WATER AND ELECTROLYTES (& IODINE)

WATER

1. **Introduction**

   A. Water is the most abundant nutrient (≈ 273 liters/cm^2 of the earth's surface):

      1) Sea water . . . . 268.45 liters
      2) Continental ice . . . . 4.50 liters
      3) Fresh water . . . . 0.10 liter
      4) Water vapor . . . . 0.003 liter

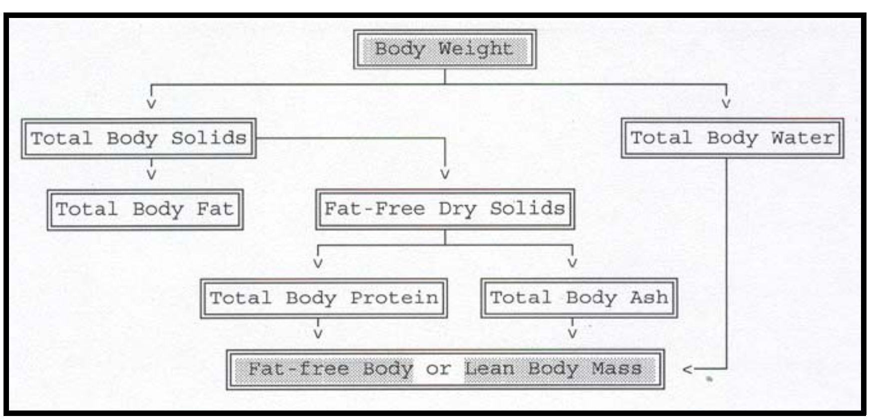
   B. Water - 1) Required by animals in the largest amount, thus, 2) probably the most important nutrient, even though not enough attention is given!

2. **Body Water Content** (e.g., swine)

Stage/day	%
Embryo	95
At birth	≈75-80
7 d	*77*
15 d	*75*
30 d	*73*
60 d	*67*
90 d	*62*
120 d	*60*
Market weight	≈ 50

3. **Body Water and Body Composition**

   A. The two-compartment model:



B. On the fat-free basis:

1) The proportion of body water, protein & ash stays relatively constant:

a) Moulton (1923; J. Biol. Chem. 57:79) postulated the concept of "chemical maturity," which he defined as "*the age at which concentrations of water, protein and mineral matters in the fat-free body mass become practically constant.*"

b) The age at which animals presumably reached chemically maturity (days):

(1) Rat, 50; guinea pig, 50; cat, 100; dog, 200; swine, 150-300; cattle, 50-300; man, 500-1,000. (Reid et al., 1955. J. Dairy Sci. 38:1344).

(2) Although various mammals become chemically mature at different ages, the proportion of the total life span expended prior to attaining it seems to be similar (3.9 to 4.6%; Moulton, 1923. J. Biol. Chem. 57:79).

2) Thus, the body composition can be determined if one of the three components can be estimated accurately.

☞ This is the basis for the "water concept" or "water dilution technique" to estimate the body composition!

C. If the body water content is known, then:

1) $\% \text{ fat} = 100 - \dfrac{\% \text{ water}}{0.732}$ or

$$\text{Total body fat} = \text{total body wt} - \frac{\text{total body water}}{0.732}$$

2) The remainder of body composition can be determined based on an another assumption that body protein & ash in fat-free, dry matters are practically constant.

Water Content (Fat-Free Basis)

Species	%
Mice	73.7
Rat	72.8
Chicken	74.2
Rabbit	72.6
Dog	75.2
Monkey	73.3
Sheep	73.3
Pig	73.5
Deer	75.0
Cattle	73.3
Man	72.2

4. **Starvation & Water Deprivation**

A. Starvation - Starving animals may lose nearly all of body fat, ½ of body protein & 40% of body weight, but they can still live!

B. Loss of body water:

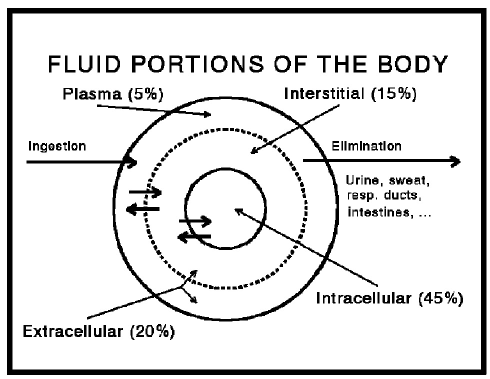
1) Water deficiency generally impairs growth/development of young animals & reduces feed intake of all animals, thus ↓ productivity.
2) With a loss of 4-5%, animals become restless and lose appetite.
3) With a loss of 6-8%, disfunction of the central nervous system & metabolic disorders may be observed (due to ↑ viscosity of blood).
4) With a loss of 15-20%, death may occur!

☞ The animal can live up to 100 days without food (. . . perhaps, stretching a bit!), but only 5-6 days without water!

5. **Functions of Water**

A. Is involved in the body temperature regulation.
B. Is an universal solvent - e.g., nutrients must be solubilized for "absorption."
C. Has an ionizing power - important in all biochemical reactions.
D. Is involved in transporting nutrients & waste products.
E. Lubricates the body.
F. Provides a cushion to fetuses, nervous system, etc.
G. Is required for milk production in lactating animals.

