OPTIMUM DIETARY ELECTROLYTE BALANCE AS INFLUENCED BY PHOSPHORUS LEVEL FOR GROWING BROILERS

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SUMMARY

Two main experiments and an auxiliary experiment were carried out to determine the effects of dietary available phosphorus and electrolyte balance on the growth performance and acid-base balance of broiler chickens. The results showed that mineral balance can affect the growth performance of broiler chickens fed practical-type diets in essentially commercial situations, and indicate that total cation-anion balance can have greater importance than electrolyte balance in Australian diets. Preliminary information on the effects of available phosphorus and electrolyte balance on acid-base balance indicated that this was not markedly affected within the range of cations and anions examined. Mortality and the incidence of leg disorders were increased in diets which contained high chloride levels (0.54%) and low electrolyte balance.

INTRODUCTION

Normal tissue function and development depend on various homeostatic mechanisms which regulate and maintain the composition of body fluids . These body fluids contain osmotically active substances, principally electrolytes such as sodium, potassium, calcium, magnesium, chloride, bicarbonate and phosphorus, which have many complex functions in the body including tissue formation, osmotic pressure regulation, acid-base balance, nerve impulse conduction, enzymatic reactions and muscle contraction. Minerals are required in the diet at certain minimal levels for all animals, but it is now well recognized that relationships exist between mineral elements in that each cannot be considered independently (see Austic 1980 for review). The balance of cations and anions in the diet of growing chickens can affect growth rate (Nesheim et al. 1964; Melliere and Forbes 1966; Mongin and Sauveur 1977; Nelson et al. 1981), acid-base balance (Hurwitz et al. 1973; Sauveur and Mongin 1978; McNab et al. 1981) , the incidence of mortality and leg disorders (Leach and Nesheim 1972; Sauveur and Mongin 1978) and digestion (Nelson et al. 1981; McNab et al. 1981).

Australian poultry diets often contain a high proportion of meat and bone meal which could result in a greater variability of mineral balance than, for overseas diets. The evidence indicates that the mineral content, of meat and bone meal has some importance in determining their ability to support growth and influence mortality (Beilharz and McDonald 1960; Sathe et al. 1964; Karunajeewa 1976) but the basis of these effects is unknown. Although Mongin (1981a; 1981b) considered that for practical purposes total mineral balance'could be ignored in favour of 'electrolyte balance' (Na + K - Cl, mEq), the effects of other ions such as magnesium and phosphorus (Nelson et al. 1981) and sulphate (Nesheim et al. 1964) may be important in certain circumstances. Certainly phosphorus is of vital importance in the animal body (Swenson 1977), and may vary considerably in diets based on meat meal.

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Two main experiments were therefore carried out to determine the effects of available phosphorus and electrolyte balance on the growth performance of broiler chickens. Level of minerals used were within the normal range for commercial broiler rations and the results provide clear evidence of the effects of available phosphorus and electrolyte balance on the growth of broiler chickens.

MATERIALS AND METHODS

Experiment 1

Plan

One thousand six hundred and eighty day-old broiler chickens with males and, females kept separate were allocated at random to the experimental diets. At each of two available phosphorus (AP) levels (0.43% and 0.78% of diet) there was four electrolyte balance (EB) levels (150, 200, 250, 300), which were calculated according to Mongin (1981a; 1981b) as (Na + K - Cl) expressed as mEq/kg of diet. The experiment, which commenced in September 1982, was a 4 x 2 x 2 x 3 factorial with a randomized complete block design where the factors were electrolyte balance, available phosphorus level, sex and block, respectively.

Husbandry

Birds were housed in a temperature controlled, fan ventilated shed with 48 floor pens (3.731 m^2/pen) which contained a deep litter of wood shavings . Thirty-five day-old checkens were placed in each pen, giving a floor area of 0.099 m^2/bird after correction for waterers and feeders. Infra-red brooding lamps were provided 24 h/d for birds to 21 d of age, then for a further 3 d from 1700 h to 8088 h. Ambient temperature in the shed was maintained at 26°C until birds were 21 d of age and thereafter at 21°C. Ventilation of the shed was 316 m^3/min, and photoperiod was 23 h/d with lights off 'between midnight and 0100 h. Fresh town water of analysed mineral composition of Na (4 ppm), Cl (12 ppm) and K (0.7 ppm) was available from plastic automatic drinkers and two tube feeders were provided for each pen.

Diets

Diets were formulated according to the known nutrient requirements of broiler chickens (ARC, 1975). The determined composition of the major dietary ingredients which were used is given in Table 1 and the composition of the starter and finisher basal diets is given in Table 2. Sodium chloride (NaCl), sodium bicarbonate ($NaHCO_3$) and potassium carbonate (K_2CO_3) were added to the basal diets in order to achieve EB levels of 150, 200, 250 and 300 mEq/kg of diet at each level. The quantities of salts added to the basal diets and the analyses of the diets are given in Table 3. Phosphorus levels of diets were altered by adding dicalcium phosphate. Adjustments were made to the limestone content (see Table 2) to maintain calcium levels.

Measurements

Food intake for birds in each pen was measured over 7 d periods, Liveweights were measured at day-old and when the birds were 21 d and 49 d of age by group weighing on a pen basis. At 49 d of age two birds in each pen (six birds/treatment) were starved (1700 h - 0800 h),

TABLE 1 Analyses of the ingredients used in the experimental diets.

