Chapter 2
Minerals in drinking water and layer production

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Introduction:

Underground water supplies, often containing high concentrations of dissolved salts, are a common source of drinking water for poultry in many countries. Recent evidence suggests that some minerals in drinking water, at concentrations similar to those found in natural sources, may exert adverse effects on the performance of growing broilers and laying hens (Balnave, D. 1998).

Sodium. Excessive levels of sodium (Na) have a diuretic effect. The normal level in water is about 32 mg/l. Studies indicate that a sodium level of 50mg/l is detrimental to broiler performance if the sulphate level is also 50mg/l or higher and the chloride level is 14 mg/l or higher (Carter and Sneed 1996) (Vohra, 1980).

Chloride. Consuming too much chloride (Cl) has a detrimental effect on metabolism. A chloride level of 14mg/l is considered normal for well water. Studies have shown that a level of 14mg/l in drinking water can be detrimental to broilers if combined with 50mg/l of sodium. Chloride levels as high as 25mg/l are not a problem if the sodium level is in the normal range (Carter and Sneed 1996) (Schwartz et al. 1984).

Sulphate. High sulphate (SO_4) levels have a laxative effect and can interfere with the intestinal absorption of minerals such as copper (Blake, J.P. 2001). Levels about 125 mg/l are regarded as normal for well water, but levels as low as 50mg/l can have a negative effect on performance if either the sodium or magnesium level is 50mg/l or more (Carter and Sneed 1996).

Magnesium. A symptom of a high magnesium (Mg) level is loose droppings. The normal level of magnesium in well water is about 14mg/l. This chemical may interact with sulphate. Studies indicate that magnesium alone at 68mg/l does not adversely affect broiler performance, but a level of 50 mg/l can be detrimental if the sulphate level is also 50mg/l or greater (Carter and Sneed 1996).

The main reported effect of waters high in these four minerals is depression of appetite, usually caused by a water imbalance rather than any specific ion. The most common exception is water containing a high level of magnesium, which is known to cause scouring and diarrhoea (FOA report on Water Quality for Agriculture). According to Keshavarz (1987) the permissible levels of Mg, SO_4, Na and Cl for poultry production are Mg 10 mg/l, SO_4 50 mg/l, Na 50 mg/l, Cl 20 mg/l. If these levels are exceeded, the water is considered potentially hazardous. “Potentially hazardous” in terms of water quality risk assessment is not a clearly definable term and refers to a range of conditions from acute toxicity to sub-clinical, manifesting as reduced production.

Both Krista et al. (1961) and Conner et al. (1969) observed differences in the tolerance of individual chickens to sodium chloride in the drinking water. The latter workers noted a similar variation in tolerance to sodium sulphate, but not to calcium and magnesium chlorides. The results presented in Chapter 1 on Mg, Na, SO_4 and Cl were found present in excess of those reported to have adverse effects by Carter and Sneed (1996).

Because of the interactions between these four constituents, they were tested simultaneously in a trial aimed at establishing whether Mg at inclusions of 250 mg/l and lower, Na at inclusions of 250 mg/l and lower, SO_4 at inclusions of 250 mg/l and lower and Cl at inclusions of 500 mg/l and lower in the drinking water of layers had a detrimental effect on production.

Materials and methods

720 Amber Link point of lay hens (20 weeks old), reared and vaccinated by a reputable organization to standard practices of the poultry industry were used as experimental animals. Water was administered to each repetition (20 birds) from a nipple drinker system connected to a calibrated 15 l Perspex cylinder via 5 nipples on a 3 m long pipe. Each nipple had the capacity to supply water to 12 layers. This nipple gives adequate amounts of water, yet maintains very dry litter and is maintenance free. The cylinders had removable lids for easy access and treatment administration and an outlet at the bottom to simplify cleaning and refilling (Figure 2.1).

Figure 2.1: Water treatment system with calibrated cylinders.

Hens were kept in a mechanically ventilated broiler house on a floor system with sawdust as bedding material. The house was divided into 36 pens of 2x3 m. Each pen housed 20 hens and was fitted with five wire nest boxes with wooden lids and hay as nesting material, placed on the floor of the broiler house. The temperature was measured every day in 5 evenly distributed spots throughout the house with twin bulb minimum/maximum thermometers. The thermometers were suspended about 1.5 m above floor level at the entrance, in the middle and at the end of the house. Ventilation shafts were opened and electric fans functioned for the duration of the trial to curb ammonia poisoning. The lighting programme during lay was according to supplier specification. A commercial laying diet with a vitamin and mineral premix was fed throughout the laying period.