6. **Absorption & Excretion**



A. Fluid fractions of the body (% of body wt) - Adapted & redrawn from Georgievskii et al., 1982. Mineral Nutrition of Animals.

◦ e.g., A Holstein cow consuming hey & lactating:

a) Intake - ≈ 53 L of drinking water/water in feed, and ≈ 3 L of metabolic water/day.
b) Elimination - ≈ 19 L of water in feces, 11 L in urine & 12 L in milk, and vaporize ≈ 14 L of water each day.

B. Water movement:

1) The gradient permeability of membranes to water (& also to electrolytes) declines almost linearly from the duodenum to ileum.
2) The movement of water molecules through cell membranes:

a) Is related to transfer of mineral elements, nutrients & waste products.
b) 1° function is to achieve "osmotic & hydrostatic equilibrium."

C. Loss of body water:

1) Through "respiration."
2) Through "evaporation" from the skin (but, very little loss via "sweat" in swine, dog & sheep).

   Examples:

   (1) A 75-kg pig given a water:feed ratio of 2.75:1 can lose ≈ 1 kg of water vapor/day (or .53 g/kg BW/h).
   (2) A 182-kg lactating sow can lose ≈ 2.32 kg/day.

3) In the feces and urine - "Nitrogenous end products" influence the degree of water loss in the feces & urine among various species:

   a) Mammals - Excrete N mostly as "urea" (which is toxic to tissues), ∴ water is required to dilute urea (which is soluble in water).
   b) Birds - Excrete mostly as "uric acid:"

      (1) Excreted in a nearly solid form, ∴ minimal loss of water.
      (2) Also, catabolism of protein to uric acid produces/provides more metabolic water than its catabolism to urea.
      (3) ∴ in general, birds: (a) have a lower water requirement, and (b) are less sensitive to a temporary water deprivation.

4) In the desert:

   a) Small desert rodents:

      (1) Lapse into a dormant state in "deep burrows," ∴ ↓ metabolic rate.
      (2) Keep the body temperature below a critical point by heat conduction, ∴ less evaporation.

   b) Camel: (Schmidt-Nielson, 1962. MO Agric. Exp. Sta. Special Rep. 21:1)

      (1) Can ↓ body water loss - Lose only ≈ 1% of body weight/d vs 4.5% for a donkey & 7%/d for a man.
      (2) Can vary body temperatures as much as 6°C (34.2 to 40.7) between the night & daytime.

7. **Source of Water**

A. Ingested water - Drinking water & water in feedstuffs.

B. Metabolic water - Originates from metabolism of CH_2O, protein and fat:

1) Glucose yields ≈ 55.5% of its weight.
2) Protein yields ≈ 41.5% of its weight.
3) Fat yields > 100% of its weight.

☞ "Poultry:" Conversion of feed into 1 Kcal yields 0.135 g water - e.g,, consumption of 300 Kcal/d yields ≈ 40 g water, which can be used to meet ≈ 15% of water requirement.

C. Hibernating animals:

1) Metabolic water is extremely important!
2) Metabolize reserves of CH_2O & fat as a source of energy for their vital processes.
3) Metabolic water generated may be enough to offset water lost via respiration & evaporation.

8. **Requirements**

☞ Vary according to species, physiological and environmental conditions!

A. Affected by: 1) Ambient temperatures, 2) Stage of growth and(or) body size, 3) Physiological state - e.g., dry or lactating, 4) Diarrhea, 5) Dietary salt & also protein, 6) Feed intake level, 7) Type of diets, 8) Stress, etc.

B. Water requirements: (Maynard et al., 1979)

Animal	Litters
Beef cow, lactating	60
Dairy cow	
Lactating	90
Maintenance	60
Horses	
Medium work	40
Lactating	50
Poultry, hen	0.5
Swine	
30 kg	6
60-100 kg	8
Lactating sow	14
Sheep	
Lactating ewe	6
Lamb	4

C. Swine & poultry:

1) Should be provided on *ad libitum* basis, and generally consume twice as much water as dry feed:

a) 2:1 ratio might be a minimum, and wider ratios are needed for young and lactating swine.
b) The ratio may increase to ≈ 5:1 during the summer or when environmental temperatures are high.

2) Broilers ↑ water consumption ≈ 7%/each 1°C ↑ the temperature above 21°C.
3) Swine - Daily feed intake is the best indicator of ad libitum water intake for ad libitum-fed pigs, and the relationship can be described by the following equations: (Brooks et al., 1984. Vet. Rec. 115:513)

a) Water (L/d) = 0.149 + (3.053 x kg dry feed) or
b) Water (L/d) = 0.788 + (2.23 x kg dry feed) + (0.367 x kg body wt$^{0.6}$)

9. **Nutrients & Toxic Elements in Water**

☞ Because of its property as an universal solvent, water may carry many essential elements, but at the same time it may contain toxic materials!

