WATER USE BY PIGS MANAGED UNDER VARIOUS CONDITIONS OF HOUSING, FEEDING, AND NUTRITION

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ABSTRACT

WATER USE BY PIGS MANAGED UNDER VARIOUS CONDITIONS OF HOUSING, FEEDING AND NUTRITION

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This study investigated the water use of lactating sows (experiment 1), suckling piglets (experiment 2), weaned piglets (experiments 3, 6 and 8) and growing pigs (experiments 4, 5, 7 and 9), according to 3 specific objectives which assessed the effects of: age, live weight, feed intake and physiological status on water demand (experiments 1 to 3); different types of drinker on water use (experiments 4 to 6); dietary mineral content on water demand (experiments 7 and 8). For all classes of pig, feed intake explained between 53 and 83% of the variation in water use ($P < 0.001$). The relationship between stage of lactation and live weight (experiments 3, 6 and 7) was confounded by feed intake. In sows water use increased linearly in the week before farrowing ($P < 0.001$) which then decreased from 12.3 $\pm$ 1.10 l the day before, to 9.3 $\pm$ 0.84 l the day of farrowing ($P < 0.001$). Water use averaged 18.9 $\pm$ 0.27 l/day in a 21 day lactation. With suckling piglets, provision of water and/or creep feed between days 8 and 21 did not influence growth ($P > 0.05$). Provision of creep feed reduced water use (0.22 $\pm$ 0.019 v 0.53 $\pm$ 0.035 l/litter day; $P < 0.001$), but water provision did not influence feed intake (34.7 $\pm$ 3.4 g/litter day; $P > 0.05$). Early weaned piglets (21 d) showed a disturbed pattern of water use in week 1 and water use averaged 0.94 $\pm$ 0.050 l/piglet day between weeks 1 and 3. In growing pigs, water use per unit of feed intake decreased linearly from 17 to 81 kg W and water use averaged 5 $\pm$ 0.16 l/day. Type of drinker influenced performance immediately after weaning ($P < 0.001$), but results with growing pigs were less conclusive. Water use from the Mono-flo nipple drinker was about twice that from 5 other types of drinker ($P < 0.001$). Dietary potassium (K) increased the water use of growing pigs by 1 l/day for every 1% increase in K between 7 and 15 g/kg feed ($P < 0.05$) , but performance was not affected ($P > 0.05$). With piglets water use and performance were not affected by variations in dietary K and Cl contents between 6.7 and 15.6; 1.4 and 3.0 g/kg feed respectively ($P > 0.05$). Growing pigs fed liquid diets utilised a supplementary water supply even though the water added to the meal exceeded ARC (1981) recommended allowances (experiment 9). Daily weight gain and conversion of dry matter improved as the moisture content of the liquid diets was increased from 67 to 88% ($P < 0.05$).

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CONTENTS

LIST OF ABBREVIATIONS

ARC	Agricultural Research Council
ADH	Antidiuretic hormone
cm^3	Centimetre(s) cubed
r	Coefficient of correlation
R^2	Coefficient of determination
CV	Coefficient of variation
CP	Crude Protein
d	Day(s)
^oC	Degrees celsius
dy/dx	Differential of X with respect to Y
DE	Digestible energy
DB	Dry bulb
DM	Dry matter
EE	Ether extract
g	Gramme(s)
>	Greater than
GE	Gross energy
h	Hour(s)
kg	Kilogramme(s)
kJ	Kilojoule(s)
<	Less than
l	Litre(s)
W	Live weight
x	Mean
MLC	Meat and Livestock Commission
MJ	Megajoules
ME	Metabolisable energy

m^3	Metre(s) cubed
m^2	Metre(s) squared
meq	Milliequivalent
mg	Milligramme(s)
ml	Millilitre(s)
mm	Millimetre(s)
min	Minute(s)
NDF	Neutral detergent fibre
NS	Not significant ($P > 0.05$)
NDBF	Number of days before farrowing
NDPF	Number of days post farrowing
NDPW	Number of days post weaning
PCV	Packed cell volume
ppm	Parts per million
%	Percentage
P	Probability level
R	Registered trade mark
RH	Relative humidity
r.s.d.	Residual standard deviation
rev	Revolutions
$\sigma\ n^{-1}$	Standard deviation corrected by one degree of freedom
s.e.	Standard error
s.e.d.	Standard error of difference
s.e.m.	Standard error of mean
v	Versus
WB	Wet bulb