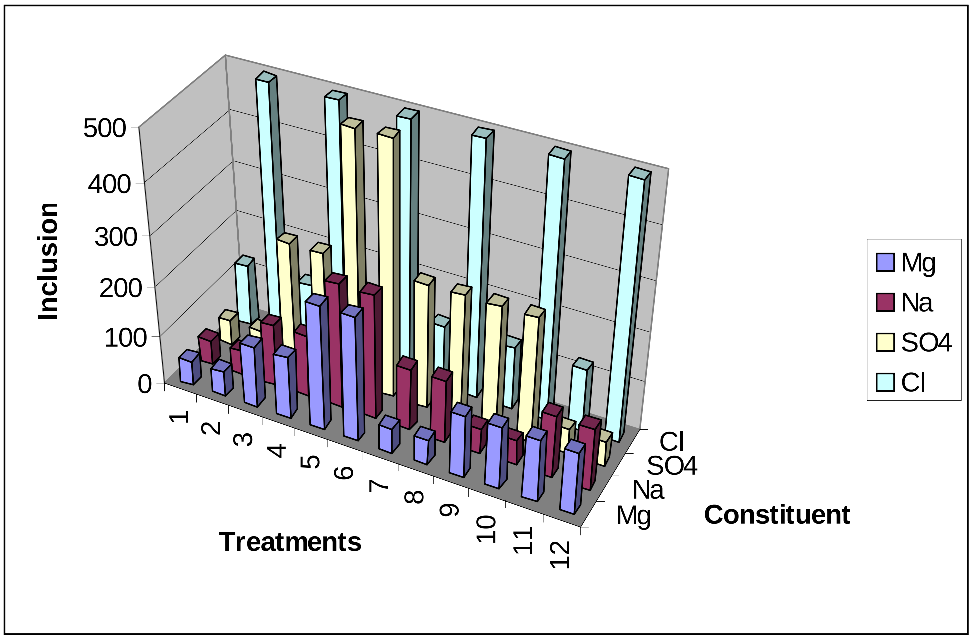
Two round pan feeders were suspended from the roof of each cage. The brim of the feeder was kept at the same height as the backs of the birds. Mg, Na, Cl and SO_4 were administered to the hens via the drinking water at the inclusion levels shown in Table 2.1. No negative control was included in the trial design. The anions and cations were added regardless of the contributions by the feed and water. These levels were selected to include the maximum acceptable level (American Water Quality

Guidelines for Poultry - Schwartz et al. 1984), a level considered average and a level more or less twice the acceptable maximum level of these four constituents. These levels were, however, still representative of the Na, Cl, SO_4 and Mg levels present in the water used by some of South Africa's poultry producers. The trial design was twelve combinations of these constituents with three repetitions and 20 birds per replicate (12 x 3 x 20). Water from the Pretoria Municipal Source was used. $MgSO_4$, $NaSO_4$, NaCl and $CaCl_2$ were used to supplement the Mg, Na, Cl and SO_4.

Table 2.1 Inclusion levels of constituents.

Constituent (mg/l)	Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6	Trt 7	Trt 8	Trt 9	Trt 10	Trt 11	Trt 12
Mg	50	50	125	125	250	250	50	50	125	125	125	125
Na	50	50	125	125	250	250	125	125	50	50	125	125
SO_4	50	50	250	250	500	500	250	250	250	250	50	50
Cl	125	500	125	500	125	500	125	500	125	500	125	500

Figure 2.2. Inclusion levels of constituents (mg/l)



Water intake, feed intake, body weight, egg production and egg weights were measured weekly over a 20 week period. A representative sample of eggs of each repetition was analyzed for eggshell thickness. The SO_4, Na, Cl and Mg contents of the eggs on a dry basis were determined. Mortalities with accompanying post mortem reports were recorded. According to Dzienkónski & Kulczycki (1975) the NaCl content of liver muscle and intestines has no diagnostic value. Therefore no analysis was done on soft tissue. Temperature was measured daily.

Statistical analysis

An analysis of variance with the GLM model (Statistical Analysis System, 1994) was used to determine the significance of differences between treatments of body weights, feed intakes, water intakes and egg production. The level of significance ($P < 0.05$) of the differences between the data observed was calculated by means of Fisher's Exact test (Samuel, 1989).

The following model was fitted to estimate covariance components for the respective ion contents of the eggs:

$Y_i = \mu + T_i + b_iB + e_i$

Y = Dependent variable, levels of Mg, SO_4, Na and Cl in the eggs:

μ = Population mean

T_i = Treatment

b_iB = Covariant, SO_4 in the case of Mg

Na in the case of SO_4

Cl in the case of Na

Ca in the case of Cl

e_i = Random effects

The following covariant components were included in the model to correct for variations in the different Mg, SO_4, Na and Cl levels in the eggs, since $MgSO_4$, $NaSO_4$, NaCl and $CaCl_2$ were used to supplement the Mg, Na, Cl and SO_4 in the feed and municipal water.

SO_4, in the case of Mg,

Na, in the case of SO_4,

Chloride, in the case of Na,

Ca, in the case of Cl.

Results and discussion

Contradicting results reported by Ross et al. (1972), which showed that a growth response was obtained from feeding SO_4 to chickens, this study shows that twelve different combinations of Mg, Na, SO_4 and Cl in the drinking water of layers over 20 weeks had no significant effect on food intake, water intake, body weight and egg production.

Balnave and Scott (1986) reported that adding a range of mineral salts to the drinking water of laying hens induced significant increases in egg shell defects. In this trial, however, egg weight and egg shell thickness were not significantly affected by adding 12 different combinations of Mg, Na, SO_4 and Cl to the drinking water of layers (Tables 2.2 – 2.11).