A. Composition of surface water[a]: (Maynard et al., 1979)

Substance	Mean	Maximum	Minimum
Phosphorus, mg/L	0.087	5.0	0.001
Calcium, mg/L	57.1	**173.0**	11.0
Magnesium, mg/L	14.3	**137.0**	8.5
Sodium, mg/L	55.1	**7,500.0**	0.2
Potassium, mg/L	4.3	370.0	0.06
Chloride, mg/L	478.0	19,000.0	0.0
Sulfate, mg/L	135.9	**3,383.0**	0.0
Copper, µg/L	13.8	280.0	0.8
Iron, µg/L	43.9	4,600.0	0.1
Manganese, µg/L	29.4	3,230.0	0.2
Zinc, µg/L	51.8	1,183.0	1.0
Selenium, µg/L	0.016	1.0	0.01
Iodine, µg/L	46.1	336.0	4.0
Cobalt, µg/L	1.0	5.0	0.0

[a]Based on more than 80,000 samples collected at 14,000 different locations over 12-yr period; "Sea water" (mg/l): Ca, 410; Mg, 1,303; Na, 10,813; sulfate, 2,713.

B. Water "hardness:"

1) Refers to a sum of Ca & Mg expressed in equivalent amounts of Ca carbonate.
2) Classification: Very soft, < 15, Soft, < 60, Hard, > 120, and Very hard, > 180 mg/liter.

C. Total dissolved solids (TDS) or "salinity:"

1) As a "drinking water, a total amount of mineral salts in water seems to be more important than the type of salts.

2) Safe levels for livestock & poultry: (Adapted from Cunha, 1977)

mg/L or ppm	Comments
< 1,000	Safe for any species.
1,000-2,999	Generally safe for all species, but may cause temporary diarrhea.
3,000-4,999	Generally safe for livestock, but can cause temporary diarrhea or refusal. Poor for poultry - watery feces & may ↓ growth & ↑ mortality.
5,000-6,999	Reasonably safe for livestock, but avoid its use in pregnant or lactating animals. Not acceptable for poultry - almost always cause some problems.
7,000-10,000	Unfit for poultry and swine. Risky for pregnant, lactating, young or stressed cattle, sheep & horses. Some may tolerate, but better to avoid!
> 10,000	Unfit for all species.

3) Effects of TDS on pig performance:

a) TDS & digestibility coefficients (%; 30 to 55-kg pigs): (Adapted from Anderson, et al., 1994. Can. J. Anim. Sci. 74:141)

Water TDS, ppm	DM	GE	CP
Exp. 1 (H_2O with Na salts):			
0	83.7	81.6	82.0
370	83.6	81.3	81.3
1000	84.0	81.8	82.7
4000	82.4	80.0	80.6
6350	83.3	81.5	81.5
8000	81.9	79.4	80.2
Exp. 2 (H_2O with sulphates):			
0	79.8[a]	78.0	78.3[a]
450	80.1[a]	78.3	79.2[a]
1100	79.2[a]	77.4	78.3[a]
4000	78.4[a]	76.6	77.3[ab]
7000	78.1[a]	76.6	77.3[ab]
11700	75.3[b]	74.1	72.2[b]

[a,b]Means within a column with different superscripts differ (*P* < .05).

b) TDS & growth performance of 4-wk old weanling pigs* (Adapted from McLeese et al., 1992. Anim. Prod. 54:135):

Water TDS, ppm:	213	2350	4390
First Exp. (20-d study):			
Water, g/d (1st 5 d)	1144		1312
Feed, g/d	565		513
Weight gain, g/d	416		354
Gain:feed, g/kg	739[a]		685[b]
Second Exp. (5-d study):			
Water, g/d (1st 5 d)	2188[a]	1454[b]	1830[ab]
Feed, g/d	190	117	170
Weight gain, g/d	104	16	48

*Unmedicated & medicated diets were used in the first & second experiments, respectively;[a,b]Means within a row with different superscripts differ (*P* < .05).

D. Nitrate & nitrite:

1) Nitrate (NO_3^-):

a) In general, pigs are not adversely affected by nitrate because there is no bacterial flora to convert nitrate to nitrite.

(1) In one study, no death was observed with 9,000 ppm nitrate, even though performance was decreased!
(2) Other research demonstrated that 330 ppm was completely safe.

b) But, bacteria in water may convert nitrate to nitrite in some situations.

2) Nitrite (NO_2^-) - Rduced form of nitrate:

a) Can combine with Hb to form Met-Hb, ∴ reducing the oxygen carrying capacity.
b) Nitrite in water may indicate "bacterial contamination."

3) Recommended limits for livestock: (mg/L)

	Nitrate	Nitrite
NAS, 1974	440	33
CAST, 1974	1320	33

ELECTROLYTES IN GENERAL

1. **Body Fluids**

A. Electrolyte composition of body fluids (swine): [Crenshaw, 1991. In: Miller, Ullrey & Lewis (Ed.) Swine Nutrition]

Item	ECF	ISF	ICF
Cations, mEq/L:			
Sodium	142	145	10
Potassium	4	4	159
Magnesium	2	2	40
Calcium	5	3	1
Total	*153*	*154*	*210*
Anions:			
Chloride	103	117	3
Bicarbonate	28	31	10
Phosphates	4	4	75
Sulfate	1	1	2
Protein	17	-	45
Others	-	1	75
Total	*153*	*154*	*210*

1) Sodium - The major cation in the extracellular fluids.
2) Chlorine - The major anion in body fluids.
3) Potassium - Serves as the major intracellular cation.

☞ All three are extremely important for the "electrolyte balance!"