Analyses (%)	Wheat	Hulled oats	Sorghum	Blood meal	Cotton-seed meal	Meat and bone meal	Soyabean meal
Dry matter	90.3	89.0	87.5	85.9	92.3	95.8	91.6
Crude protein	12.9	13.0	11.2	85.8	34.7	51.1	44.4
Ether extract	2.1	8.0	3.13	0.12	4.1	10.7	2.4
Acid-detergent fibre	ND[§]	4.8	4.87	0.30	16.9	ND	8.6
Calcium	0.06	0.04	0.02	0.01	0.46	9.00	0.35
Total phosphorus	0.21	0.30	0.21	0.10	0.90	3.90	0.65
Phytic acid phosphorus	0.17	0.21	ND[§]	-	ND	-	0.47
Inorganic phosphorus[†]	0.04	0.09	0.06	0.10	0.27	3.90	0.18
Sodium	0.01	0.01	0.003	0.45	0.15	0.72	0.01
Potassium	0.45	0.25	0.37	0.28	1.28	0.51	2.13
Chloride	0.06	0.05	0.05	0.30	0.10	0.49	0.02
Magnesium	0.15	0.15	0.14	0.03	0.55	0.23	0.36
Sulphate	0.006	0.010	-	0.028	0.030	0.110	0.052

[§] ND, not determined.

[†] Calculated as the difference between total phosphorus and phytic acid phosphorus.

liveweight measured and slaughtered and processed to determine weight of the abdominal fat pad, dressing percentage and moisture retention. Moisture retention was determined by chilling the eviscerated carcass in a water tank for 3 h then draining for 1 h followed by re-weighing. Tibial leg bones at 49 d, blood sera and plasma at 21 d and 49 d of age were sampled for mineral analyses but these results are unavailable at this time. Litter moisture was determined by sampling at three locations in each pen. Samples were oven-dried at 80°C for 7 d.

Experiment 2

Plan

This experiment which commenced in March 1983, consisted of two parts. The first and major part was an experiment essentially similar to Experiment 1 with birds in floor pens in a temperature controlled shed. The second, carried out in conjunction with the first, involved a small number of birds housed in a wire-cage brooder unit from 0 - 21 d of age. The aim of this smaller experiment was to measure the effect of EB and AP on (a) the metabolisable energy (AME) content of the starter diets, on (b) water intake and moisture content of excreta, and on (c) acid-base balance. These two experiments will be referred to as Experiment 2A (shed) and 2B (brooder).

In Experiment 2A, 1536 day-old male broiler chickens were allocated at random to the experimental diets. At each of three AP levels (0.43%, 0.60% and 0.78% of diet) there were four EB levels (150, 200, 250 and 300 mEq/kg). The experiment was a 4 x 3 x 4 factorial with a randomized complete block design where the factors were EB level, AP level and block, respectively.

TABLE 2 Composition (%) of basal diets.

Ingredient	Experiment 1 Starter diet (1-21d)	Experiment 1 Finisher diet (21-49d)	Experiment 2 Starter diet (1-21d)	Experiment 2 Finisher diet (21-49d)
Wheat	43.00	46.00	40.75	46.00
Sorghum	15.00	15.00	15.00	15.00
Hulled oats	10.00	10.00	10.00	10.00
Cottonseed meal	5.00	3.50	5.00	3.50
Soyabean meal	8.00	5.00	8.00	5.00
Blood meal	3.00	2.50	4.00	2.50
Meat and bone meal	9.00	9.00	9.00	9.00
Mixed tallow	3.00	4.00	3.50	4.50
Starch	-	0.80	-	-
Limestone	1.420	1.420	1.420	1.420
Methionine	0.250	0.190	0.250	0.195
Lysine HCl	0.266	0.171	0.206	0.190
Rice hulls	1.470	1.700	1.580	1.309
Premix †	0.494	0.494	0.483	0.483
Calculated composition (%, AR).				
Metabolisable energy (MJ/kg)	12.35	12.57	12.35	12.57
Crude protein	20.7	18.7	20.8	17.6
Ether extract	6.4	7.3	7.0	6.9
Linoleic acid	1.4	1.5	1.4	1.4
Total lysine	1.25	1.05	1.25	1.05
Methionine + cystine	0.89	0.78	0.87	0.78
Calcium	1.32	1.32	1.31	1.32
Total phosphorus	0.62	0.58	0.61	0.58
Available phosphorus	0.43	0.41	0.43	0.41
Sodium (%)	0.112	0.112	0.117	0.109
Potassium (%)	0.576	0.576	0.569	0.500
Chlorine (%)	0.170	0.170	0.177	0.171

† Premix supplied the following per kg diet:- Vitamin A, 10,000 I.U., vitamin D_3 2,200 I.U.; vitamin E, 20 mg; vitamin K, 3.15 mg; thiamine, 1 mg; riboflavin, 8 mg; niacin 30 mg; pantothenic acid, 15 mg; biotin, 0.15 mg; pyridoxine, 6 mg; folic acid, 3 mg; cyanocobalamin, 0.02 mg; choline chloride, 1300 mg; ascorbic acid, 25 mg; manganese, 100 mg; zinc, 60 mg; copper, 8 mg; iron, 80 mg; iodine, 0.4 mg; molybdenum, 0.5 mg; selenium, 0.1 mg; monensin, 85 mg; flavophospholipol, 5 mg; 3-nitro-4 hydroxy phenyl arsonic acid, 50 mg; ethoxyquin, 125 mg.

In Experiment 2B, 120 birds of the same batch were allocated at day-old to a six-tiered electrically-heated brooder unit with four cages per tier, Birds received the same starter diets as those birds in Experiment 2A but only the low (0.43%) and high (0.78%) AP levels were used. The experiment was a 4 x 2 x 3 factorial with a completely random design where the factors were EB level, AP level and replications, respectively.