Mortalities were not linked to the addition of Mg, Na, SO_4 or Cl to the drinking water

The Na and Mg contents of the eggs did not differ significantly between treatments, but the Cl and SO_4 contents did show significant differences (Table 2.12), which support the work done by Machlin et al. (1953). The Cl level in treatment three (Mg - 125; Na – 125; Cl – 125 and SO_4 – 250 mg/l) was 6735.69 mg/kg and in treatment eleven (Mg - 125; Na – 125; Cl – 125 and SO_4 – 50 mg/l) it was 8234.43 mg/kg. The differences between treatments seven and ten is proportionate to the 125 mg/l and 500 mg/l Cl added to the drinking water. The SO_4 contents of the eggs of treatments three (337.77 mg/kg) differed significantly from the levels present in treatments six (118.84 mg/kg) and treatment nine (126.02 mg/kg). The differences between treatments three and six are in agreement with the amounts of SO_4 added to the water, 250 and 500 mg/l respectively, but the significance of the differences between treatments three and nine are not clear since they both received 250 mg/l SO_4 added to the water.

No significant interactions occurred between minerals administered. The treatments given to the hens in the water had no significant influence on egg production (P = 0.7449) (Table 2.2, 2.3 and 2.4). There were no interactions between the treatments given and the week of production (P = 0.1839).

Table 2.2 Mean egg production criteria of hens receiving different levels of Mg, SO_4, Na and Cl in the drinking water.

Trt	Egg production eggs/hen/week (SD±0.1027) (P = 0.7449)	Egg production % (SD±1.4666) (P = 0.7449)	Egg weight g/egg (SD±0.6798) (P = 0.2959)	Egg shell thickness (mm) (P = 0.4291)
1	5.639[a]	80.558[a]	53.856[a]	0.333[a] (SD±0.0115) SD±0.0115
2	5.681[a]	81.156[a]	52.501[a]	0.330[a] (SD±0.0100) SD±0.0100
3	5.521[a]	78.870[a]	52.758[a]	0.337[a] (SD±0.0058) SD±0.0058
4	5.655[a]	80.784[a]	52.417[a]	0.343[a] (SD±0.0153) SD±0.0153
5	5.778[a]	82.544[a]	53.418[a]	0.333[a] (SD±0.0058) SD±0.0058
6	5.784[a]	82.639[a]	52.473[a]	0.336[a] (SD±0.0058) SD±0.0058

7	5.787[a]	82.672[a]	52.970[a]	0.340[a] (SD±0.0000) SD±0.0000
8	5.655[a]	80.789[a]	53.068[a]	0.340[a] (SD±0.0100) SD±0.0100
9	5.669[a]	80.990[a]	54.564[a]	0.350[a] (SD±0.0000) SD±0.0000
10	5.761[a]	82.295[a]	54.297[a]	0.337[a] (SD±0.0153) SD±0.0153
11	5.603[a]	80.042[a]	53.503[a]	0.347[a] (SD±0.0058) SD±0.0058
12	5.604[a]	80.064[a]	52.195[a]	0.330[a] (SD±0.0200) (SD±0.0200) SD±0.0200

- Means with different superscripts, differed significantly at a $P < 0.05$ significance level.

The egg weights (Table 2.2 and 2.5) were not significantly influenced by the treatments given ($P = 0.2959$). The eggs increased in weight as the hens got older. No interactions occurred between the treatments given and the production week of the hens ($P = 0.0843$).

Table 2.3. Weekly egg production of hens (eggs/hen/week) receiving 12 different combinations of Na, Cl, Mg and SO_4.

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
21	0.033	0.000	0.050	0.050	0.100	0.017	0.000	0.000	0.100	0.133	0.033	0.017
22	0.950	1.000	0.800	1.217	1.267	1.017	0.967	0.867	1.200	1.400	0.733	1.067
23	4.383	4.400	3.150	3.667	3.683	3.683	3.600	3.650	4.333	3.967	3.200	3.817
24	6.117	5.583	6.117	5.800	6.067	6.333	6.517	6.067	6.050	6.167	6.050	6.100
25	6.533	6.500	6.767	6.667	6.550	6.733	6.717	6.467	6.433	6.417	6.467	6.500
26	6.217	6.450	6.450	6.550	6.600	6.817	6.617	6.600	6.417	6.583	6.517	6.483
27	6.550	6.683	6.300	6.650	6.533	6.750	6.704	6.267	6.467	6.117	6.233	6.418
28	6.850	6.766	7.050	6.917	7.133	7.117	6.967	7.000	6.667	7.017	7.000	6.817
29	6.183	6.333	6.367	6.400	6.433	6.467	6.433	6.383	6.417	6.483	6.350	6.300
30	6.577	6.626	6.563	6.600	6.917	6.867	6.750	6.683	6.661	6.675	6.589	6.467
31	6.736	6.311	6.363	6.217	6.783	6.784	6.683	6.517	6.531	6.473	6.404	6.633
32	6.560	6.765	6.275	6.583	6.833	6.746	6.767	6.717	6.574	6.742	6.587	6.450
33	6.357	6.241	5.971	6.383	6.500	6.394	6.417	6.433	6.216	6.574	5.961	6.317

Table 2.3. Weekly egg production of hens (eggs/hen/week) receiving 12 different combinations of Na, Cl, Mg and SO_4 (continued).

