Evaluation of Sodium Bicarbonate, Chloride, or Sulfate with a Coccidiostat in Corn-Soy or Corn-Soy-Meat Diets for Broiler Chickens

D. M. HOOGE,*[,1] K. R. CUMMINGS,† and J. L. McNAUGHTON‡

*Hooge Consulting Service, Inc., 8775 North Cedar Pass Road, Eagle Mountain, Utah 84043-3186; †Church and Dwight Co., Inc., 469 North Harrison Street, Princeton, New Jersey 08543-5297; and ‡PARC Institute, Inc., P.O. Box 1161, Easton, Maryland 21601

ABSTRACT During the period from January to June, combined-sex broiler chickens were inoculated with coccidia via drinking water at 14 d of age. In a completely randomized design (eight replicate pens; 88 chicks per pen) using built-up litter, experimental diets contained monensin plus 0.20% dietary sodium bicarbonate (SBC), which provided 0.054% sodium and 0.144% bicarbonate. Treatment with SBC significantly improved coccidial lesion score, 45-d body weight, and feed efficiency compared with monensin alone. In a 2 × 5 factorial trial using built-up litter pens (eight replicate pens; 88 chicks per pen) *vs* each ionophore alone, 0.20% dietary SBC with monensin significantly improved body weight, uniformity, and feed efficiency; 0.20% SBC with halifuginone, lasalocid, monensin, or salinomycin significantly reduced mortality; and 0.20% SBC with lasalocid, monensin, or salinomycin significantly increased breast meat yield.

In a 2 × 4 factorial trial (12 replicate pens; 88 chicks per pen) on built-up litter, corn-soy and corn-soy-meat diets (higher potassium, lower chloride) with monensin were evaluated using 0.054% sodium from SBC, NaCl, or sodium sulfate decahydrate (SSD). With both diet types, SBC (0.20%) or NaCl (0.139% extra) significantly improved weight uniformity, feed efficiency, mortality, and breast meat yield; however, the SSD results were closer to controls. In a 21-d battery brooder test using similar diets and design (2 × 4 factorial; 4 replicate pens; 10 chicks per pen), SBC and NaCl significantly reduced coccidial lesion scores; SSD produced a significant, but weaker effect. Extra NaCl significantly increased water intake (~37%), water excretion (~27%), and litter moisture (~22%) with both diet types. The SSD did not affect water intake.

(*Key words*: animal byproducts, ionophore coccidiostats, sodium bicarbonate, sodium chloride, sodium sulfate)

1999 Poultry Science 78:1300–1306

INTRODUCTION

Use of coccidiostats, especially ionophores, in broiler feeds is the primary method for prevention and control of the economically important disease, coccidiosis. Sodium sources such as NaCl (W. W. Saylor and J. C. Fleet, circa 1984, unpublished data, personal communication) and sodium bicarbonate (SBC; Hooge *et al*., 1999) appear to complement ionophores; however their relative efficacies have not been established. Sodium sulfate decahydrate (SSD), primarily studied for its methionine-sparing ability at marginal or deficient levels of dietary methionine (Soares, 1974), has soluble sodium that can potentially interact with ionophores. Sulfate *per se* acidifies body fluids, as shown, for example, by Saroka and Combs (1986) who used each of two sources of dietary methionine, a sulfur-containing amino acid, to lower urinary pH in broiler chickens.

The influence of sodium sources when using various coccidiostats needs to be compared in corn-soy-meat vs corn-soy diets because the latter have lower potassium, another monovalent cation, as some of the soybean meal is replaced by animal byproducts. Pesti (1998) observed no significant differences in male broiler performance on litter with semduramicin (Aviax®)[2] at 25 mg/kg in corn-soy or corn-soy-meat (12% animal byproduct) diets, and combined-sex broilers fed semduramycin in battery brooders showed no significant performance differences among three electrolyte balances (Na+K–Cl = 231, 275, or 362 mEq/kg), adjusted with a variety of electrolyte salts, including SBC plus potassium carbonate.

Hurst *et al*. (1974) found that broiler chicks in battery brooders performed better with 0.30% dietary NaCl than with 0.075 to 0.225% NaCl, and performed equally well with 0.30% as with 0.375% NaCl, when monensin was included at 121.3 mg/kg in the feed to 4 wk of age. Nam *et al*. (1979) conducted litter and battery brooder trials

Received for publication December 14, 1998.
Accepted for publication May 2, 1999.
[1]To whom correspondence should be addressed: danhooge@fiber.net
[2]Registered trademark of Pfizer Animal Health, Exton, PA 19341.