TABLE 3 Composition and analyses of the experimental diets (Experiment 1).

	Electrolyte balance (Na + K - Cl) (mEq/kg)							
	150		200		250		300	
Composition (%)	S[+]	F[§]	S	F	S	F	S	F
Basal*	99.90	99.78	99.57	99.44	99.22	99.09	98.87	98.75
NaCl	0.100	0.100	0.100	0.100	-	-	-	-
$NaHCO_3$	-	-	0.170	0.170	0.460	0.460	0.630	0.630
K_2CO_3	-	0.125	0.165	0.290	0.325	0.450	0.500	0.625
Analyses (%)[†]								
Sodium	0.150		0.200		0.248		0.298	
Potassium	0.576		0.676		0.774		0.880	
Chloride	0.210		0.210		0.151		0.151	

[+] Starter diets

[§] Finisher diets

[*] Basal diet with either low (0.43%) or high (0.78%) available phosphorus (see Table 2).

[†] Calculated from ingredient composition. The basal diets contained 0.112% Na, 0.576% K and 0.170% Cl prior to addition of any salts. Additional salts as given above were added at the expense of rice hulls.

Husbandry

Shed conditions (Experiment 2A) were essentially similar to those in Experiment I, except only thirty-two birds were placed in each pen. In Experiment 2B, five day-old chickens were placed in each of the 24 brooder cages. Temperature in the brooder during the first 7 d period was 35°C and gradually decreased thereafter such that temperature was 25° C when the birds were 21 d of age.

Diets

Type and composition of the ingredients and diets were similar to those given for Experiment 1 (see Tables 1 and 2). Sodium chloride (NaCl), sodium bicarbonate ($NaHCO_3$), potassium chloride (KCl) and potassium carbonate (K_2CO_3) were added to the basal diets in order to achieve the four EB levels at each of the three AP levels. The quantities of salts added to the basal diets and the analyses of the diets are given in Table 4.

Measurements

In Experiment 2A food intake for birds in each pen was measured over 7 d periods. Liveweights were measured at day-old and when the birds were 21 d, 42 d and 49 d of age by group weighing on a pen basis. At 7 d, 14 d, 28 d and 35 d of age a sample of 10 birds per pen were weighed.

In Experiment 2B birds were wing-banded and food and water intake for birds in each cage were measured over 7 d periods, and liveweights of individual birds at day-old and at 7 d, 14 d and 21 d of age. Water

TABLE 4 Composition and analyses of the experimental diets (Experiment 2)[†]

	Electrolyte balance (Na + K - Cl) (mEq/kg)							
	150		200		250		300	
Composition (%)	S[+]	F[§]	S	F	S	F	S	F
Basal[*]	99.20	99.10	99.09	98.99	98.99	98.88	98.83	98.69
NaCl	0.192	0.272	0.192	0.272	0.192	0.272	0.105	0.115
$NaHCO_3$	0.077	-	0.077	-	0.077	-	0.191	0.204
KCl	0.533	0.432	0.318	0.222	0.103	0.013	-	-
K_2CO_3	-	0.199	0.322	0.516	0.643	0.832	0.873	0.987
Analyses (%)[†]								
Sodium	0.215		0.215		0.215		0.215	
Potassium	0.841		0.927		1.013		1.100	
Chloride	0.540		0.440		0.340		0.240	

[+] Starter diets.

[§] Finisher diets.

[*] Basal diet with either low (0.43%), medium (0.60%) or high (0.78%) available phosphorus (see Table 2).

[†] The basal diets contained 0.117% Na, 0.569% K and 0.177% Cl. Added salts replaced rice hulls.

turnover was measured in two birds per cage (six birds/treatment) over the period 14 - 21 d of age. Birds were injected with tritiated water (10 μCi/kg liveweight) and blood sampled from the wing vein 3 h and again 6 d after injection. Specific radioactivity of plasma samples was determined in a Tri-Carb scintillation counter using standard procedures. At 21 d of age a further two birds per cage were selected and blood samples (2 ml) taken from the wing vein into heparinised syringes which were sealed and placed on ice prior to measurement of pH, pCO_2, pO_2 and HCO_3^- using a Corning pH/Blood Gas analyser.

Metabolisable energy (ME) content of the starter diets was measured by total collection of the excreta over a four-day period between 14 - 21 d of age (Experiment 2B).

Chemical Analyses and Calculations

proximate and mineral analyses of the diets were carried out using standard procedures (AOAC, 1975). Phytate was determined by the method of Latta and Erkin (1980). The balance between total'cations and anions in the diets was calculated-using the assumptions given by Melliere and Forbes (1966).

Statistics

Results from Experiments 1 and 2A were analysed by factorial analysis with block effect, and results from Experiment 2B were analysed by two-way analysis of variance.

RESULTS

Experiment 1

Mortality and culls in the period from when the birds were day-old to 21 d of age was 2.3% and from 21 d to 49 d of age it was 1.1%. There were no significant effects of AP level of EB or sex on mortality and culls.

Liveweights at 21 d and 49 d of age are given in Table 5, and liveweight gain, food intake and food conversion ratios are given in Table 6. Birds which received diets with high AP rather than low AP had lower ($P < 0.01$) liveweights at 21 d (523 g versus 560 g) and at 49 d (2134 g versus 2191 g) of age.