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INTRODUCTION

In his comprehensive review on the water metabolism of mammals, Professor Robert M Chew made the following conclusions:

'It is necessary to recognise that there is no single water requirement for a species or individual; the amount drunk depends upon factors such as: temperature, humidity, diet, frequency with which water is provided, conditions of caging and stresses of the environment. The evaluation of published data is very uncertain unless such experimental conditions are described'.

These conclusions are at variance with the recommendations of The 1981 Agricultural Research Council's Working Party on the Nutrient requirements of the pig or with The Ministry of Agriculture, Fisheries and Food's Codes of Recommendations for the Welfare of Livestock: Pigs, which both suggest that the water requirements of pigs can be satisfied by some definitive allowances.

The ARC Working Party did not take into consideration the various "factors" that influence the water needs of pigs even though they acknowledged that pigs show considerable variations in individual water consumption when offered unrestricted access to a supply of drinking water. Because of the limited information available on the factors which influence the water needs of pigs The Working Party simply could not decide nor were able to explain whether these variations represented "unimportant idiosyncrasies or physiological needs which should be met". On the other hand, given the fact that the number of publications on the water needs of the pig have been very limited, and that the evaluation of such data **is** very uncertain, it is difficult to support ARC's justification for recommending discrete allowances for the various categories of pig. There is a need to address the conclusions made by Chew some 27 years ago, as our present knowledge on the factors which influence the water needs of pigs has remained almost static since 1967, when ARC published almost the same recommendations as in 1981.

SECTION I REVIEW OF LITERATURE

CHAPTER 1 WATER METABOLISM OF THE PIG

1.1 Introduction

Water constitutes more that 50 per cent of the empty body weight of pigs and other mammalian species. The water content of the body decreases with increasing weight and age and this relationship is discussed with respect to the composition of growth from birth to maturity. This is followed by an outline of the internal regulation of body water content, maintenance of osmotic homeostasis and factors which control and initiate thirst in the pig. The final part of this chapter considers various published values on obligatory water inputs and losses in pigs. These values are subsequently used in a factorial calculation to estimate the amount of daily water required to maintain the body water balance of a growing pig weighing 60 kg W.

1.2 Water content of the body

Comparative data on entire and fat-free body composition and water content of different species is given in Table 1.1. In pigs the relationship between total body water content (Y; kg) and empty body weight (X; kg) for gilts, castrates and entire males has been described by the following equations based on sequential slaughter data recently published by Whittemore, Tullis and Emmans (1988).

$$Y = 1.008\ X^{0.830}\ \text{(Gilts)}$$
$$Y = 1.241\ X^{0.778}\ \text{(Castrates)}$$
$$Y = 0.928\ X^{0.862}\ \text{(Entire Males)}$$

Variations in body water content are primarily attributable to variation in body fat content. This is apparent from a comparison of the coefficients of variation (cv) for the water content of

Table 1.1. Entire and fat-free body composition of different mammalian species

Species	Entire (%)				Fat-free (%)		
	Water	Protein	Fat	Ash	Water	Protein	Ash
Calf, newborn	74	19	3	4.1	76.2	19.6	4.2
Calf, fat	68	18	10	4.0	75.6	20.0	4.4
Steer, thin	64	19	12	5.1	72.6	21.6	5.8
Steer, fat	43	13	41	3.3	72.5	21.9	5.6
Sheep, thin	74	16	5	4.4	78.4	17.0	4.6
Sheep, fat	40	11	46	2.8	74.3	20.5	5.2
Hen	57	21	19	3.2	70.2	25.9	3.9
Rabbit	69	18	8	4.8	75.2	19.6	5.2
Horse	61	17	17	4.5	73.9	20.6	5.5
Mouse	66	17	13	4.5	75.4	19.4	5.2
Rat	65	22	9	3.6	71.7	24.3	4.0
Guinea Pig	64	19	12	5.0	72.7	21.6	5.7
Pig	49	12	36	2.6	77.0	18.9	4.1
$\bar{x}$	61.1	17.1	17.8	4.0	74.3	20.8	4.9
CV	17.9	19.5	79.2	20.7	3.1	11.1	14.3