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
34	5.800	6.183	5.869	6.233	6.333	6.099	6.223	6.100	6.137	6.458	5.979	6.032
35	6.067	6.346	5.943	6.200	6.283	6.186	6.427	6.017	6.340	6.477	6.281	6.221
36	6.019	6.074	5.911	6.050	6.117	6.070	6.321	6.350	6.052	6.592	6.255	5.850
37	6.136	6.389	6.402	6.392	6.450	6.381	6.579	6.217	6.190	6.628	6.436	6.081

Table 2.4. Weekly egg production (%) of hens receiving 12 different combinations of Na, Cl, Mg and SO_4.

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
21	0.476	0.000	0.714	0.714	1.429	0.238	0.000	0.000	1.429	1.905	0.476	0.238
22	13.571	14.286	11.429	17.381	18.095	14.524	13.810	12.381	17.143	20.000	10.476	15.238
23	62.619	62.857	45.000	52.381	52.619	52.619	51.429	52.143	61.905	56.667	45.714	54.524
24	87.380	79.762	87.381	82.857	86.667	90.476	93.095	86.667	86.429	88.095	86.429	87.143
25	93.333	92.857	96.667	95.238	93.571	96.190	95.952	92.381	91.905	91.667	92.381	92.857
26	88.810	92.143	92.143	93.571	94.286	97.381	94.524	94.286	91.667	94.048	93.095	92.619

Table 2.4. Weekly egg production (%) of hens receiving 12 different combinations of Na, Cl, Mg and SO_4 (continued).

Weeks	Treatment											
	1	2	3	4	5	6	7	8	9	10	11	12
27	93.571	95.476	90.000	95.000	93.333	96.429	95.777	89.524	92.381	87.381	89.048	91.679
28	97.857	96.667	100.714	98.810	101.905	101.667	99.524	100.000	95.238	100.238	100.000	97.381
29	88.333	90.476	90.952	91.429	91.905	92.381	91.905	91.190	91.667	92.619	90.714	90.000
30	92.719	94.709	87.619	89.524	92.143	95.238	90.714	90.952	90.238	88.095	93.271	91.190
31	93.960	94.656	93.759	94.286	98.810	98.095	96.429	95.476	95.150	95.363	94.135	92.381
32	96.228	90.159	90.902	88.810	96.905	96.917	95.476	93.095	93.296	92.469	91.491	94.762
33	93.709	96.640	89.637	94.048	97.619	96.378	96.667	95.952	93.910	96.316	94.098	92.143
34	90.815	89.153	85.301	91.190	92.857	91.341	91.667	91.905	88.797	93.910	85.163	90.238
35	82.857	88.333	83.847	89.048	90.476	87.130	88.897	87.143	87.669	92.256	85.414	86.178
36	86.667	90.661	84.900	88.571	89.762	88.371	91.817	85.952	90.576	92.531	89.724	88.872
37	85.990	86.772	84.436	86.429	87.381	86.717	90.301	90.714	86.453	94.173	89.361	83.571
38	87.657	91.270	91.462	91.328	92.143	91.153	93.985	88.810	88.434	94.6887	91.942	86.867

Table 2.5. Weekly egg weight (g) of eggs of hens receiving 12 different combinations of Na, Cl, Mg and SO_4.

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
21	17.167	0.000	13.067	13.800	13.128	10.433	0.000	0.000	27.822	40.706	12.100	11.967
22	42.672	40.778	42.127	41.115	40.060	42.132	41.820	43.129	42.696	42.070	42.770	40.751
23	45.534	44.717	44.890	43.753	44.866	44.701	45.945	45.280	45.964	44.570	50.844	44.648
24	54.906	53.402	49.837	49.749	51.143	50.821	51.763	51.227	51.039	50.574	50.530	49.787
25	53.614	52.352	51.669	51.717	52.147	52.179	53.592	52.911	53.080	52.100	52.750	51.434
26	53.707	53.820	53.079	53.079	53.634	53.090	54.501	54.568	54.004	52.887	53.880	52.423
27	54.496	54.841	53.868	53.535	54.509	53.897	55.441	55.517	55.136	5.649	54.324	53.531
28	55.446	55.176	54.771	54.587	55.836	54.967	55.852	56.041	56.222	54.931	55.287	54.246
29	57.190	56.177	55.376	55.353	56.652	55.916	56.988	56.907	56.766	55.666	56.212	55.180
30	56.694	56.178	55.752	55.363	56.505	55.712	56.995	56.461	56.417	55.774	56.167	55.016
31	57.720	55.400	57.527	56.035	57.774	56.182	57.195	57.635	57.999	56.786	57.537	56.107
32	58.919	58.458	56.325	55.624	59.149	57.093	57.628	58.954	58.883	57.499	58.203	56.900
33	59.013	58.979	59.089	59.723	59.594	58.458	59.564	59.549	59.906	58.727	59.269	57.721

Table 2.5. **Weekly egg weight (g) of eggs of hens receiving 12 different combinations of Na, Cl, Mg and SO_4 (continued).**