There was a significant ($P < 0.01$) effect of sex on the influence of AP on liveweight at 21 d and 49 d of age, in that high AP diets caused a greater reduction in liveweight relative to low AP diets for males rather than females. The adverse effects of high AP on liveweight at 49 d of age were partially alleviated at the two highest levels of EB (250 and 300 mEq/kg). The optimum EB in diets with low AP appeared to be 200 mEq/kg, but liveweight at 49 d of age was only significantly ($P < 0.05$) greater at this EB than at 300 mEq/kg. Although high EB alleviated the effects of high AP, the liveweights attained were not as great as for low AP diets at 200 mEq/kg. This was probably related to cation-anion balance, which is shown in Figure 1.

TABLE 5 The effects of dietary available phosphorus level and electrolyte balance on liveweights of male and female broiler chickens at 21 d and 49 d of age (Experiment 1).

Available phosphorus in diet	Electrolyte balance (mEq/kg)	Liveweight (g) at: 21 d Male	21 d Female	49 d Male	49 d Female
Low (0.43%)	150	594	523	2387	2001
	200	602	540	2429	2005
	250	587	526	2370	1989
	300	580	524	2401	1942
High (0.78%)	150	525	506	2279	1946
	200	536	508	2277	1956
	250	547	509	2341	1961
	300	542	514	2333	1978
SEM (df = 30)		7		23	

Food intake was depressed by high AP both between 0-21 d ($P < 0.01$) and 21-49 d ($P < 0.05$) of age. There was a significant ($P < 0.05$) interaction between AP and EB between 0-21 d of age; food intake (0-21 d) was lower on the low AP diets at the two highest EB levels (250 and 300 mEq/kg) relative to the lower levels of EB. These effects were not evident for diets with high AP. High AP increased ($P < 0.05$) food conversion (FCR) between 0-21 d of age.

Dressed carcass weights, moisture retention and abdominal fat pad weights, expressed as a percentage of liveweight, for birds slaughtered

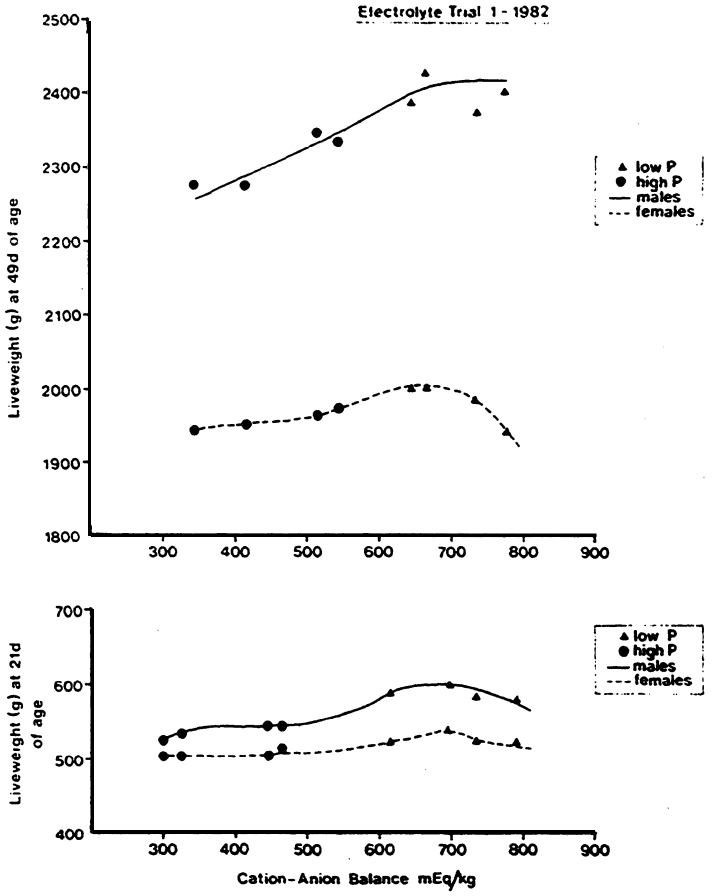

Figure 1. The effect of dietary cation-anion balance on the liveweight of broiler chickens at 21 d and 49 d of age (Experiment 1).

Dressed carcass weights, moisture retention and abdominal fat pad weights, expressed as a percentage of liveweight, for birds slaughtered at 49 d of age, are given in Table 7. Dressed carcass weight (% of liveweight) was slightly but significantly ($P < 0.05$) lower for birds on the high AP rather than the low AP diets (68.7% versus 69.6%) but was not affected by EB or sex. However there was a significant ($P < 0.05$) interaction between AP and EB (see Table 7). Moisture retention in the carcass as measured by the procedure given (see Materials and Methods) was not influenced by AP, EB or sex. Abdominal fat pad weight (% of liveweight) was increased ($P < 0.05$) by high AP compared with low AP in the diet (3.12% versus 2.82%) and females had a higher ($P < 0.01$) abdominal fat pad weight (% of liveweight) than males (3.39% for females compared to 2.54% for males). EB had no apparent influence on this trait nor was there any interactions detected.

Mean litter moisture was 11.2% when the birds were 21 d of age and was not affected by AP, EB or sex. At 49 d of age litter moisture was higher ($P < 0.05$) for those pens in which birds received the high AP rather than the low diets (26.5% versus 23.8%).

Experiment 2A

Mortality in the period from when the birds were day-old to 21 d of age was 2.2% and from 21 d to 49 d of age it was 1.7%. The overall (0-49 d) mortality (including culls) was higher ($P < 0.05$) on diets with an EB level of 150 mEq/kg than on the other diets. The proportion of birds affected by leg disorders and curled toes decreased with increasing EB.