2. **Electrolytes**

A. A general definition - "*Substances that dissociate into ions when in solution & capable of conducting electricity.*"

B. Functions:

1) Osmotic pressure regulation & maintenance of water balance.
2) Nerve impulse conduction.
3) Muscle contraction.
4) Acid-base balance.
5) Enzymatic reactions - A component of enzymes or activate enzymes.

SODIUM AND CHLORINE (SALT)

1. **General**

A. The distribution of "population centers" was predicated by three factors, **salt** (NaCl), **water** & **food** in ancient times!

B. Salt is among the first specific nutrients recognized to be "essential."

C. Na & Cl are treated together because of their close relationships, and also it is a common practice to supplement together.

2. **Sodium**

A. The body contains ≈ 0.2% Na (≈ 75% in body fluids and 25% in bones).

B. Functions:

1) Involved in maintenance of osmotic pressure (chief cation of extracellular fluid).
2) Involved in maintenance of body fluid balance/hydration of tissues.
3) Involved in the action of heart & maintenance of membrane potential, i.e., nerve impulse transmission & conduction.

   ☞ These functions are highly dependent on a proper proportion of Na & K!

4) Involved in maintenance of blood pH (acid-base balance).
5) Involved in active transport system for sugars, amino acids, etc.

3. **Chlorine**

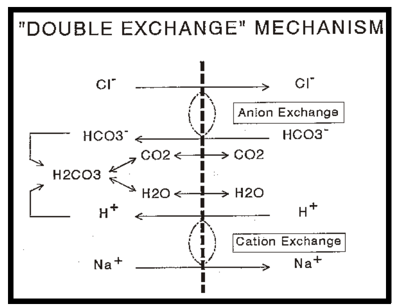
   A. Closely related to Na - Usually 1 g Na & .812 g Cl in soft tissues (i.e., 1:.812 ratio).
   B. The body contains 30-50 mEq/kg fat-free wt (15-20% bound to organic molecules).
   C. Functions - Mainly to ensure a proper fluid-electrolyte balance:

      1) Acid-base balance (2/3 of acidic ions in the blood).
      2) Osmolarity (1° anion in extracellular fluids).
      3) Important component of gastric secretion (HCl).
      4) Also, Cl^- may activate enzymes, especially α-amylase.

4. **Absorption and Excretion of Na & Cl**

   A. Absorption:

      1) Readily absorbed by the GI tract regardless of sources.
      2) Absorbed against concentration gradient - "Double exchange mechanism?"



   B. Excretion:

      1) Na - 99% or more in the urine, and increase the loss via sweat with high temperatures.
      2) Cl - 90-95% in the urine, 4-8% in the feces & 2% via the skin, and temperatures influence a proportion of loss via various routes.

5. **Homeostasis**

   A. Deficit of Na:

      1) JG (Juxtaglomerular) cells:

         a) Can sense ↓ blood pressure of Na concentration.
         b) A source of renin in kidneys and blood stream.

      2) Functions of aldosterone?

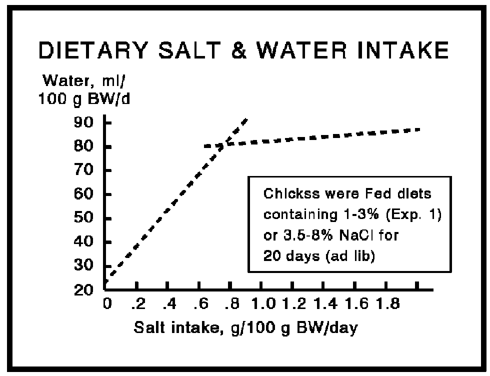
         a) Increase permeability to Na?
         b) ↑ ATP?
         c) ↑ activity of Na pump?

JG cells:
↓ BP/Na:
(Prorenin)
Angiotensinogen ↓ (kallikrein)
↓ <———— Renin
Angiotensin I
↓ (dipeptidyl-carboxypeptidase)
Angiotensin II
↓ (acts on adrenal cortex;
↓ also vasoconstriction)
Aldosterone
↓
↑ Na & water retention → ***↑ ECF volume***
(Also ↑ K excretion!)

B. Dietary salt & Na excretion: (Mason & Scott, 1974. Q. J. Exp. Physiol. 59:103)

	Excretion of Na			
Cl, % DM	Urine	Feces	Total	Urine, L/d
0.25	6	8	14	1.7
1.7	175	22	197	2.7
4.2	440	32	471	3.1
6.7	705	33	739	4.0
9.3	1042	40	1081	7.7
11.8	1182	47	1229	9.2
14.3	1335	159	1495	9.7

C. Salt & water intake in chicks - Adapted & redrawn from Paver et al., 1953. Cited by Mongin, 1980. In: Proc. IMC Conf.



B. Homeostasis:

1) Na - Maintained by adjusting the rate of excretion, i.e., simply ↑ excretion when consumed “excess” Na.
2) Cl - Affected by changes in concentrations of Na and K, i.e., its homeostasis is secondary to Na/K, and there seems to be no direct hormonal or CNS control.

☞ The availability of water is extremely important in animals’ ability to tolerate diets containing high concentration of salt!

6. **Deficiency & Toxicity**

A. Deficiency:

1) General symptoms:

a) “Salt craving,” i.e., licking soils, rocks, woods & other objects.
b) Depressed appetite, consequently ↓ productivity.