Maynard et al. (1979)

fat-free and entire body weights. On a fat-free basis body water content shows a greater constancy than either protein or ash content as indicated by a markedly low coefficient of variation. Because of the constancy of fat-free water content, Roubicek (1969) suggested that in mammals body fat content could be estimated from the determination of total body water content according to the following equation:-

$$\text{Percent body fat} = 100 - 1.37 \text{ Percent body water}$$

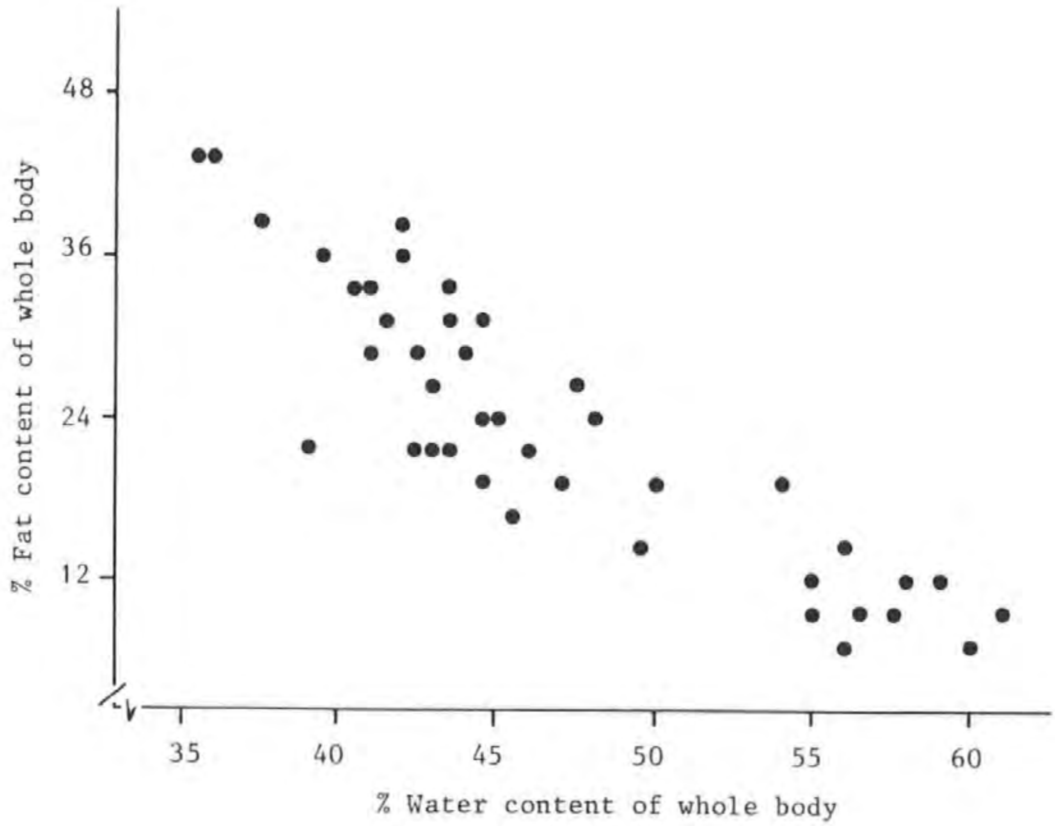
This can be compared with the following equation fitted to the data of Whittemore et al. (1988) pooled for castrates, gilts and entire males:-

Percent body fat = 84 - 1.29 Percent body water ($P < 0.001$; r.s.d. 4.70; R^2 0.79)

The negative relationship between body fat and water content can be explained by the fact that lean and lipid tissue on average contain 75-80% and 9-12% water by weight respectively (Whittemore and Elsley, 1979).