TABLE' 6 The effects of dietary available phosphorus level and electrolyte balance on liveweight gain, food intake and food conversion of male and female broiler chickens between day-old to 21 d of age and between 21 d to 49 d of age (Experiment 1).

Available phosphorus in diet	Electrolyte balance (mEw/kg)	Liveweight gain (g/bird)		Food intake (g/bird)		Food conversion (g food/g gain)	
		Male	Female	Male	Female	Male	Female
			0 - 21 d of age				
Low (0.43%)	150	555	484	942	870	1.70	1.80
	200	562	502	915	883	1.63	1.76
	250	548	487	901	830	1.64	1.70
	300	540	485	913	832	1.69	1.71
High (0.78%)	150	485	467	839	810	1.73	1.73
	200	497	469	883	820	1.78	1.75
	250	508	470	901	829	1.77	1.76
	300	503	475	840	862	1.67	1.82
SEM (df = 30)		7		19		0.04	
			21 - 49 d of age				
Low (0.43%)	150	1793	1478	3826	3290	2.14	2.23
	200	1827	1464	3831	3319	2.10	2.27
	250	1793	1463	3772	3431	2.12	2.35
	300	1821	1418	3850	3161	2.12	2.23
High (0.78%)	150	1755	1440	3524	3282	2.01	2.28
	200	1741	1448	3659	3322	2.10	2.29
	250	1794	1452	3807	3301	2.12	2.27
	300	1791	1464	3755	3304	2.10	2.26
SEM (df = 30)		15.0		75		0.05	

Liveweights at 21 d, 42 d and 49 d of age are given in Table 8, and liveweight gain, food intake and food conversion ratios are given in Table 9. Similar to the effects obtained in Experiment I high levels of available phosphorus reduced ($P < 0.01$) liveweight at 21 d of age; means were 632 g, 619 g and 603 g for birds on the low, medium and high AP diets respectively. However, liveweights at 42 d and 49 d of age were not significantly affected by dietary level of AP although the trends were similar; mean liveweights at 49 d of age were 2360 g, 2344 g and 2335 g for birds on the low medium and high AP diets respectively. The effects of total cation-anion balance on liveweights at 21 d, 42 d and 49 d of age are shown in Figure 2. Food intake was slightly but not significantly reduced by high AP diets between day-old and 21 d of age and between 21 d to 49 d of age. Food conversion was higher ($P < 0.05$) between day-old and 21 d of age for birds on both the medium and high AP diets compared with those on the low AP diet. There was an interaction ($P < 0.05$) between AP level and EB for liveweight at 21 d of age, due to birds on the EB diet of 200 mEq/kg being heavier than birds on 150 and 300 mEq/kg for the low AP diet. EB was without effect on the medium and high AP diets for liveweight at 21 d of age. However liveweight at 49 d of age was influenced ($P < 0.05$) by EB with an optimum of 250 mEq/kg; means were 2317 g, 2340 g, 2377 g and 2351 g for birds on diets with an EB of 150, 200, 250 and 300 mEq/kg respectively. Litter moisture was higher ($P < 0.01$) in pens which received the lowest EB diet (150 mEq/kg) at 21 d of age (21% litter moisture for EB of 150 versus, 15% for diets with other EB levels) and there was a tendency for higher litter moisture with the high AP diet at 49 d of age but this was not significant. Dressed carcass weight (% of liveweight) averaged 68.2% and was unaffected by dietary treatment.

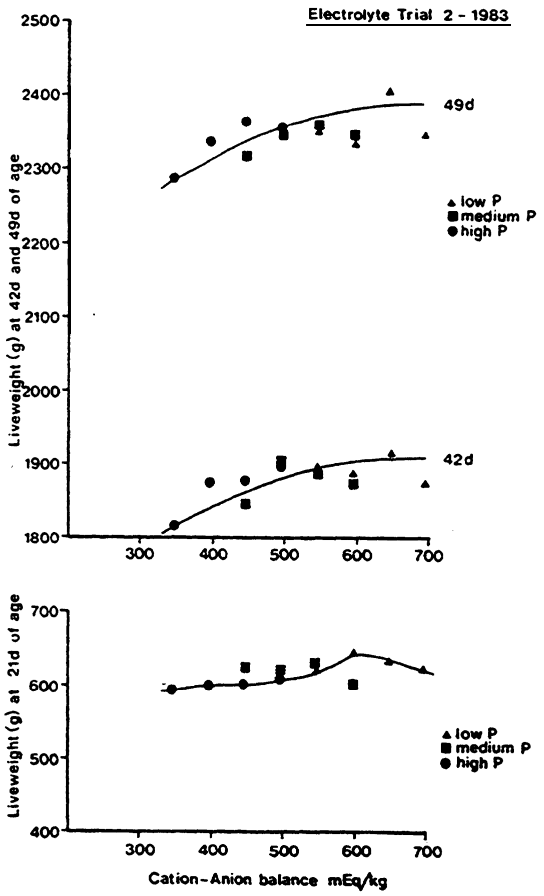

Figure 2. The effect of dietary cation-anion balance on the liveweight of broiler chickens at 21 d, 42 d and 49 d of age (Experiment 2).

TABLE 7 The effects of dietary available phosphorus level and electrolyte balance on the dressing percentage, moisture retention and abdominal fat content of male and female broiler chickens 49 d of age (Experiment 1).