Abbreviation Key: BMD® = bacitracin methylene disalicylate; SBC = sodium bicarbonate; SSD = sodium sulfate (decahydrate).

with broiler chicks fed corn-soy diets and found 0.15% sodium (source not mentioned) to be adequate with either monensin or lasalocid compared to 0.10, 0.20, or 0.35% sodium. Higher sodium levels did not provide additional benefit. Gard *et al*. (1980) conducted a series of seven litter pen trials involving 218,200 birds (210 pens) with monensin at 100 or 121 ppm and sodium at 0.11, 0.17 to 0.19, and 0.24 to 0.27% using NaCl as the supplement. Broilers receiving 0.17 to 0.19% sodium had heavier ($P <$ 0.10) weights than those fed 0.11% or 0.24 to 0.27% sodium. Increasing monensin from 100 to 121 mg/kg did not appear to increase the requirement for sodium from NaCl. Edwards (1985) found significant improvements in 3-wk body weights and feed efficiencies of broiler chicks with or without monensin with increasing dietary NaCl levels from 0.1125 to 0.225, 0.3375, and 0.45%.

Mongin (1968: 214) stated that "sodium bicarbonate seems to be a privileged element" because it provides sodium, favorably affects blood pH ("can influence the balance of H^+ ions"), and supplies beneficial bicarbonate. Damron *et al*. (1986) concluded that the sodium in SBC was equally bioavailable to that in NaCl for broiler chicks. Jensen (1982) reported that 4-wk broiler chick weights were significantly improved by 0.65% dietary SBC, compared to results of the control or 0.45% extra NaCl treatment, when a high level of monensin (160 mg/kg) was fed. With monensin at an approved level of 120 or 0 mg/kg, no significant sodium source effects were found.

Coccidia-infected chicks were found by Stephens *et al*. (1974) to have decreased pH of intestinal contents near the invasion sites (infected vs control intestinal pH): *Eimeria acervulina*, 4.96 vs 6.02; *Eimeria brunetti*, 5.84 vs 7.02; and *Eimeria mivati*, 5.58 vs 6.40. This result was presumed to be due to loss of cellular contents, which are acidic, into the lumen of the intestine or to destruction of cells that produce the hormone secretin, which regulates bicarbonate output from the pancreas. With *Eimeria necatrix*, significant reductions in the pH of intestinal contents have been observed on the 6th and 9th d postinoculation of a severe infection (Stephens, 1965). Fox *et al*. (1987) reported that feeding broiler chicks 1% dietary SBC numerically improved gains and feed efficiencies when birds were uninfected or inoculated with *E. acervulina* compared to results of unsupplemented chicks. However, 1% dietary SBC failed to alleviate the duodenal pH decrease (pH 4.35 vs 6.51 in control duodenal contents) in infected chicks.

Merrill (1993) reported, based on a survey of SBC use in broiler feeds in western Europe, that 0.2% was the most common level used, in conjunction with 0.1% added NaCl; and the main purpose was to lower dietary chloride and reduce wet litter problems. Diets typically contained not more than 25% soybean meal and included fish meals, the latter having about 0.60% each of sodium and chloride. In diets without fish meal, it was typical to add up to 0.4% SBC.

In the absence of a coccidiostat, SBC substantially increased the number of sporozoites in cross-sectional intestine (*E. acervulina*, 48% increase; *E. maxima*, 68% increase) following inoculation compared to inoculated control birds (P. C. Augustine, 1997. USDA-ARS-LPSI, Bldg 1100 BARC-East, Beltsville, MD 20705; personal communication). With SBC plus 121 mg/kg monensin, intestinal *E. acervulina* sporozoite counts were increased by 6.4% and *E. maxima* developmental stage counts were increased by 104%, compared to results for monensin alone. Enhancement of coccidial invasion by SBC was associated with reduced coccidial lesions and improved performance of chicks, suggesting a possible stimulation or acceleration of immunity, appearing to improve the efficacy of the ionophore coccidiostat. This effect was opposite that of betaine, also studied by Augustine (1997), which helps cells to resist the invasion of coccidia into intestinal epithelium and enhance ionophore effectiveness.

Hooge *et al*. (1999) reported optimal levels of dietary SBC to be 0.20 to 0.30% for broilers fed ionophores, grown on built-up litter, and given a coccidial inoculation, based on significant improvements in weights, feed efficiencies, coccidial lesion scores, mortalities, and carcass yields, compared to control results in several dose-response studies. All parameters were not significantly different in every test, but each parameter was significantly improved in one or more trials.

The objectives of the experiments herein were to evaluate dietary SBC (0 or 0.20%) with each of three ionophore coccidiostats or a chemical coccidiostat and to compare corn-soy vs corn-soy-meat diets supplemented with NaCl, SBC, or sodium sulfate decahydrate[3] (SSD; Na_2SO_4-$10H_2O$) for broiler chickens grown on built-up litter or in battery brooders. A coccidial inoculation with three *Eimeria* species was used as the stressor model in each trial. The influence of SBC on diet type was evaluated because corn-soy-meat diets contain lower potassium and higher chloride than corn-soy diets.