Therefore an increase in absolute body fat content is associated with a decrease in absolute body water content (Figure 1.1). This is further demonstrated by data presented in Table 1.2 on the body composition of pigs from 1.5 to 145 kg W obtained from a sequential slaughter trial conducted by Shields, Mahan and Graham (1983). As the ratio of body protein to fat content decreases with age there is a corresponding reduction in percent body water content. This reduction commences before birth and progresses rapidly in early age and plateaus as the animal approaches mature weight (Moulton, 1923; Whittemore et al., 1988).

Figure 1.1 Relationship between percentage body water content and percentage body fat content of pigs between 52 and 332 days of age.



Whittemore et al. (1988)

Table 1.2. Percentage composition of the empty and fat-free body of pigs from 1.5 to 145 kg W

Live weight (kg)	Empty body (%)				Fat-free basis (%)		
	Water	Protein	Fat	Ash	Water	Protein	Ash
1.5	82.06	10.11	1.73	3.12	86.12	10.61	3.27
6.4	71.60	15.17	11.01	3.01	79.75	16.89	3.35
18	69.32	15.75	11.33	2.16	79.47	18.05	2.48
36	66.08	16.31	11.47	2.77	77.58	19.17	3.25
54	58.48	16.00	17.25	2.79	75.67	20.71	3.62
73	56.58	14.64	22.98	2.49	76.75	19.86	3.38
91	53.33	14.33	28.04	2.48	76.02	20.44	3.54
109	51.01	14.40	30.42	2.47	75.13	21.23	3.63
127	42.32	13.73	39.43	2.44	72.35	23.48	4.17
145	42.28	12.61	41.10	2.37	73.26	22.07	4.17
x	59.30	14.31	21.48	2.61	77.21	19.25	3.49
CV	21.81	12.90	61.16	11.55	5.08	18.60	13.91

Shields et al. (1983)

A decrease in body water content with age is not only due to an increase in body fat content, but also to a decrease in the moisture content of fat and lean tissue per se (Table 1.3).

The stomach and the lumen of the digestive tract can contain a considerable quantity of fluid. An adult pig weighing 190 kg W, can have a total digestive capacity of about 27 litres (Maynard, Loosli, Hintz and Warner, 1979). The amount of digestive water can be very variable, but it may be included in measurements of total body water.

1.3 The internal control of body water balance and thirst

It would be difficult to discuss thirst and the internal mechanisms which maintain osmo-equilibrium without referring to mineral balance, thermoregulation, digestion and many other physiological parameters in which water plays an important role. This section will present only an outline of the internal mechanisms which are specific to the control of thirst and the maintenance of water balance.

Antidiuretic hormone (ADH) secreted from the posterior lobe of the pituitary gland, and aldosterone, a hormone produced by the adrenal zona glomerulosa, control mineral and water balance by exerting their effect on renal function. Osmoreceptors in the hypothalamus cause the release of ADH whenever the osmotic pressure of blood in the internal carotid artery increases. ADH then acts by increasing the permeability of kidney collecting ducts causing an increased reabsorption of water from the glomerular filtrate (Frandson, 1986). Therefore this hormone is

Table 1.3. Changes in the composition of body fat and muscle of growing pigs with age

	Longissimus dorsi muscle				**Subcutaneous back fat**					
					Outer layer			**Inner layer**		
Age (weeks)	**% fat**	**% tissue**	**% water**	**% water fat-free basis**	**% fat**	**% tissue**	**% water**	**% fat**	**% tissue**	**% water**
Birth	1.92	16.61	81.47	83.05	6.22	8.89	84.89	6.22	8.89	84.89
4	4.32	19.92	75.75	79.17	75.37	5.11	19.52	76.84	4.66	18.50
8	4.73	19.05	76.22	80.00	76.69	6.65	16.66	76.90	8.01	15.09
16	3.39	20.95	75.66	78.31	84.45	6.41	9.14	87.79	4.84	7.37
20	4.02	21.61	74.37	77.48	85.91	3.89	10.20	90.72	2.72	6.56
28	5.62	22.61	71.77	76.04	92.44	2.63	4.93	94.33	1.90	3.77

McMeekan (1940)

essentially involved in water conservation which is achieved by increasing urine concentration.