Available phosphorus in diet	Electrolyte balance (mEq/kg)	Dressed carcass weight*		Moisture retention**		Abdominal fat pad weight	
		(% of liveweight)					
		Male	Female	Male	Female	Male	Female
Low (0.43%)	150	69.1	70.5	2.4	2.8	2.5	3.3
	200	69.5	70.1	1.8	2.8	2.5	3.5
	250	68.8	69.1	2.6	3.2	2.3	3.2
	300	70.2	69.6	1.6	3.1	2.5	2.9
High (0.78%)	150	70.2	68.0	3.6	2.2	2.3	3.6
	200	68.3	68.0	2.5	4.6	2.8	3.4
	250	69.0	70.1	2.2	2.0	3.2	3.6
	300	67.4	68.6	2.6	2.7	2.3	3.8
SEM (df = 30)		0.66		0.66		0.27	

* Weight of eviscerated carcass without the neck, feet and giblets.

** Percentage moisture retained in carcass after chilling and draining.

TABLE 8. The effects of dietary available phosphorus level and electrolyte balance on liveweight of male broiler chickens at 21 d, 42 d and 49 d of age (Experiment 2A).

Available phosphorus in diet	Electrolyte balance (mEq/kg)	Liveweight (g) at : 21 d	42 d	49 d
Low (0.43%)	150	624	1894	2350
	200	647	1887	2335
	250	634	1919	2408
	300	623	1871	2349
Medium (0.60%)	150	626	1843	2316
	200	620	1902	2349
	250	627	1892	2363
	300	601	1873	2349
High (0.78%)	150	596	1815	2286
	200	602	1873	2338
	250	602	1879	2362
	300	612	1900	2356
SEM (df = 33)		7	26	25

Experiment 2B

Four birds died during the experiment, two due to starvation, one due to naval infection and another to fatty liver disease. Similar to Experiment 2A, liveweight at 21 d of age was lower ($P < 0.01$) for birds on 'high rather than low AP diets (581 g versus 611 g), and food intake was reduced ($P < 0.05$) in a similar manner (890 g for high AP compared to 941 g for low AP diet). Results are given in Table 10. EB did not affect either liveweight at 21 d or food intake from day-old to 21 d of age. Food conversion and water intake were not influenced by either AP or EB. However the food:water ratio was reduced ($P < 0.01$) by high AP compared to low AP (0.56 versus 0.61) and was reduced ($P < 0.05$) by diets with a low EB compared to a higher EB (means were 0.56, 0.58, 0.59 and 0.61 for EB of 150, 200 and 300 mEq/kg respectively). The parameters measured when the birds were 22 d of age to assess acid-base balance, blood pH, HCO_3^-, pCO_2 and pO_2, were not influenced by either AP or EB. There was a tendency for pH to increase with increasing EB in the diet; means were 7.297, 7.319, 7.329 and 7.369 for diets of 150, 200, 250 and 300 mEq/kg respectively.

DISCUSSION

Available phosphorus level was the major dietary factor which determined the growth of broiler chickens in the present studies. Electrolyte balance calculated as described by Mongin (1981a; 1981b) had some influence in that higher levels of sodium and potassium improved final liveweight when the diet contained relatively high levels of available phosphorus. Since Australian broiler diets may contain a high proportion of meat and bone meal (7-14%) the available phosphorus level can be expected to vary somewhere between 0.5% to 0.9%. The results of the present studies demonstrate that attention to electrolyte balance in such diets could result in improved liveweight gain. More importantly however the present studies provide strong evidence for the concept of cation-anion balance rather than that advanced by Mongin (1981a; 1981b) of electrolyte balance. Special recognition must be given to the differences between the work described by Mongin and that described here. Mongin (1981a; 1981b) used mainly purified diets with a wide range of electrolyte balance (0 - 600 mEq/kg) and chickens were taken to 28 d of age. The present studies used practical, commercial-type diets with a narrow but realistic range of electrolyte balance (150 - 300 mEq/kg) and chickens were taken to 49 d of age. The latter point is important because there were differences in response between day-old to 21 d of age and between 21 d and 49 d of age in the present studies, where the major effects of dietary available phosphorus were manifested in the early growth phase (0 - 21 d of age). For example, food conversion (g feed/g liveweight gain) was increased by high available phosphorus in the period between day-old to 21 d of age but not in the period between 21 d to 49 d of age.

The effects of available phosphorus, electrolyte balance and overall cation-anion balance found in Experiment 1 were influenced by the sex of the broiler chickens. Males were more severely affected by high available phosphorus levels than were females, and again. this was particularly evident in the early growth phase from day-old to 21 d of age. Liveweight at 49 d of age for female broiler chickens were less affected by dietary cation-anion balances in the range from 350 mEq/kg to 730 mEq/kg than were males but were more adversely affected when cation-anion balance became greater than 730 mEq/kg (see Figure 1).

TABLE 9 The effects of dietary available phosphorus level **and** electrolyte balance on liveweight gain, food intake and food conversion of male broiler chickens between day-old to 21 d of age and between 21 d to 49 d of age (Experiment 2A).