MATERIALS AND METHODS

Experimental Design and Statistical Analysis

A completely randomized design with two treatments was used in Experiment 1. Dietary treatments were control diets vs diets containing a 0.20% level of SBC[4] (Table 1). There were eight replicate pens, each containing 88 combined sex birds (44 males and 44 females) per treatment. Birds were grown to 45 d of age on litter, and coccidial lesions were scored at 23 d.

Experiment 2 used a 2 × 5 factorial arrangement with two levels of dietary SBC (0, 0.20%) and five coccidiostats

[3]Southeastern Minerals, Inc., Bainbridge, GA 31718.
[4]Sodium bicarbonate supplied by Church and Dwight Co., Inc., Princeton, NJ 08543-5297.

TABLE 1. Experimental corn-soy and corn-soy-meat unmedicated basal diets for broiler chickens

Ingredient	Corn-soy diets			Corn-soy-meat diets		
	Starter	Grower	Finisher	Starter	Grower	Finisher
	(%)					
Corn, yellow	55.61	62.78	66.36	55.87	64.10	70.57
Soybean meal 48% CP	36.32	29.96	27.27	25.05	17.81	12.36
Meat & bone 50% CP	. . .	. . .	. . .	7.00	7.00	7.00
Meat blend 58% CP	. . .	. . .	. . .	7.00	7.00	7.00
Fat blend, 8,157 kcal ME/kg	4.90	4.26	3.85	4.38	3.53	2.72
Limestone	0.73	0.95	0.92	. . .	. . .	. . .
Defluorinated phosphate	1.68	1.45	1.19	. . .	. . .	. . .
Salt (sodium chloride)	0.29	0.27	0.25	0.28	0.23	0.18
Trace mineral premix[1]	0.05	0.05	0.05	0.05	0.05	0.05
Vitamin premix[2]	0.05	0.05	0.05	0.05	0.05	0.05
DL-methionine	0.198	0.058	0.01	0.148	0.058	0.02
Calculated analysis[3]						
CP	22.50	20.00	19.00	24.57	21.78	19.71
Crude fat	7.23	6.79	6.48	7.69	7.08	6.45
ME, kcal/kg	3,200	3,230	3,252	3,200	3,230	3,252
Calcium	0.90	0.90	0.80	1.20	1.18	1.17
Total P	0.69	0.63	0.57	0.90	0.88	0.86
Available P	0.45	0.40	0.35	0.71	0.70	0.69
Lysine	1.21	1.03	0.96	1.20	1.00	0.85
Methionine	0.55	0.38	0.32	0.51	0.38	0.32
Met + Cys	0.93	0.73	0.66	0.93	0.77	0.68
Sodium	0.22	0.20	0.18	0.22	0.20	0.18
Potassium	0.90	0.80	0.76	0.76	0.65	0.56
Chloride	0.21	0.20	0.19	0.29	0.27	0.24

[1]PARC Institute, Inc. trace mineral premix contributed per kilogram of diet: iron, 13.2 mg from ferrous sulfate monohydrate; manganese, 66.9 mg from manganese sulfate; zinc, 53.4 mg from zinc sulfate; copper, 2 mg from copper sulfate; iodine, 0.5 mg from calcium iodate; and selenium, 0.2 mg from sodium selenite.

[2]PARC Institute, Inc. vitamin premix contributed per kilogram of diet: vitamin A, 14,330 IU from retinyl acetate; cholecalciferol, 6,173 IU from cholecalciferol; vitamin E, 33.1 IU (mg) from dl-alpha-tocopherol acetate; menadione, 2.91 mg from MSBC, vitamin B_{12}, 26.5 mcg; biotin, 0.132 mg from d-biotin; folic acid, 1.65 mg; niacin, 88.3 mg; pantothenic acid, 24.2 mg; pyridoxine, 4.4 mg from pyridoxine HCl; riboflavin, 14.3 mg; and thiamine, 4.4 mg from thiamine mononitrate.

[3]See Materials and Methods, Feeds and Feeding section for information on nutrient and coccidiostat assays and compliance.

(none, halifuginone, lasalocid, monensin, salinomycin).[5] There were eight replicate pens of 88 chicks each (44 males and 44 females) per treatment. The broilers were grown to 45 d of age on litter.

In Experiments 3 and 4, identical 2 × 4 factorial arrangements with two diet types (corn-soy or corn-soy-meat) and four sources of sodium were utilized. Sodium sources were: SBC, NaCl, or SSD. Experiment 3 was conducted for 45 d on litter, and Experiment 4 was carried out on raised wire floors for 21 d. In Experiment 3, there were 12 replicate pens of 88 chicks (44 males and 44 females) per treatment. In Experiment 4, there were four replicate battery brooder pens of 10 chicks each (5 males, 5 females) per treatment.

Data were subjected to ANOVA procedures according to experimental design to detect any significant effects. When effects were found to be significant for a parameter, means were separated by the Least Significant Difference (LSD; $P < 0.05$) procedure (Steel and Torrie, 1960).