Aldosterone is released when circulating levels of sodium (Na^+) are too low to maintain a normal level of blood pressure and volume. It acts on the kidney tubules causing reabsorption of sodium ions, thus restoring blood volume by stimulating the osmotic pull of water back into the circulatory system (McDonald, 1980). Although their mode of action is well documented, there is little evidence to indicate that these hormones play a central role in the manifestation of thirst and drinking activity. The renal renin-angiotensin system is considered to be the most important internal mechanism regulating water balance through thirst.

The kidneys release an enzyme called renin (Cook, 1971) in response to internal signals which arise from the result of a negative body water balance that could be rectified by an increased water intake. Renin enters the venous circulation of the kidneys and reacts with α-globulins to produce a decapeptide called angiotensin I. Angiotensin I is converted into a potent dipsogen, angiotensin II, as it passes through the capillaries of the lungs (McFarlane, 1976).

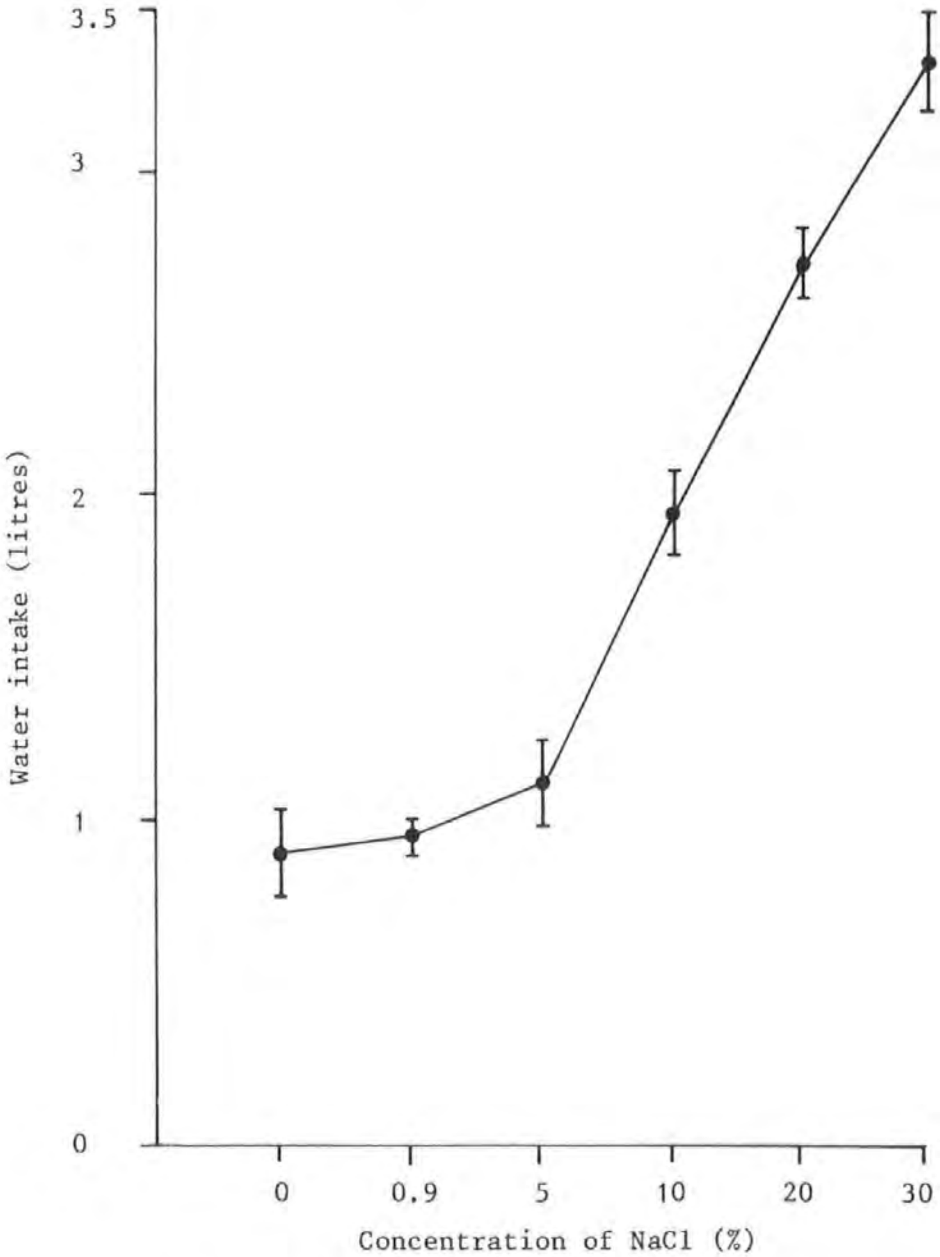
The dipsogenic properties of angiotensin II and its site of action in the hypothalamus which initiates drinking activity have been studied in detail by Epstein, Fitzsimons and Simons (1969), Fitzsimons (1969) and Fitzsimons and Simons (1969). Intracranial injections of angiotensin solution into various regions of the hypothalamus in rats of normal and positive water balance have been found to induce a drinking reponse. Epstein et al. (1969) found the dipsogenic effect of angiotensin to be so potent that it made manually restrained rats struggle to reach a water supply. More recently Baldwin and Thornton (1986) found that in pigs intracerebroventricular injections of angiotensin II solution were more effective in evoking a drinking response in the presence of sodium ions.