2) Specific symptoms:

a) Na - Decreased urinary & salivary Na, increased renin secretion, and decreased kidney weight.
b) Cl - Reduced blood & urinary Cl, and kidney damages (e.g., extensive general cell damage, hyperplasia, calcification, etc.).

B Toxicity (salt):

1) Swine: (Bohstedt & Grummer, 1954. J. Anim. Sci. 13:933)

   a) Can induce "salt poisoning" by feeding diets containing 6-8% salt, and restricting water intake.
   b) Signs? - Nervousness, staggering, weakness, paralysis, convulsion, blindness, etc.

2) Fowl - Edema & ↑ mortality rate with about 4% or higher. (Tracor-Jitco, Inc., 1974)
3) Maximum tolerable levels: (NRC, 1980)

Lactating cows	4%
Cattle & sheep	9%
Swine	8%
Poultry	2%
Horses & rabbits	3%

7. **Requirements**

A. For many years, it's a standard practice to add 0.5% salt to all swine diets, and also for other nonruminant species.
B. For swine, renewed interest in reevaluating the requirement because of "Na build-up" in the cropland.
C. Requirements: (NaCl = 40% Na & 60% Cl)

	Na, %	Cl, %
Swine (NRC, 1998):		
Growing pigs	0.10-0.25	0.08-0.25
Gestating sows & boars	0.15	0.12
Lactating sows	0.20	0.16
Poultry (NRC, 1994):		
Chickens	0.12-0.20	0.11-0.20
Turkeys	0.12-0.17	0.12-0.15
(Similar requirements for ducks, pheasants, & quails!)		
Horses NRC, 1989):		
Growing	0.10	-
Working	0.30	-
	(0.50-1.0% salt?)	

POTASSIUM

1. **General**

A. The third most abundant mineral in the body.
B. The most abundant in muscle tissues.
C. Functions:

1) The major intracellular cation, ∴ important for "osmolarity" of body fluids and(or) water balance.
2) Acts as available base, ∴ important for "acid-base equilibrium."
3) Has an important function in excitability of nerves & muscles:

    a) Low levels can reduce frequency & amplitude of heart contractions.
    b) Excess levels can induce cardiac arrest. [For instance, saturated KCl has been used as an agent for "euthanasia(?)."]

4) Activates enzymes or functions as a cofactor in several enzyme systems - e.g., involved in activation of ATPase or serving as a cofactor for K-dependent phosphatase.

2. **Absorption/Excretion & Homeostasis**

A. Absorption - Mainly from the upper SI by simple diffusion, and the digestibility of most forms of K in typical diets is ≈ 95%, ∴ highly available.
B. Excretion:

    1) Excrete excess K 1° via the urine (≈ 95%).
    2) Thermal stress ↑ the loss via sweat.
    3) Also, excreted in milk & eggs.

C. Kidney is the main homeostatic mechanism to maintain a stable tissue level of K:

    1) ↓ BP → Renin → Angiotensinogen → Angiotensin I → Angiotensin II → Aldosterone.
    2) Net effects of aldosterone are to "↑ Na & ↓ K" in the extracellular fluid.

D. The maintenance of K between intra- & extracellular fluids is controlled by "Na-K pump or Na-K ATPase," i.e., three Na pumped out of the cell & two K diffused into the cell.
E. Effects of "Na-K exchanges?" - e.g.

    1) Transmission of nerve impulses.
    2) Secondary transport of nutrients such as glucose.
    3) Maintenance of osmotic pressure, water balance, acid-base balance, etc.

3. **Deficiency & Toxicity**

A. Deficiency:

    1) Many symptoms/signs are results of impaired intracellular cation balance & malfunctions of nervous & muscle systems.

2) Not likely to observe the K deficiency under normal conditions.
3) But, K intake, diarrhea, vomiting, high NaCl intake, environmental temperatures & others may have effects on the K status.
4) Signs:

   a) Reduced feed intake (usually the first sign) & depressed growth.
   b) Muscular weakness, nervous disorder & paralysis.
   c) Degeneration of vital organs (e.g., heart).

B. Toxicity:

1) Not likely to occur under practical conditions.
2) A maximum tolerable level - Established to be ≈ 3% for cattle & sheep, and limited data on nonruminant species, but a 3% maximum seems to be satisfactory.

4. **Requirements/Factors Affecting Requirements**

A. Requirements:

Animal	%
Swine (NRC, 1998):	
Growing pigs	0.17-0.30
Sows/boars	0.20
Poultry (NRC, 1994):	
Chickens	0.25
Broilers	0.30
Turkeys	0.40-0.70

B. The requirements are affected by the stress:

1) "Stress" → ↑ adrenal cortex activity → ↑ K excretion → "Deficiency!"
2) ∴ supplemental K may be beneficial or even necessary in some situations.

5. **Supplemental K for Feeder Pigs**

A. Dietary K & feeder pig performance: (Jesse et al., 1988. J. Anim. Sci. 66:1325)

Phase	Contr. (0.64% tot. K)	K Suppl. (1.00% tot. K)
Weight gain, kg/d		
0-14 d	0.65	0.65
14-28 d	0.56	0.60
28-42 d	0.59	0.66
0-42 d	0.60	0.64

☞ Improved weight gain, but no response in feed efficiency, and saw no response to K supplementation in other trials.