[5]Coccidiostat tradenames and manufacturers were: halifuginone, Stenorol®, Hoechst-Roussel AgriVet Co., Somerville, NJ 08876-1258; lasalocid, Avatec®, Roche Vitamins, Inc., Paramus, NJ 07652; monensin, Coban®, Elanco Animal Health, Eli Lilly Corporate Center, Indianapolis, IN 46285; and salinomycin, Bio-Cox®, formerly supplied by Agri-Bio Corp., Gainesville, GA 30503; presently supplied by Roche Vitamins, Inc.

Animals and Facilities

The three broiler chicken floor pen trials and a battery brooder trial were conducted over the period of January 7 to July 10, 1992, during winter, spring, and summer. Chicks were grown on built-up litter, with a covering of new litter, exposing them to a "natural" coccidial challenge. Birds were kept in facilities that were well insulated, power ventilated with wall fans, and electrically lighted (continuous). Warm-room brooding was used during the 21-d starting periods.

Peterson × Arbor Acres male and female chicks were utilized in all studies. All chicks were vaccinated for Mareks, Newcastle, and Infectious Bronchitis diseases at the hatchery. Each litter floor pen contained 88 chicks at placement (0.069 m^2 per bird) in Experiments 1, 2, and 3. Each battery brooder pen held 10 chicks (four pens and 40 birds total per treatment). Each chick that died during the first 7 d of a trial was replaced with a bird of the same sex from the same shipment. On the day of placement, chicks were considered to be 1 d old. No chicks were replaced after noon on Day 7. Mortality was recorded daily.

Feeds and Feeding

Practical corn, soy, and blended fat formulas were used in Experiments 1 and 2 as basal diets and in Experiments

3 and 4 as diets without animal by-products to compare with corn-soy-meat diets. Experiments 3 and 4 evaluated diets with SBC, SSD, or extra NaCl, in addition to that already in the basal diets. All feeds were formulated to meet or exceed 1984 National Research Council (1984) nutrient requirements, not 1994 specifications, because these experiments were performed before their release. The SBC was added "on top" of basal formulas, adding to the total batch weight, rather than being "formulated in". In Experiments 3 and 4, other sodium sources were added "on top" of the basal control diets to provide 0.054% additional sodium, as contained in 0.20% SBC. All feeds in all experiments contained bacitracin methylene disalicylate (BMD®)[6] at 55 mg/kg.

A sample of each experimental feed in each test was analyzed for crude protein, calcium, phosphorus, sodium, and coccidiostat prior to use. For each sample and procedure, these nutrients were found to be in compliance within acceptable ranges around the target levels according to standards in the *AOAC Official Methods of Analysis*, 15th ed. (see Association of American Feed Control Officials, 1993), developed using t values with 90% confidence intervals for infinity. Using approved lab techniques, the acceptable analytical variation ranges were: crude protein (AOAC 954.01), ± (20/target + 2)%; calcium (AOAC 968.08), ± 10%; phosphorus (AOAC 965.17), ± (3/target + 8)%; and sodium by atomic absorption, ± 20%, or by the ICP method, ± 15%. Coccidiostat assays were also performed prior to use of experimental diets, and coccidiostats were found to be within the assigned tolerance limits for compliance for each product (for example, monensin or salinomycin, ± 25%).

Starter feeds were crumbled and fed from 0 to 21 d of age. Grower feeds were pelleted and fed from 21 to 41 d of age. Finisher feeds were pelleted and fed from 41 d to 45 d of age. Feed consumption was determined by pen, and feed conversions were calculated. Adjusted feed conversions were reported in Experiments 1 and 3, and these were determined by adding the weight of removed and dead birds to total live weight and dividing this into the total feed consumed. Body weight variability (CV percentage), a measure of uniformity, was calculated as (sample standard deviation/mean) × 100.

Coccidial Inoculation and Lesion Scoring

Coccidiosis lesions were scored in Experiments 1 and 3. Lesions were visually scored in the upper small intestine, middle small intestine, lower small intestine, and ceca. Scores for these locations were totalled for a composite score per bird. The five-point system (0 to 4) was used for scoring, with categories as follows: 0 = normal, 1 = slight lesions, 2 = moderate lesions, 3 = severe lesions, and 4 = extremely severe lesions (Johnson and Reid, 1970).

[6]Alpharma Animal Health Division, Fort Lee, NJ 07024.

Breast Yields, Litter Moisture, Water Intake, and Excretion

Breast meat yields were boneless, skinless muscle weight as a percentage of live weight in Experiment 3. Litter moisture contents were determined at 45 d of age in Experiment 3. Water intakes in Experiment 4 were determined from 14- to 21-d of age. Moisture excretion as a percentage of water consumed was reported in Experiment 4 and was calculated as [(Fecal + Urinary Moisture)/Water Intake] × 100 = percentage.