As water and its metabolism is intimately associated with many other physiological processes, the diversity and number of internal stimuli which could prime the renin-angiotensin system are likely to be enormous.

According to Fitzsimons (1969) the primary internal receptors involved in osmoregulation are located in the vasculature. These receptors respond to increased plasma osmorality resulting from extracellular dehydration through water loss. Ingram and Stephens (1979) initiated drinking in pigs by inducing extracellular dehydration with intraveneous injections of NaCl solution. It was found that drinking occurred in direct proportion to the concentration of the salt solution (Figure 1.2). Similar responses have been observed in dogs (Holmes and Gregersen, 1950) and in rats (Gilman, 1937; Fitzsimons, 1961a).

It is not clear from the available evidence whether baro-receptors are involved in thirst. Fitzsimons (1961b) and Oatley (1964) evoked a drinking response in rats after blood withdrawal

Figure 1.2 Mean water intake (± s.e.) of pigs over a 2 hour period following intravenous injections of NaCl of varying concentrations.



Ingram and Stephens (1979)

from the tail. Conversely Ingram and Stephens (1979) could not get a response with young pigs when mild hypovolaemia was produced by drawing 500 ml of blood via a jugular catheter. This lack of response to blood withdrawal on thirst in the pig agrees with observations on dogs by Holmes and Montgomery (1953) and on rats by Schneider (1962). Therefore it seems unlikely that day to day variations in blood volume are involved in the activation of the renin-angiotensin thirst system.

There is some evidence to indicate that hypothalamic and peripheral thermoreceptors may play a role in thirst. Ingram and Stephens (1979) produced a drinking response in young pigs when thermal stimuli were applied to areas of the skin on the trunk, the scrotum and to central regions in the hypothalamus and spinal cord, all of which are known to be involved in thermoregulation.

The renin-angiotensin system may also exert an influence on ADH and aldosterone secretion thereby linking renal output to active rehydration (McFarlane, 1976; McDonald, 1980).

1.4 Obligatory water inputs and losses

Under contemporary systems of housing, feeding and management, pigs obtain their water from two main sources, drinking water and water added to the feed and/or moisture content of the feed. A third source is water formed as a by-product of the oxidative catabolism of dietary carbohydrates, fat, protein, and the metabolism of body tissues.

Pigs lose water via four routes. The two main channels of losses are in the urine and faeces. Further losses occur by perspiration and transpiration from the skin and during exhalation from the respiratory tract.

The following sections consider published values on the magnitude of the various inputs and losses and summarise the data using a 60 kg W growing pig as an empirical model.

(i) Water in feed

The moisture content of most cereal based pig diets is about 14%, which represents only a small proportion of total daily water intake. As variations in the moisture content of compound feeds are quite small, the contribution of water in feed to the pig's total daily water intake clearly depends on the amount of 'dry' feed consumed. For example if a growing pig weighing 60 kg W fed ad libitum consumes 2.72 kg of an air-dry diet containing 13 MJ DE/kg and 14% moisture per day (ARC, 1981), the quantity of water ingested in the feed would be 0.38 l/day. Therefore the remaining need for water under a dry feeding system must be satisfied by the provision of a supply of drinking water.