Weeks	Treatment											
	1	2	3	4	5	6	7	8	9	10	11	12
34	59.922	59.535	59.471	58.771	60.269	58.638	59.886	60.259	59.987	59.301	59.381	59.140
35	59.949	59.937	59.507	59.307	60.595	59.004	60.642	60.299	60.416	59.648	61.447	58.978
36	58.674	60.136	59.937	59.508	60.417	59.217	60.396	60.424	60.824	59.700	59.846	59.348
37	59.700	59.876	59.175	59.188	60.343	58.715	60.328	60.551	60.604	59.762	59.440	58.755
38	59.356	59.396	59.066	58.284	59.526	58.257	59.538	59.684	60.049	59.061	57.984	58.199
39	58.591	58.386	57.868	57.412	58.800	57.607	58.354	58.906	59.031	58.420	58.588	57.574

Food intake over the whole experimental period was not significantly influenced by the addition of Mg, SO_4, Na and Cl to the drinking water (Table 2.6).

Table 2.6. LS Means for food intake (kg) of hens receiving different levels of Mg, SO_4, Na and Cl in the drinking water.

Treatment	Food intake (kg)/hen/day (SD±0.0073) (P = 0.9809)
1	0.149[a]
2	0.154[a]
3	0.145[a]
4	0.151[a]
5	0.144[a]
6	0.141[a]
7	0.146[a]
8	0.145[a]
9	0.142[a]
10	0.144[a]
11	0.149[a]
12	0.145[a]

- Means with different superscripts, differed significantly at a $P < 0.05$ significance level.

The weekly food intake (Table 2.7) was not significantly influenced ($P = 0.9809$) by the addition of Mg, SO_4, Na and Cl to the drinking water. As the hens aged, food intake and egg production increased over the weeks. There was no significant interaction between the treatments given to the hens and the week in which the treatment was given ($P = 0.3783$).

Table 2.7. Weekly food intake (kg) of hens receiving 12 different combinations of Na, Cl, Mg and SO_4.

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
21	0.099	0.106	0.094	0.110	0.097	0.088	0.093	0.090	0.104	0.090	0.082	0.093
22	0.140	0.145	0.136	0.137	0.135	0.128	0.134	0.138	0.135	0.130	0.131	0.128
23	0.149	0.152	0.140	0.141	0.144	0.123	0.137	0.129	0.134	0.128	0.137	0.134
24	0.150	0.146	0.139	0.135	0.138	0.128	0.139	0.135	0.135	0.128	0.137	0.130
25	0.150	0.142	0.142	0.136	0.138	0.130	0.142	0.135	0.134	0.133	0.146	0.134
26	0.144	0.146	0.142	0.136	0.133	0.134	0.140	0.138	0.135	0.135	0.149	0.128
27	0.136	0.134	0.135	0.131	0.127	0.127	0.137	0.131	0.126	0.125	0.154	0.129
28	0.144	0.143	0.133	0.134	0.131	0.132	0.133	0.132	0.132	0.130	0.141	0.134
29	0.142	0.140	0.135	0.121	0.129	0.134	0.134	0.131	0.129	0.130	0.144	0.130

Table 2.7. **Weekly food intake (kg) of hens receiving 12 different combinations of Na, Cl, Mg and SO_4 (continued).**

Weeks	Treatment											
	1	2	3	4	5	6	7	8	9	10	11	12
30	0.141	0.146	0.139	0.175	0.135	0.133	0.135	0.138	0.130	0.136	0.150	0.140
31	0.156	0.160	0.158	0.160	0.161	0.153	0.152	0.159	0.152	0.158	0.157	0.162
32	0.163	0.173	0.164	0.165	0.158	0.156	0.158	0.166	0.151	0.158	0.158	0.158
33	0.167	0.174	0.162	0.167	0.163	0.167	0.162	0.165	0.160	0.175	0.169	0.168
34	0.164	0.177	0.157	0.167	0.158	0.159	0.163	0.154	0.156	0.168	0.151	0.164
35	0.164	0.181	0.157	0.172	0.159	0.161	0.165	0.163	0.164	0.170	0.167	0.172
36	0.172	0.187	0.180	0.181	0.174	0.172	0.180	0.180	0.177	0.185	0.175	0.175
37	0.155	0.167	0.150	0.169	0.146	0.152	0.154	0.157	0.148	0.155	0.160	0.165
38	0.157	0.168	0.149	0.176	0.161	0.149	0.160	0.166	0.153	0.156	0.157	0.159
39	0.153	0.160	0.154	0.174	0.156	0.156	0.157	0.165	0.157	0.156	0.160	0.158

The addition of Mg, SO_4, Na and Cl, to the drinking water showed no significant effect on body weights of the hens over the trial period (Table, 2.8).

Table 2.8. LS Means for body weight (kg/hen) of hens receiving different levels of Mg, SO_4, Na and Cl in the drinking water.

Treatment	Body weight (kg/hen) (SD±0.02090) ($P = 0.4542$)
1	1.846
2	1.859
3	1.833
4	1.839
5	1.849
6	1.808
7	1.818
8	1.820
9	1.859
10	1.858
11	1.806
12	1.805

The weekly body weights (Table 2.9) were not significantly influenced ($P = 0.4542$) by the addition of Mg, SO_4, Na and Cl to the drinking water. Body weight increased over weeks as the hens aged. There was no significant interaction between the treatments given to the hens and the week in which the treatment was given ($P = 0.2116$).