RESULTS

Experiment 1

A level of 0.20% SBC in broiler chicken diets containing monensin at 110 g/ton significantly ($P < 0.05$) reduced coccidial lesion scores by 79.7%, increased body weights by 0.98%, and improved mortality adjusted feed efficiency by 1.22% compared to control results (Table 2). This test was on built-up litter, and chickens were given a coccidial inoculation through the drinking water at 14 d of age. Mortality was low during the 45-d trial.

Experiment 2

When broilers were grown on built-up litter and given a coccidial challenge without a coccidiostat, addition of 0.20% dietary SBC had essentially no effect on body weight, uniformity, feed efficiency, mortality, or breast meat yield compared to control results (Table 3). Monensin plus 0.20% SBC significantly ($P < 0.05$) improved body weight, CV, and feed efficiency compared to results for the respective control diet without SBC. Mortality was significantly ($P < 0.05$) reduced by each of the coccidiostats in combination with 0.20% SBC compared to respective 0% SBC control results. Breast meat yield as a percentage of live weight was significantly ($P < 0.05$) increased by 0.20% SBC and either lasalocid, monensin, or salinomycin, compared to control diets without SBC.

Experiment 3

Table 4 contains results from birds inoculated with three species of coccidia at 14 d of age, grown on built-up litter, and fed corn-soy vs corn-soy-meat diets with various sodium sources. Using corn-soy diets with monensin at 121 mg/kg, none of the sodium sources significantly ($P < 0.05$) increased body weight, but 0.20% SBC or 0.139% NaCl significantly ($P < 0.05$) improved weight uniformity compared to controls, SSD producing an intermediate and significant ($P < 0.05$) result. Adding either 0.20% SBC or 0.139% NaCl significantly ($P < 0.05$) improved mortality-adjusted feed efficiency and mortality compared to the control or 0.397% SSD diets.

Using corn-soy-meat diets, body weights were not significantly affected by sodium sources, but SBC or NaCl significantly ($P < 0.05$) reduced body weight CV percent-

TABLE 2. Effects of dietary sodium bicarbonate, 0 or 0.20%, with monensin at 121 mg/kg on 23-d coccidial lesion score and 45-d performance of broiler chickens on built-up litter and given a coccidial challenge via drinking water at 14 d of age, Experiment 1

Dietary treatments[1]	Composite coccidial lesion score	Body weight	Mortality-adjusted feed/body weight	Mortality
		(kg)	(kg:kg)	(%)
Control	3.688[a]	2.172[b]	1.889[a]	1.525[a]
0.20% Sodium bicarbonate	0.750[b]	2.198[a]	1.866[b]	3.177[a]
SEM	0.37	0.001	0.001	1.79

[a,b]Means within a column and with no common superscript differ significantly by the Least Significant Difference procedure ($P < 0.05$).

age compared to the control, with SSD treatment CV percentage being intermediate and significantly ($P < 0.05$) different from control (see Table 4). Mortality adjusted feed efficiency and mortality were significantly better with either 0.20% SBC or 0.139% NaCl than with control or SSD treatments.

In Table 4, for corn-soy diets, litter moisture was significantly ($P < 0.05$) increased with 0.20% SBC, but to a lesser extent than with 0.139% NaCl, compared to control or SSD results. The SSD was added "on top" of the formula, as were the other sodium sources, contributing extra sodium, but did not stimulate water intake to the same extent as SBC or NaCl. Excess water intake and excretion resulted in increased moisture in the litter. The chloride ion appeared to be responsible for some of the additional litter moisture content because NaCl increased litter moisture to a greater extent than either SBC or SSD. Breast meat yield was significantly increased by either SBC or NaCl compared to control or SSD treatments.

Experiment 4

The treatments in this battery brooder trial were identical in design to litter-pen Experiment 3, except that Experiment 4 was conducted for only 21 d, and water intake and excretion were also determined (see Table 5). With corn-soy diets containing monensin at 121 mg/kg, extra supplemental NaCl significantly ($P < 0.05$) improved 21-d body weight compared to other treatments. Mortality was significantly ($P < 0.05$) lower with diets containing SBC or extra NaCl than with control or SSD diets. Using corn-soy-meat diets, 21-d body weight, feed efficiency, and mortality were significantly ($P < 0.05$) improved with SBC or NaCl compared to the control diet, and SSD results were not significantly different from the control values.

Corn-soy diets with either of the three sodium sources gave significantly ($P < 0.05$) lower 21-d coccidial lesion scores than unsupplemented diets. The 14- to 21-d water intake was significantly increased by 0.139% extra NaCl compared to all other treatments. Water excretion as a percentage of intake was significantly increased by extra NaCl compared with the control; dietary SBC resulted in an intermediate and significant increase as well. Feeding SSD had no effect on water intake.