B. Dietary K supplementation and feeder pig performance: (Brumm and Schricker, 1989. J. Anim. Sci. 67:1411)

Added KCl, %[a]:	0	0.48	0.96	1.44
Feed intake, kg/d				
0 to 2 wk	0.88	0.93	0.87	0.95
0 to 12 wk	1.91	1.94	1.92	1.99
12 to final	2.66	2.78	2.71	2.80
Overall	2.09	2.14	2.11	2.18
Weight gain, kg/d				
0 to 2 wk	0.36	0.35	0.35	0.35
0 to 12 wk	0.60	0.59	0.60	0.60
12 to final	0.63	0.63	0.59	0.59
Overall	0.60	0.60	0.60	0.60
Feed:gain				
0 to 2 wk	2.50	2.76	2.60	2.76
0 to 12 wk	3.20	3.31	3.21	3.32
12 to final	4.33	4.46	4.64	4.78
Overall	3.46	3.59	3.53	3.66
No. of pigs dead or removed	5	4	3	6

[a]Added KCl during a 14-d receiving period & from d 84 to final period (d 110 & d 111 for Trial 1 & 2, respectively.)

☞ **The Bottom Line?** Corn-soy diets contain sufficient K for a period of stress associated with marketing and transport of feeder pigs.

6. Supplemental K has been shown to spare amino acids in poultry, but it has not been demonstrated in swine!

IODINE

1. **Introduction**

A. Present in the thyroid as mono-, di-, tri- and tetraiodothyronine.
B. Important in regulation of the metabolic rate.
C. "Hypothyroidism" can be a problem in the Northwestern and the Great Lakes regions because of a low iodine content of soils, ∴ "low-iodine" feeds.

☞ Unlike in the past, however, the problem may exist elsewhere in today's production system because of the extensive movement/transportation (. . . including international trades) of feed ingredients (. . . 1° concerned with grains).

D. Deficiency:

1) Enlarged thyroid or goiter.
2) Poor growth rate - Resulting from ↓ metabolic rate, cell differentiation/growth.
3) In severe cases, animals become lethargic, and pigs may be stunted.

4) Reduced reproductive performance (low conception rate, libido, etc.), and also ↓ milk production.

2. **Requirements**

A. Affected by the presence of goitrogenic substances in some feed ingredients such as rapeseed, linseed, peanuts & soybeans.
B. Typical corn-soy diets without iodine supplement contain sufficient goitrogens to ↑ the size of thyroid 5- to 6-fold.
C. The requirement (pigs) is estimated based on the amount of dietary iodine needed to prevent hypertrophy of thyroid in growing pigs fed a corn-soy diet.
D. Requirements (mg/kg):

1) Swine, all classes (NRC, 1998) 0.14
2) Chickens & broilers (NRC, 1994) 0.35
3) Laying hens (NRC, 1994) 0.33-0.35
4) Turkeys (NRC, 1994) 0.40
5) Horses (NRC, 1989) 0.10

3. **Sources**

A. Iodized salts (sodium or potassium iodide):

1) Contain 0.01% stabilized iodide or 0.0076% iodine.
2) Addition of 0.20% iodized salt to corn-soy diets supplies ≈ 0.15 ppm iodine.

B. Dicalcium phosphate contains ≈ 10 ppm iodine, ∴ addition of 1.5% dical to corn-soy diets supplies ≈ 0.15 ppm iodine.

ELECTROLYTE BALANCE

1. **General**

A. Traditionally, the interest of physiologists, chemists & biochemists.
B. During the last 15-20 years (especially, since early 80s), animal nutritionists started considering the "dietary electrolyte balance."
C. Electrolyte balance:

1) Dietary macromineral balance or dietary undetermined anion (dUA):

$$\text{dUA (mEq/kg)} = \boldsymbol{\sum(Na + K + Ca + Mg) - \sum(Cl + P + S)}$$

a) Represents in part "acidogenicity or alkalinogenicity" of diets.
b) If dietary mineral cations > mineral anions, there must be an equivalent excess of organic anions such as bicarbonate, citrate & acetate to preserve an "electrical neutrality."
c) The dietary content of individual minerals is irrelevant for this consideration, i.e., only interested in "charges."
d) Expressed in terms of milliequivalent per kg (mEq/kg):

(1) e.g., Conversion of % Na (.1%) to mEq/kg:

(a) % to mg/kg (x 10,000):

0.1 x 10,000 = 1,000 (or 0.1/100 x 1,000,000)

(b) Divide the result by MW:

1,000/23 = 43.5

(c) Multiply by the valence.

43.5 x 1 = 43.5 mEq/kg

(2) Or, use conversion factors:

Conversion table (% to mEq/kg)[a]

Mineral	MW	Valence	Conv. factor
Sodium (Na)	23.0	+1	+435
Potassium (K)	39.1	+1	+256
Calcium (Ca)	40.1	+2	+499
Magnesium (Mg)	24.3	+2	+823
Chloride (Cl)	35.5	-1	-282
Phosphorus (P)	31.0	-1.75	-565
Sulfur (S)	32.1	-2	-623

[a]mEq/kg = mineral (%) x conversion factor.

e.g.: 0.1% Na = .1 x (+ 435) = + 44 mEq/kg,
0.5% K = .5 x (+ 256) = + 128 mEq/kg, and
0.15% Cl = .15 x (- 282) = - 42 mEq/kg. . . , etc., and use these values to estimate the dietary undetermined anion.