Table 2.9. Weekly body weight (kg/hen) of hens receiving 12 different combinations of Na, Cl, Mg and SO_4 (SD±0.024)

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
20	1.498	1.521	1.484	1.524	1.520	1.497	1.516	1.508	1.545	1.516	1.447	1.493
21	1.618	1.639	1.589	1.642	1.648	1.596	1.606	1.599	1.651	1.630	1.545	1.579
22	1.754	1.744	1.700	1.728	1.748	1.699	1.715	1.727	1.761	1.733	1.677	1.697
23	1.769	1.753	1.768	1.767	1.808	1.740	1.769	1.762	1.797	1.772	1.734	1.696
24	1.805	1.784	1.784	1.799	1.819	1.761	1.786	1.742	1.795	1.801	1.753	1.755
25	1.823	1.812	1.791	1.821	1.845	1.778	1.812	1.810	1.837	1.843	1.779	1.786
26	1.829	1.847	1.829	1.835	1.868	1.798	1.818	1.824	1.851	1.818	1.794	1.787
27	1.834	1.848	1.829	1.835	1.845	1.780	1.845	1.810	1.848	1.818	1.775	1.813
28	1.858	1.881	1.849	1.861	1.876	1.827	1.814	1.854	1.903	1.862	1.828	1.791
29	1.858	1.880	1.842	1.855	1.873	1.826	1.845	1.843	1.871	1.839	1.835	1.807
30	1.911	1.964	1.877	1.896	1.906	1.887	1.900	1.910	1.914	1.866	1.910	1.868
31	1.938	1.901	1.849	1.870	1.892	1.835	1.859	1.860	1.918	1.899	1.851	1.854
32	1.923	1.945	1.939	1.918	1.941	1.884	1.906	1.905	1.949	1.982	1.890	1.891
33	1.865	1.884	1.906	1.900	1.939	1.925	1.812	1.735	1.839	1.843	1.842	1.783
34	1.928	1.964	1.938	1.926	1.915	1.927	1.923	1.942	1.951	1.974	1.945	1.911

Table 2.9. Weekly body weight (kg/hen) of hens receiving 12 different combinations of Na, Cl, Mg and SO_4 (SD±0.024) (continued).

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
36	1.919	1.947	1.910	1.869	1.908	1.748	1.912	1.905	1.925	1.941	1.859	1.927
37	1.928	1.974	1.908	1.918	1.846	1.903	1.852	1.887	1.961	1.981	1.901	1.876
38	1.909	1.892	1.893	1.878	1.891	1.877	1.855	1.891	1.943	1.977	1.874	1.890
39	1.931	1.950	1.938	1.930	1.908	1.885	1.868	1.892	1.927	1.978	1896	1.893
40	1.928	1.948	1.950	1.952	1.894	1.892	1.850	1.889	1.918	1.975	1.895	1.909

Table 2.10. LS Means for water intake (l) of hens receiving different levels of Na, Mg, Cl and SO_4 in the drinking water.

Treatment	Water intake (l)/hen/day (SD±0.0046) (P = 0.5557)
1	0.224[a]
2	0.230[a]
3	0.220[a]
4	0.224[a]
5	0.230[a]
6	0.225[a]
7	0.229[a]
8	0.224[a]
9	0.225[a]
10	0.216[a]
11	0.230[a]
12	0.221[a]

The weekly water intake (Table 2.11) was significantly influenced (P = 0.0001) by the addition of Cl, SO_4, Na and Mg to the water.

Water intake increased over weeks as the hens aged and egg production increased. This is due to a marked increase in water intake during the period when an egg is formed. The overall increase in fluid intake is associated with a fall in plasma osmolarity of up to 14% and an increase in urine minute volume. This can be explained as a simple osmotic adjustment (Howard, 1975).

Plasma osmolarity changes follow alterations in ingestive activity with a phase lag of less than 0.5 h, indicating rapid assimilation of ingested water, but changes in renal output are much slower (1.5 h later). They are quantitatively insufficient to account for the increased fluid intake occurring at that time (Howard, 1975). There was a significant interaction between the treatments given to the hens and the week in which the treatment was given (P = 0.0098). This effect was however not sustained when looking at the whole trial period. No significant differences in water intake occurred between treatments over the experimental period (Table 2.10).

Table 2.11. Weekly water intake of hens receiving 12 different combinations of Na, Cl, Mg and SO_4.