Using corn-soy-meat diets, coccidial lesion scores were significantly improved by diets containing each of the sodium sources compared to the control diets (Table 5). Water intake was significantly ($P < 0.05$) elevated only

TABLE 3. Effects of dietary sodium bicarbonate, 0 or 0.20%, with or without one of four coccidiostats on 45-d performance of broiler chickens on built-up litter and given a coccidial inoculation via drinking water at 14-d of age, Experiment 2

Dietary treatments: Coccidiostat[1]	SBC[2]	Body weight	Body weight variability CV	Feed/body weight	Mortality	Breast meat
	(%)	(kg)	(%)	(kg:kg)	(%)	(% Live weight)
No coccidiostat	0	1.860[d]	11.20[c]	1.923[a]	17.19[a]	11.56[def]
No coccidiostat	0.2	1.858[d]	11.59[c]	1.923[a]	16.76[a]	11.80[de]
Halifuginone	0	1.937[bc]	11.58[c]	1.832[bcd]	9.23[b]	11.79[de]
Halifuginone	0.2	1.940[ab]	11.74[c]	1.801[cd]	4.54[d]	11.99[cd]
Lasalocid	0	1.917[bc]	13.11[ab]	1.848[bc]	10.23[b]	11.30[ef]
Lasalocid	0.2	1.952[ab]	12.76[b]	1.808[cd]	3.83[d]	12.47[bc]
Monensin	0	1.879[cd]	12.67[b]	1.882[ab]	11.51[b]	10.99[f]
Monensin	0.2	1.935[b]	11.47[c]	1.824[cd]	5.40[cd]	12.89[ab]
Salinomycin	0	1.955[ab]	13.11[ab]	1.829[bcd]	8.38[bc]	11.29[ef]
Salinomycin	0.2	1.984[a]	12.76[b]	1.781[d]	4.54[d]	13.21[a]
SEM		0.001	0.014	0.001	5.92	0.15

[a–f]Means within a column and with no common superscript differ significantly by the Least Significant Difference procedure ($P < 0.05$).

[1]Coccidiostats were included at the following levels in milligrams/kilogram of complete feed: halifuginone (Stenorol®), 3; lasalocid (Avatec®), 99; monensin (Coban®), 121; and salinomycin (BioCox®), 66.

[2]SBC = sodium bicarbonate.

TABLE 4. Effects of sodium bicarbonate, chloride, or sulfate decahydrate with monensin at 121 mg/kg in corn-soy or corn-soy-meat diets on 45-d performance of broiler chickens on built-up litter and given a coccidial inoculation at 14 of age, Experiment 3

Dietary treatments[1]	Body weight	Body weight variation	Adjusted feed/body weight	Mortality	Litter moisture	Breast meat	Skin tears and scratches per bird
	(kg)	(CV %)	(kg:kg)	(%)	(%)	(% Live weight)	
C-S; CON	2.025[ab]	13.56[a]	1.930[a]	12.90[a]	29.31[cd]	11.67[c]	1.04[a]
C-S; SBC	2.020[ab]	11.34[d]	1.874[cd]	3.47[c]	30.83[b]	12.43[ab]	0.90[a]
C-S; NaCl	2.027[ab]	11.08[bc]	1.879[c]	4.07[c]	34.23[c]	12.59[a]	1.17[a]
C-S; SSD	2.009[b]	12.70[bc]	1.910[ab]	8.83[b]	28.26[d]	11.13[d]	0.98[a]
C-S-M; CON	2.019[ab]	13.10[ab]	1.911[ab]	13.19[a]	26.23[e]	11.52[c]	1.17[a]
C-S-M; SBC	2.037[a]	11.49[d]	1.868[cd]	3.18[c]	29.53[c]	12.60[a]	1.40[a]
C-S-M; NaCl	2.024[ab]	11.07[d]	1.846[d]	2.48[c]	33.56[a]	12.36[ab]	1.06[a]
C-S-M; SSD	2.014[ab]	12.54[c]	1.890[bc]	7.64[b]	28.89[cd]	12.18[b]	1.06[a]
SEM	0.001	0.09	0.001	1.75	0.67	0.06	0.08

[a–d]Means within a column and with no common superscript differ significantly by the Least Significant Difference procedure ($P < 0.05$).

[1]Diet types were C-S = corn-soy and C-S-M = corn-soy-meat. Sodium sources provided 0.054% additional sodium: 0.20% SBC (sodium bicarbonate), 0.139% NaCl, and 0.397% SSD (sodium sulfate decahydrate). CON = control.

with extra NaCl compared to the control and SSD treatments. Diets with 0.139% added NaCl diets significantly ($P < 0.05$) increased 14- to 21-d water excretion compared to all other treatments.