Available phosphorus in diet	Electrolyte balance (mEq/kg)	Liveweight gain (g/bird)	Food intake (g/bird)	Food conversion (g food/g gain)
		0 - 21 d of age		
Low (0.43%)	150	581	978	1.69
	200	604	975	1.62
	250	591	974	1.65
	300	580	934	1.61
Medium (0.60%)	150	585	985	1.68
	200	577	964	1.67
	250	584	1008	1.73
	300	559	975	1.70
High (0.78%)	150	554	895	1.62
	200	559	960	1.72
	250	560	952	1.70
	300	569	979	1.73
SEM (df = 33)		7	23	0.03
		21 - 49 d of age		
Low (0.43%)	150	1726	3761	2.18
	200	1687	3834	2.27
	250	1774	3817	2.15
	300	1726	3691	2.14
Medium (0.60%)	150	1690	3721	2.20
	200	1729	3732	2.16
	250	1736	3874	2.23
	300	1748	3744	2.14
High (0.78%)	150	1690	3620	2.15
	200	1736	3713	2.14
	250	1760	3736	2.14
	300	1744	3878	2.22
SEM (df = 33)		23	70	0.03

These differences would have to be considered in any recommendations concerning optimum cation-anion balance in diets for broiler chickens given that commercially the sexes are usually reared together. Although the results of Experiment 2 (Figure 2) were not as marked as for Experiment 1 there is the same tendency toward maximum liveweight in the region of a cation-anion balance of between 600 - 700 mEq/kg. Within the context of possible variations in dietary mineral levels in practical diets, this range of cation-anion balance is extremely narrow.

TABLE 10 The effects of dietary available phosphorus level and electrolyte balance on production parameters of male broiler chickens housed in a brooder to 21 d of age (Experiment 2B).

AB†	EB‡	Live-weight 21 d of age (g)	Food intake (g/bird)	Food conversion (g food/ g gain)	Water intake (ml/ bird)	Food:water ratio
Low (0.43%)	150	627	956	1.64	1630	0.59
	200	610	923	1.63	1505	0.61
	250	613	953	1.68	1585	0.60
	300	595	931	1.69	1490	0.62
High (0.78%)	150	579	878	1.65	1660	0.53
	200	566	851	1.63	1565	0.54
	250	597	942	1.70	1657	0.57
	300	581	923	1.72	1544	0.60
SEM (df = 16)		16	28	0.04	53	0.002

† Available phosphorus

‡ Electrolyte balance

The physiological reasons for the observed effects of the balance between cations and anions in the diet on growth rate and performance could not be ascertained from the present studies. Usually it is considered that the adverse effects are due to alterations in acid-base status of the body. Mongin (1981a; 1981b) concluded that this was because metabolic pathways could not function under conditions of acidosis or alkalosis and were more involved in homeostatic regulation than in growth processes. However the results presented by Mongin (1981a; 1981b) on the effect of electrolyte balance on blood bicarbonate level show some evidence of a plateau around the region of dietary electrolyte balance from 150 to 350 mEq/kg. Based on the liveweight data provided (Mongin, 1981a; 1981b) there was not a good relationship between growth rate and blood bicarbonate level within this range of electrolyte balance. Certainly if extreme electrolyte balances are used (Mongin 1981a; 1981b; McNab *et al*, 1981) then there is good evidence to suggest that altered acid-base balance is the major cause of observed growth depressions. For example the range of electrolyte balance investigated by Mongin (1981a; 1981b) was -200 mEq/kg to 350 mEq/kg. McNab *et al* (1981) found a relationship between dietary electrolyte balance and blood bicarbonate level but this was due mainly to the effect of a very high (0.64%) chloride content of one of the diets. Similarly Hurwitz *et al.* (1973) demonstrated a sigmoidal relationship between chloride content of the diet and blood pH, but two of their diets were deficient in chloride and another two diets had added calcium chloride ($CaCl_2$), which is known to produce acidosis in birds because the calcium is not absorbed and therefore must be excreted in the form of calcium carbonate. Similarly O'Dell *et al.* (1956)

found that high dietary levels of available phosphorus (0.9 - 1.7%) depressed the growth rate of guinea pigs, but the beneficial effects observed for excess cations on growth were only partially explained by maintenance of ideal acid-base balance.

There was no relationship found between acid-base balance and growth rate in the period from day-old to 21 d of age in the present study (Experiment 2B). This was despite the marked effect of high dietary available phosphorus on growth rate during this period. However it is well known that determinations on venous blood may not give an accurate assessment of acid-base balance (Gardner 1978) so no conclusion can be made at this time concerning the exact relationship between acid-base balance and growth rate within the range of cations and anions examined here. Other reasons may explain the effect of cation-anion balance on growth and performance. Nitrogen metabolism may be influenced, and there is good evidence to show that amino acid metabolism and mineral nutrition are interrelated (Austic and Calvert 1981). Also, digestion may be influenced by cation-anion balance. Nelson et al. (1981) found that high dietary concentrations of cations relative to anions depressed dry matter and amino acid digestion and the metabolisable energy of the diet. McNab et al. (1981) found that the apparent metabolisable energy content of the diet was reduced by low rather than high electrolyte balance.

The incidence of tibial dyschondroplasia is genetically (Leach and Nesheim 1965; 1972; Riddell 1976; Sheridan et al. 1978; Burton et al. 1981) and nutritionally (Leach and Nesheim 1972; Sauveur and Mongin 1978) determined. Burton et al. (1981) found differences between broilers from the three major breeding organisations in the incidence of tibial dychrondroplasia, and these differences were not related to liveweight at 49 d of age. Nelson et al. (1981) found that cation-anion balance influenced the occurrence of crooked legs in broiler chickens, but Riddell (1976) noted that other skeletal defects such as twisted legs were unrelated to tibial dyschondroplasia. In the present study there were no effects of available phosphorus level or electrolyte balance on mortality or the incidence of leg disorders in Experiment 1, but there was an increase in mortality and the incidence of leg disorders in Experiment 2 with decreasing electrolyte balance. These differences were probably related to the chloride content of the diet, rather than to electrolyte balance or cation-anion balance *per se* (Leach and Nesheim 1972; Sauveur and Mongin 1974; Riddell 1975; 1976).