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
21	0.146	0.149	0.141	0.147	0.153	0.137	0.140	0.140	0.155	0.146	0.142	0.134
22	0.196	0.193	0.189	0.188	0.184	0.283	0.186	0.196	0.191	0.195	0.204	0.179
23	0.220	0.212	0.214	0.209	0.217	0.202	0.217	0.219	0.213	0.217	0.225	0.199
24	0.216	0.210	0.215	0.223	0.210	0.213	0.217	0.220	0.217	0.204	0.227	0.194
25	0.218	0.221	0.223	0.230	0.227	0.223	0.228	0.226	0.219	0.217	0.235	0.216
26	0.226	0.240	0.232	0.232	0.237	0.238	0.235	0.233	0.233	0.220	0.236	0.215
27	0.230	0.243	0.227	0.237	0.239	0.237	0.248	0.242	0.234	0.225	0.242	0.237
28	0.238	0.247	0.233	0.244	0.242	0.248	0.242	0.240	0.233	0.225	0.238	0.227
29	0.215	0.219	0.206	0.215	0.217	0.218	0.214	0.215	0.207	0.208	0.219	0.217
30	0.242	0.243	0.229	0.235	0.245	0.243	0.243	0.239	0.236	0.226	0.241	0.245
31	0.279	0.279	0.248	0.260	0.278	0.277	0.277	0.262	0.281	0.244	0.261	0.262
32	0.248	0.248	0.248	0.249	0.265	0.261	0.255	0.249	0.238	0.239	0.254	0.248
33	0.226	0.225	0.217	0.216	0.235	0.227	0.224	0.220	0.222	0.206	0.229	0.231

Table 2.11. Weekly water intake of hens receiving 12 different combinations of Na, Cl, Mg and SO_4 (continued)

Weeks	Treatment											
	1	2	3	4	5	6	7	8	9	10	11	12
35	0.229	0.245	0.231	0.235	0.246	0.239	0.240	0.231	0.238	0.229	0.234	0.238
36	0.218	0.227	0.212	0.221	0.228	0.211	0.224	0.213	0.222	0.214	0.242	0.230
37	0.236	0.249	0.234	0.235	0.250	0.236	0.252	0.228	0.247	0.226	0.254	0.240
38	0.215	0.229	0.208	0.220	0.223	0.220	0.226	0.215	0.226	0.209	0.224	0.217
39	0.242	0.245	0.236	0.246	0.252	0.240	0.254	0.237	0.248	0.232	0.246	0.248
40	0.224	0.234	0.231	0.230	0.226	0.230	0.231	0.226	0.226	0.229	0.228	0.230

Levels of Cl, Na, SO_4 and Mg ions (mg/kg) present in the eggs (Table 2.12).

SO_4, Na, Cl and calcium were included in the model as covariance components to correct for variations in the different Mg, SO_4, Na and Cl levels in the eggs, since $MgSO_4$, $NaSO_4$, NaCl and $CaCl_2$ were used to supplement the Mg, Na, Cl and SO_4.

Chloride contents of the eggs:

Chloride with calcium as a covariant had a P-value of 0.1906 and Cl with Na as a covariant had a P-value of 0.3738. Neither of the interactions between the covariants and treatments were significant.

The Cl contents of the eggs differed significantly (P = 0.0032). The Cl level in treatment three (Cl of 125 and SO_4 of 250 mg/l) was 6735.69 mg/kg and 8234.43 mg/kg for treatment 11 (Cl of 125 and SO_4 of 50 mg/l). The significance of this is not clear since both treatments received 125 mg/l Cl in the drinking water, but it highlights the significance of the interactions between these four elements, since only the SO_4 levels differed between treatments. The differences between treatments seven and ten are however proportionate to the 125 mg/l and 500 mg/l Cl added to the drinking water.

Sulphate contents of the eggs:

The SO_4 contents of the eggs of treatments three (337.77 mg/kg) differed significantly (P = 0062) from the levels present in treatments six (118.84 mg/kg) and nine (126.02 mg/kg). The differences between treatments three and six are in agreement with the amounts of SO4 added to the water (250 and 500 mg/l respectively), but the significance of the differences between treatments three and nine are not clear since they both received 250 mg/l SO_4 added to the water.

Sulphate with Na as covariant had a P-value of 0.6083 and SO_4 with Mg covariant had a P-value of 0.6122. Neither of the interactions between the covariants and treatments was significant.

Na contents of the eggs:

No significant differences occurred between treatments given and the Na levels found in the eggs (P = 0.2920).

Na with SO_4 as covariant had a P - value of 0.9980 and Na with Cl as covariant had a P - value of 0.8409. The interaction between Cl and treatment was significant (P = 0.0001) which implies that in some treatments, the Cl levels had a different influence on the Na levels in other treatments.

Mg contents of the eggs:

No significant differences occurred between treatments given and the Mg levels found in the eggs (P = 0.2409).

Magnesium with SO_4 as covariant had a P - value of 0.3221. No significant interactions occurred between the covariant and treatments given.

<u>Ca contents of the eggs:</u>
No significant differences occurred between treatments given and the calcium levels found in the eggs (P = 0.3585).

Ca with Cl as covariant had a P - value of 0.9863. No significant interactions occurred between the covariant and treatments given.