DISCUSSION

Using broiler chickens on built-up litter and inoculated with coccidia by water, dietary SBC (0.20%) significantly ($P < 0.05$) enhanced the effects of coccidiostats on body weight, weight uniformity, feed efficiency, coccidial lesion scores (all with monensin), mortality (halifuginone, lasalocid, monensin, salinomycin), and breast meat yield (lasalocid, monensin, salinomycin). The improvement in breast meat yield may have been due to an increase in tissue or in tissue water content due to added dietary sodium. Excess NaCl may cause tissue swelling due to an increase in intercellular water, and this may have occurred with SBC. At this point, the cause of increased breast yield with SBC has not been determined.

The results corroborate research by Hooge *et al*. (1999) with broiler chickens under similar conditions using monensin or salinomycin and dietary SBC. Pesti (1998) observed no significant improvements in combined-sex broiler performance in battery brooders with semduramicin (Aviax®; registered trademark of Pfizer Animal Health) at 25 mg/kg in diets with three electrolyte balances (231, 275, or 362 mEq/kg), adjusted with a variety of electrolyte salts, including SBC plus potassium carbonate. Dietary SBC was not evaluated as a supplement by itself. Fox *et al*. (1987) reported that feeding broiler chicks a level of 1% dietary SBC failed to alleviate the duodenal pH decrease to 4.35 in *E. acervulina*-infected chicks compared to the normal pH of 6.51 in control birds.

The SBC (0.20%) added “on top” of the formula, raised dietary sodium 0.054%, moderately increasing water in-

TABLE 5. Effects of dietary sodium bicarbonate, chloride, or sulfate decahydrate with monensin at 121 mg/kg in corn-soy or corn-soy-meat diets on 21-d performance of broiler chickens in battery brooder pens and given a coccidial inoculation by drinking water at 14 d of age, Experiment 4

Dietary treatments[1]	Body weight	Feed/body weight	Mortality	Composite coccidial lesion score	14- to 21-d Water: Intake	14- to 21-d Water: Excretion
	(g)	(g:g)	(%)		(kg/chick)	(% of intake)
C-S; CON	557[c]	1.372[bc]	17.50[a]	2.88[ab]	1.343[b]	23.91[c]
C-S; SBC	574[c]	1.358[c]	7.50[bcd]	1.63[cd]	1.306[b]	26.45[b]
C-S; NaCl	597[a]	1.330[c]	2.50[d]	1.38[d]	1.751[a]	31.35[a]
C-S; SSD	570[c]	1.337[c]	12.50[abc]	1.81[bcd]	1.329[b]	23.92[c]
C-S-M; CON	565[c]	1.409[ab]	17.50[a]	3.88[a]	1.266[b]	26.13[b]
C-S-M; SBC	595[ab]	1.348[c]	5.00[cd]	1.50[d]	1.488[ab]	27.56[b]
C-S-M; NaCl	596[a]	1.330[c]	5.00[cd]	1.63[cd]	1.819[a]	32.30[a]
C-S-M; SSD	575[bc]	1.432[a]	15.00[ab]	2.69[bc]	1.402[b]	25.76[bc]
SEM	0.001	0.001	22.40	0.28	0.06	0.94

[a–d]Means within a column and with no common superscript differ significantly by the Least Significant Difference procedure ($P < 0.05$).

[1]Diet types were C-S = corn-soy and C-S-M = corn-soy-meat. Sodium sources provided 0.054% additional sodium: 0.20% SBC (sodium bicarbonate), 0.139% NaCl, and 0.397% SSD (sodium sulfate decahydrate). CON = control.

take, water excretion, and litter moisture Therefore, SBC should probably be "formulated in", but the resulting lower levels of total sodium and chloride, due to partial replacement of NaCl, may then influence results and would need to be verified in future research.

In the extra NaCl treatments, total added NaCl levels in the starter, grower, and finisher diets, respectively, were: corn-soy 0.429, 0.409, and 0.389%; and corn-soy-meat 0.419, 0.369, and 0.319%. In the corn-soy and corn-soy-meat with extra NaCl treatments, total calculated sodium levels in the starter, grower, and finisher diets, respectively, were 0.274, 0.254, and 0.234%. In the extra NaCl treatments, chloride levels in starter, grower, and finisher diets, respectively, were: corn-soy 0.294, 0.284, and 0.274%; corn-soy-meat 0.374, 0.354, and 0.324%.

Adding extra NaCl (0.139%) "on top" of complete feed formulas significantly ($P < 0.05$) enhanced the effectiveness of monensin on weight uniformity, feed efficiency, coccidial lesion score, mortality, and breast meat yield. However, the extra NaCl had significant ($P < 0.05$) effects on water intake (+36.9%), water excretion (+27.2%), and litter moisture (+22.1%). Percentages in parentheses were averaged across diet types.

