,000 ppm Fisher Cl^- standard.

VITA

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70 LH