Table 2.12. Levels of Cl, Na, SO_4 and Mg ions present in the eggs (mg/kg)

Treatment	Chloride (SD ± 273.76)	Sulphates (SD ± 39.47)	Sodium - SD	Magnesium (SD ± 162.03)	Calcium (SD ± 235.88)
1	6973.03[a]	292.55[a]	5699.93[a] (SD ± 197.76)	1623.05a	2998.09[a]
2	7525.76[a]	227.21[a]	6087.09[a] (SD ±143.71)	1786.90a	2467.04[a]
3	6735.69[ab]	337.77[ab]	5944.22[a] (SD ±175.00)	1359.91[a]	2468.57[a]
4	6877.76[a]	174.40[a]	6022.40[a] (SD ± 366.52)	1440.45[a]	2533.26[a]
5	7108.77[a]	194.17[a]	6240.55[a] (SD ± 154.05)	1395.84[a]	2564.05[a]
6	7066.79[ac]	118.84[c]	5568.65[a] (SD ± 636.88)	1197.97[a]	2489.72[a]
7	6409.41[bc]	138.99[a]	5620.40[a] (SD ± 792.30)	1293.93[a]	2445.63[a]
8	6907.07[a]	139.12[a]	5931.51[a] (SD ± 140.28)	1270.32[a]	2731.94[a]
9	7494.88[a]	126.02[cd]	5580.26[a] (SD ± 157.11)	1272.69[a]	2796.67[a]
10	8044.47[d]	169.08[a]	5159.12[a] (SD ± 204.08)	1592.91[a]	3207.99[a]
11	8234.43[c]	285.64[a]	4730.77[a] (SD ± 1129.46)	1209.03[a]	2358.63[a]
12	7370.41[a]	233.23[a]	5536.02[a] (SD ± 168.63)	1195.96[a]	2516.78[a]

A large number of chemicals occur naturally in ground water. They are usually present in amounts that do not interfere with the metabolism or digestive functions of chickens or turkeys. When the levels of certain chemicals are out of balance, however, they can - by themselves or in combination with other chemicals - affect poultry performance. Excessive levels of Na have a diuretic effect. The normal Na level in water is about 32 mg/l. Carter and Sneed (1996) indicated that a Na level of 50 mg/l is detrimental to broiler performance if the SO_4 level is also 50 mg/l or higher and the Cl level is 14 mg/l or higher.

Consuming too much Cl has a detrimental effect on metabolism. A Cl level of 14 mg/l is considered normal for well water. Carter and Sneed, (1996) have shown that a level of 14 mg/l in drinking water can be detrimental to broilers if combined with 50 mg/l of Na. Cl levels as high as 25 mg/l are not a problem if the Na level is in the normal range.

Because of the conflicting reports on recommended maximum tolerable levels of SO_4 in the drinking water for poultry, it is important to consider dietary sulphur contributions when evaluating the potential problems associated with high SO_4 concentrations in the water for poultry. Clinical signs of decreased production or increased faecal moisture may be an indication that SO_4 or sulphur concentrations in the feed and water need to be evaluated. Because of limited studies involving the role of S-compounds in the nutrition of simple-stomached mammals, the biologic importance or possible detrimental effect of inorganic SO_4 is poorly understood (Veenhuizen et al. 1992). High $S0_4$ levels have a laxative effect. Levels of about 125 mg/l are regarded as normal for well water, but levels as low as 50 mg/l can have a negative effect on performance if either the Na or Mg level is 50 mg/l or more (Carter and Sneed, 1996).

$MgSO_4$ was more toxic for chickens than was Na_2SO_4 when given in water at a concentration of 4000 mg/l. Lethal concentrations of Na and $MgSO_4$ were said to be between 16000 and 20000 mg/l of 23000 mg/l of total salt. It is therefore important to evaluate the source of SO_4 as well as the amount of total salts in the water in order to measure the potential impact on performance, because Mg may be more detrimental than Na when combined with SO_4 in water (Adams *et al*., 1975).

Waterborne Mg can make an important contribution to the total daily intake of Mg. Waterborne Mg is in the form of hydrated ions and has a higher bioavailability than Mg in food. The contribution of water Mg to animals that drink water with high Mg levels could be crucial in the prevention of Mg deficiency (Durlach et al. 1989). A symptom of a high Mg level is loose droppings. The normal level of Mg in well water is about 14 mg/l. This chemical may interact with SO_4. Carter and Sneed (1996) indicated that Mg alone at 68 mg/l does not adversely affect broiler performance, but a level of 50 mg/l can be detrimental if the SO_4 level is also 50 mg/l or greater.

Pang et al. (1977) found that tolerance to saline drinking water markedly increased with age. This susceptibility is because of a relative renal insufficiency in regulation of salt and water excretion at a young age.

Conclusion

Previously, so-called saline ground water sources in southern Africa with naturally high levels of Na Cl, Na_2SO_4 and Mg SO_4 were considered unsuitable for livestock and poultry consumption. This study shows that 12 different combinations of Mg, Na, Cl and SO_4 had no significant effect on growth, food and water intake, egg production or egg quality.

Poultry producers in areas with naturally high levels of these minerals in their ground water can therefore continue to function successfully if the concentrations present are up to 250 mg/l of Mg, 500 mg/l of Cl, 500 mg/l of SO_4 and 250 mg/l of Na.

At these levels the minerals manifested themselves in the egg contents and the effect thereof on the consumer needs to be investigated further. Machlin et al. (1953) presented data showing that the hen could incorporate inorganic SO_4 into the egg.

Since artificially enriched eggs are in the order of the day in this century, the possibility of creating a niche market for “mineral enriched eggs” is a possibility.