These findings agree with those of Hurst *et al*. (1974), who reported that 4-wk performance of broiler chicks in battery brooders was equivalent with either 0.30 or 0.375% dietary NaCl, but that 0.075 or 0.225% NaCl was insufficient, with monensin at 121.3 mg/kg. Similarly, Edwards (1985) found significant improvements in 3-wk broiler chick weights and feed efficiencies with or without monensin with increasing dietary NaCl levels from 0.1125 to 0.225, 0.3375, and 0.45%. However, Jensen (1982) found with a high dietary level of monensin (160 mg/kg) that 4-wk broiler chick weights were not improved by 0.45% NaCl but were significantly improved with 0.65% SBC. Gard *et al*. (1980), from a series of seven litter pen trials with monensin at 100 or 121 mg/kg at various locations in the U.S., concluded that 0.17 to 0.19% sodium, apparently from NaCl in practical diets, produced heavier ($P < 0.10$) broiler weights than either 0.11% or 0.24 to 0.27% sodium. Increasing monensin from 100 to 121 mg/kg did not appear to increase the requirement for sodium (from NaCl presumably).

Effects of dietary sodium sources (bicarbonate, chloride, and sulfate) with monensin on broiler production and processing parameters were similar in corn-soy and corn-soy-meat diets. The SSD produced some significant ($P < 0.05$) effects, but these changes were typically smaller and less effective than those with SBC or NaCl when contributing equal amounts of sodium (i.e., 0.054%).

REFERENCES

Association of American Feed Control Officials, Inc., 1993. Pages 106–107 *in*: Official Publication. Atlanta, GA.

Augustine, P. C., 1997. Effect of betaine on the growth performance of chicks inoculated with mixed cultures of avian *Eimeria* species and on invasion and development of *Eimeria tenella* and *Eimeria acervulina in vitro* and *in vivo*. Poultry Sci. 76:802–809.

Damron, D. L., W. L. Johnson, and L. S. Kelly, 1986. Utilization of sodium from sodium bicarbonate by broiler chicks. Poultry Sci. 65:782–785.

Edwards, H. M., Jr., 1985. Observations on several factors influencing the incidence of tibial dyschondroplasia in broiler chickens. Poultry Sci. 64:2325–2334.

Fox, M. C., D. R. Brown, and L. L. Southern, 1987. Effect of dietary buffer additions on gain, efficiency, duodenal pH, and copper concentration in liver of *Eimeria acervulina*-infected chicks. Poultry Sci. 66:500–504.

Gard, D. I., C. N. Murphy, B. F. Schlegel, L. V. Tonkinson, and R. H. Wellenreiter, 1980. Monensin and sodium levels in broiler rations. Poultry Sci. 59:1612.

Hooge, D. M., K. R. Cummings, J. L. McNaughton, C. L. Quarles, and B. A. George, 1999. Dietary sodium bicarbonate, coccidial challenge, and ionophore coccidiostats, in broiler chickens. J. Appl. Poult. Res. 8:89–99.

Hurst, R. E., E. J. Day, and B. C. Dilworth, 1974. The effects of monensin and sodium chloride on broiler performance. Poultry Sci. 53:434–436.

Jensen, L. S., 1982. Factors affecting magnitude of monensin-induced growth depression. Pages 51–57 *in*: Proceedings Georgia Nutrition Conference, February 17–19, Atlanta, GA.

Johnson, J., and W. M. Reid, 1970. Anticoccidial drugs: Lesion scoring techniques in battery and floor-pen experiments with chickens. Exp. Parasitol. 28:3–36.

Merrill, D., 1993. Survey by SRI International for Church & Dwight Company, Inc. on Sodium Bicarbonate Use in the Western European Animal Feed Market. Church & Dwight Co., Inc., Princeton, NJ.

Mongin, P., 1968. Role of acid-base balance of physiology of egg shell formation. World's Poult. Sci. J. 24:200–230.

Nam, C. W., B. Manning, M. B. Patel, and J. McGinnis, 1979. Observations of the effects of different dietary sodium levels and coccidiostats (monensin and lasalocid) on growth, feed efficiency, water intake, and mortality in broilers. Poultry Sci. 58:1088.

National Research Council, 1984. Nutrient Requirements of Poultry. 8th rev. ed. National Academy Press, Washington, DC.

Pesti, G., 1998. Influence of Aviax® on several nutritional responses. Pages 1–9 *in*: Pfizer Animal Health Pacesetters Conference, Atlanta, GA.

Saroka, J. M., and G. F. Combs, Jr., 1986. Studies of the renal excretion of the hydroxyl analogue of methionine by the chick. Poultry Sci. 65:1375–1382.

Soares, J. H., Jr., 1974. Experiments on the requirement of inorganic sulfate by the chick. Poultry Sci. 53:246–252.

Steel, R.G.D., and J. H. Torrie, 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York, NY.

Stephens, J. F., 1965. Some physiological effects of coccidiosis caused by *Eimeria necatrix* in the chicken. J. Parasitol. 51:331–335.

Stephens, J. F., W. J. Borst, and B. D. Barnett, 1974. Some physiological effects of *Eimeria acervulina, E. brunetti*, and *E. mivati* infections in young chickens. Poultry Sci. 53:1735–1742.