The effects of mineral intake on the moisture content of the excreta of chickens have been discussed by Mongin (1981a; 1981b). Excess sodium and/or potassium increase the moisture content whereas chloride is apparently without effect. The results of the present studies are conflicting to some degree. In Experiment 1, there was an increase in litter moisture due to a high available phosphorus content in the diet when the litter was sampled when birds were 49 d of age. In Experiment 2A the major effect was observed at 21 d of age where the lowest electrolyte balance (150 mEq/kg), and therefore the highest chloride content, increased litter moisture compared to the other levels of electrolyte balance, and available phosphorus level was without effect. Measurement of water intake (Experiment 2B) clarified the situation; there were no effects of available phosphorus or electrolyte balance on water intake (mls/bird) but when expressed as a ratio of food intake it was shown that per unit of food intake the water intake was increased on the high available phosphorus diets compared to the low available phosphorus diets and there was a similar effect for diets with lower electrolyte balances rather than the higher electrolyte balances. This latter effect tended to be more marked for birds on the high available phosphorus diet. The results on water intake would probably give a more accurate assessment of the possible effects on litter moisture than would actual determination of litter moisture.

CONCLUSIONS

The present studies have demonstrated that economically important variables in broiler production can be influenced by the interaction between dietary minerals. Certainly high levels of available phosphorus (> 0.60%) can depress production and performance, especially during initial growth. Although the effects of high available phosphorus were not ameloriated by the balance between sodium, potassium and chloride in the-diet during initial growth, during the latter growth phase higher levels of sodium and potassium relative to chloride partially alleviated these adverse effects of high available phosphorus. The results expressed in terms of overall cation-anion balance indicated that this method may be more applicable to the Australian situation because of the relatively high levels of inclusion of meat and bone meal in diets for broiler chickens. However such a supposition requires further testing, especially with regard to specificity of minerals within a given cation-anion balance.

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REFERENCES

A.R.C. (1975). Agricultural Research Council: "The Nutrient Requirements of Farm Livestock No. 1. Poultry", 2nd edition, London.

AUSTIC, R.E. (1980). In. Proc. 1980. Cornell Nutrition Conference for Feed Manufacturers, Cornell University, Ithaca, N.Y. pp 12-17.

AUSTIC, R.E. and CALVERT, C.C. (1981). Fed. Proc. 40(1): 63 - 67.

BEILHARZ, R.G. and McDONALD, M.W. (1960). Aust. Vet. J. **36**: 89-90.

BURTON, R.W., SHERIDAN, A.K. and HOWLETT, C.R. (1981). Br. Poult. Sci. **22**: 153-160.

GARDNER, M.L.G. (1978). Medical Acid Base Balance. The Basic Principles. Bailliere Tindall, London.

HURWITZ, S., COHEN, I., BAR, A. and BORNSTEIN, S. (1973). Poult. Sci. 52 : 903-909.

KARUNAJEEWA, H. (1976). Aust. J. Exptl. Agric. Anim. Husb. 16 : 685-690.

LEACH, R.M. and NESHEIM, M.C. (1965). J. Nutr. **86**: 236-244.

LEACH, R.M. and NESHEIM, M.C. (1972). J. Nutr. **102**: 1673-1680.

McNAB, J.M., BLAIR, J.C., DEWAR, W.A. and DOWNIE, J.N. (1981). In. Proceedings of the 3rd European Symposium on Poultry Nutrition, 26-29 October, 1981, Scotland, U.K. pp 132-136.

MELLIERE, A.L. and FORBES, R.M. (1966). J. Nutr. **90**: 310-314.

MONGIN, P. (1981a). In. Recent Advances in Animal Nutrition - 1981 (W. Haresign, editor), Butterworths. (London, Boston) pp 109-119.

MONGIN, P. (1981b). Proc. Nutr. Soc. **40**: 285-294.

MONGIN, P. and SAUVEUR, B. (1977). In. Growth and Poultry Meat Production (K.N. Boorman and B.J. Wilson, editors), British Poultry Science Ltd., pp 235-247.

NELSON, T.S., KIRBY, L.K. and JOHNSON, I.B. (1981). Poult. Sci. 60: 786-789 .

NELSON, T.S., KIRBY, L.K., JOHNSON, Z.B. and BEASLEY, J.N. (1981). Poult. Sci. 60: 1030-1035.

NESHEIM, M.C., LEACH, R.M., ZEIGLER, T.R. and SERAFIN, J.A. (1964). J. Nutr. 84: 361-366.

O'DELL, B.L., VANDEPOPULIERE, J.M., MORRIS, E.R. and HOGAN, A.G. (1956). Proc. Soc. Exp. Biol. Med. 91: 220-223.

RIDDELL, C. (1975). Avian Dis. 19: 443-462.

RIDDELL, C. (1976). Poult. Sci. 55: 145-151.

SATHE, B.S., CUMMING, R.B. and McCLYMONT, G.L. (1964). Aust. J. Agric. Res. 15: 200-

SAUVEUR, B. and MONGIN, P. (1978). Ann. Biol. anim. Bioch. Biophys. 18: 87-98.

SAUVEUR, B. and MONGIN, P. (1974). Proc. 15th Wld. Poultry Congr., New-Orleans, pp 180-181.

SHERIDAN, A.K., HOWLETT, C.R. and BURTON, R.W. (1978). Br. Poult. Sci. 19: 491-499.

SWENSON, M.J. (1977). Dukes Physiology of Domestic Animals. 9th Edition, Cornell University Press, Ithaca, London.