2) "Dietary electrolyte balance (dEB)" is a simplified version, and may be appropriate to use in most circumstances:

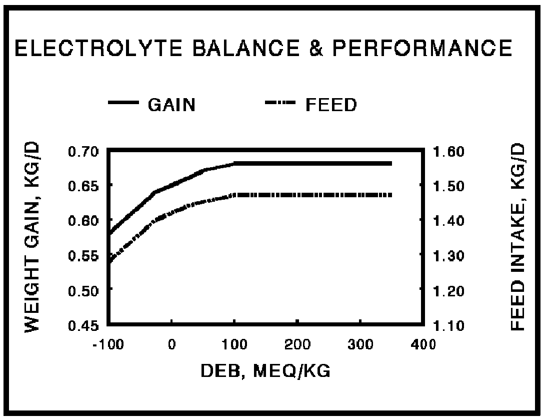
dEB (mEq/kg) = **Na + K - Cl**

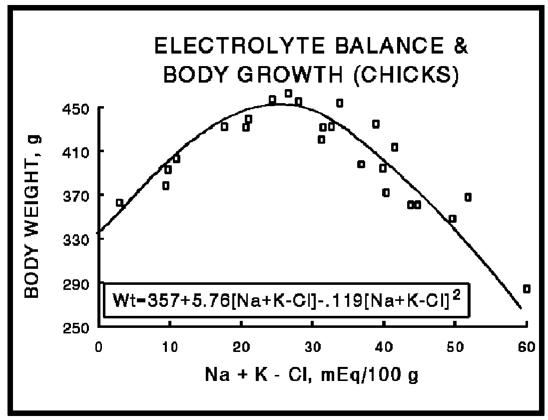
2. **Dietary Electrolyte & Animal Performance?**

A. Confounded by:

1) Deficiency/toxicity of each mineral.
2) Availability of each mineral.
3) Environmental conditions such as presence of diseases, ambient temperatures, availability of water, stress, etc.

B. Effect of electrolyte balance on performance of pigs (Patience et al., 1987. J. Anim. Sci. 64:457 - Left) and chicks (Mongin, 1980. Proc. 3rd. Annu. Int. Mineral Conf. - Right)





C. Electrolyte balance and nutrient digestibility (%) measured at the end of the small intestine of pigs: (Haydon & West, 1990. J. Anim. Sci. 68:3687)

dEB, mEq/kg:	-50	100	250	400
Nitrogen*	68.9	72.8	75.4	76.1
Gross energy*	63.3	68.4	69.6	72.3
Dry matter*	62.0	67.2	68.6	71.5
Indispensable amino acid:				
Arg*	84.3	85.6	86.8	87.0
His*	79.6	81.4	82.3	83.6
Ile*	80.2	80.9	82.5	83.0
Leu*	77.3	78.8	78.0	81.3
Lys*	79.4	82.2	83.6	83.6
Met	75.4	78.4	76.9	79.2
Phe*	78.8	80.1	81.3	82.5
Thr*	66.9	70.3	72.3	72.4
Val*	76.0	77.4	78.6	79.7

* Linear effect, $P = 0.01$ to .10. Also observed similar linear effects on all dispensable amino acids.

1). The bottom line? - Electrolyte balance can influence the nutrient digestibility & performance of pigs.
2) Practical swine diets - ≈ 175 meq/kg, ∴ provide a margin of safety, but with ↑ use of lysine·HCl, may become a concern for practical diets!

D. Effect of dietary chloride, sulfate, and phosphate on broiler chickens.

1) Chloride & sulfate: (Ruiz-López et al., 1993. Poult. Sci. 72:1693)

Diet	% of diet	14-d gain, g	14-d feed, g	Feed: gain
Basal	-	365[a]	537[ab]	1.47[b]
+80 meq Cl^-/kg	0.284% Cl¶	343[ab]	601[a]	1.76[ab]
+160 meq Cl^-/kg	0.567% Cl¶	355[ab]	537[ab]	1.52[ab]
+240 meq Cl^-/kg	0.850% Cl¶	307[b]	459[b]	1.51[b]
+80 meq SO_4^{2-}/kg	0.128% S§	349[ab]	579[a]	1.67[ab]
+160 meq SO_4^{2-}/kg	0.256% S§	362[a]	613[a]	1.71[ab]
+80 meq SO_4^{2-}/kg	0.128% S£	328[ab]	590[a]	1.83[a]
+160 meq SO_4^{2-}/kg	0.256% S£	365[a]	568[a]	1.54[ab]

¶ Cl from $CaCl_2 \cdot 2H_2O$; § S from $Na_2SO_4 + K_2SO_4$; £ S from $Ca_2SO_4 \cdot 2H_2O$; [a,b]Means within columns with no common superscripts differ, $P < 0.05$.

2) Chloride & phosphate: (Ruiz-López et al., 1993. Poult. Sci. 72:1693)

Diet	% of diet	13-d gain, g	13-d feed, g	Feed: gain
Basal	-	431[a]	662[ab]	1.55
+80 meq Cl^-/kg	0.284% Cl¶	437[a]	594[bc]	1.37
+160 meq Cl^-/kg	0.567% Cl¶	400[a]	607[bc]	1.52
+240 meq Cl^-/kg	0.850% Cl¶	338[b]	516[c]	1.52
+80 meq HPO_4^{2-}/kg	0.124% P§	455[a]	681[ab]	1.50
+160 meq HPO_4^{2-}/kg	0.248% P§	441[a]	620[ab]	1.41
+80 meq $H_2PO_4^{2-}$/kg	0.124% P£	461[a]	711[a]	1.54
+160 meq $H_2PO_4^{2-}$/kg	0.248% P£	419[a]	593[bc]	1.41

¶ Cl from $CaCl_2 \cdot 2H_2O$; § P from $CaHPO_4 \cdot 2H_2O$; £ P from $Ca(H_2PO_4)_2 \cdot H_2O$; [a,b,c]Means within columns with no common superscripts differ, $P < 0.05$.

☞ Excess Cl can clearly depress the performance of broiler chickens, thus, perhaps, have to consider the amino acid requirement established by using amino acid·Cl!?

ELECTROLYTES AND IODINE FOR FISH

1. **Osmoregulation**

A. Osmotically active solutes:

1) Predominant minerals are Na, K & Cl.
2) Ca, Mg, bicarbonate & phosphate are not directly involved, but influence functions of the kidney.
2) Proteins play a small part but important in moving fluids across the cell membrane.

B. Ionic composition and osmolarity:
1) Fish maintain electrolyte levels significantly different from their environment.
2) Fresh water fish can maintain "hypertonic" blood vs external medium by:

a) Active uptake of salts by the gill.
b) Having low body surface permeability.
c) Having high glomerular filtration rate of the kidney along with tubular & bladder reabsorption of filtered ions.

3) Marine fish can maintain "hypotonic" blood vs external medium by:

a) Losing water via any permeable body surface, and gaining salts.
b) Replacing lost water by drinking sea water.
c) Absorbing monovalent ions & water into blood, and accumulating divalent ions in the intestine to maintain the same osmolarity as blood.
d) Enhancing further water conservation by ↓ glomerular filtration (the kidney serving 1° as a divalent ion secretory organ).
e) Excreting excess monovalent ions derived from swallowed seawater & passive uptake across the body surface 1° by the gill.

2. **Na, K & Cl**

A. Na & Cl are 1° cation & anion, respectively, of the ECF, and K & Mg are 1° ICF cations.
B. The osmotic pressure of the ICF & ECF is tightly controlled mostly by energy-dependent mechanism that determines/regulates the rate of absorption of Na & water by epithelial membranes of the gill, gut, integument & kidney.
C. Deficiencies have not been produced in fish, even though they are necessary for osmoregulation, pH balance, nerve impulse, gastric juice, "chloride shift" in the transport of CO_2 & carbonate, etc.
D. Most fresh & seawater fish environments contain adequate levels of these elements, ∴ can absorb via the gill in fresh water fish & the gut in seawater fish.
E. Excrete "excesses" efficiently, ∴ 8-12% salt has no adverse effects.

3. **Iodine**

A. Needed for the thyroid hormone synthesis along with Tyr - Thyroid hormones influence cellular oxidation, growth, other endocrine glands, neuromuscular functions, circulatory dynamics, and metabolism of major nutrients.
B. Fish can obtain I from water via branchial pumps & feed sources:

1) Rainbow trout obtain ≈ 80% from water, 19% from diets & 1% by recycling.
2) With a low or absent of dietary uptake, they can maintain plasma I by absorbing environmental I & mobilizing I bound to plasma proteins & tissue I.
3) ≈ 5% of I consumed is utilized by the thyroid.

C. "Iodide" trapped in the thyroid gland:

1) Oxidized to iodine, which is probably mediated by peroxide enzyme(s).
2) Iodination of Tyr to form mono and diiodotyrosine.
3) Two iodotyrosine to form thyroxine (T_4).
4) One mono & one diiodotyrosine to form triiodothyronine (T_3).

D. Both T_3 & T_4 occur in blood.
E. T_3 binds more strongly to plasma protein vs T_4, ∴ T_3 turnover is slower.
F. Both are excreted extensively in the bile, but other routes (kidney & gills) may also be involved.
G. Factors affecting blood I:

1) Dietary & water I levels.
2) Elevated water temperature, which ↑ excretion rate.
3) Sexual maturation.
4) Ability of fish to bind I to plasma proteins.

H. Deficiency or hypothyroidism:

1) Insufficient dietary I is probably the most common cause.
2) Early 1910s, "carcinoma" in brook trout was diagnosed correctly as "thyroid hyperplasia," and demonstrated this disease could be controlled by I supplementation.

I. A minimum dietary requirement of most fish species has not been established, and requirements are likely to be influenced by growth rate, sex, age, physiological status, environmental stress, disease, I content of water & other factors.

4. **Requirements**

A. Various species of fish probably require the same minerals as warm blood animals for tissue formation and various metabolic processes.
B. Requirements (%)[a]: (NRC, 1993)

Species	Na	Cl	K	I
Channel catfish	R	R	R	1.1 (E)
Rainbow trout	0.6 (E)	0.9 (E)	0.7	1.1
Pacific salmon	NT	NT	0.8	0.6-1.1
Common carp	NT	NT	NT	NT
Tilapia	NT	NT	NT	NT

[a]R = required in diet, but quantity not determined; E = estimated; NT = not tested.