In pipeline wet feeding systems, the mixing of a copious volume of fresh water with the dry meal ration prior to feeding increases the contribution of dietary water to total water intake. When no other drinking water supply is available for wet fed pigs, which is common in commercial practice, the entire daily water intake of pigs is derived from the liquid diet.

Therefore, the total quantity of water ingested would be determined by the amount of liquid feed consumed and the ratio of water to meal in the liquid diet.

Unlike dry compound feeds, the use of liquid ingredients and by-products such as whey, skimmed milk, swill and sugar beet pulp in pipeline feeding systems can considerably increase the variability of water ingested with the dry feed component. This is due to the highly variable dry matter content of liquid feed ingredients.

Under some circumstances the amount of water ingested can be either insufficient or excessive when no allowance is made for the water content of the liquid ingredient used in a pipeline feeding system. In this context the practical value of published recommendations on the water requirements of pigs is limited unless the moisture content of liquid ingredients and by-products is taken into account.

(ii) Water derived from metabolic processes

Metabolic water is one of the end products of the oxidation of organic dietary nutrients, fat depots and tissue protein. According to Yang, Price and Aherne (1984) every kg of air-dry feed eaten will contribute between 0.38 and 0.48 l of metabolic water, which is similar to a value of 0.4 l/kg feed intake estimated by ARC (1981).

As oxidative catabolism is an exergonic process, metabolic water is a by-product of the common energy metabolism pathway.

Complete oxidation of 1 g of fat and 1g of carbohydrate will yield 0.81 and 0.5 ml of metabolic water respectively:-

Stearic acid

$$H_2C(CH_2)_{16}\ COOH + 26O_2 \longrightarrow 18CO_2 + 18H_2O$$

Molecular weights 312 + 624 = 684 + 252

Metabolic water/g fat oxidized = 252/312 = 0.81 ml

Glucose

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

Molecular weights 168 + 144 = 228 + 84

Metabolic water/g carbohydrate oxidized = 84/168 = 0.5 ml

(Edwards and Hassall, 1971)

Similarly the catabolism of amino-acids, which is more complex than fatty acid and mono-saccaride metabolism, yields an equivalent 0.4 ml of water per gramme of protein oxidized (Maynard, Loosli, Hintz and Warner, 1979).

According to Maynard _et al._ (1979), metabolic water comprises about 5 to 10 per cent of the total water requirements of domestic animals. This contribution cannot be increased, because the additional water produced above a basal rate is offset by increased pulmonary water loss due to a higher respiratory ventilation required to expel CO_2 and metabolic heat.

The amount of metabolic water produced from the catabolism of protein and non-protein substrates can be estimated from measurements of total daily urinary nitrogen output and total daily oxygen consumption. Although the catabolism of protein is a potential source of metabolic water, the deamination of dietary protein which is surplus to the animal's requirement will increase the amount of urinary water demand for urea excretion. Similarly the ingestion of poor quality dietary protein has been found to increase the water to feed intake ratio of growing pigs possibly due to an increased demand for urea excretion (Garrigus, 1948). However simple calculations can give an indication of the extent of metabolic water produced from different substrates:-

Table 1.4 Relationship between metabolic water produced and oxygen required for the catabolism of protein, carbohydrate and fat

Substrate oxidized	Metabolic water produced (ml/g substrate)	Oxygen required (l/g substrate)
Protein	0.40	0.97
Carbohydrate	0.50	0.90
Fat	0.81	1.50

Assuming:-

Urinary nitrogen output is 0.52g N/kg W per day (Forbes and Walker, 1968).
Protein = N x 6.25.
Urinary N is derived entirely from protein catabolism.
Density of O_2 is 1.33 g/l.
Oxygen consumption at basal metabolic rate by a pig at 20^{o}C ambient temperature is 14.4 l/kg W per day (Ingram and Legge, 1969/70).
Ratio of O_2 used for fat and carbohydrate oxidation is 5:2.

Then:-

Protein oxidized 6.25 x 0.52 = 3.25 g/kg W per day.
Oxygen required for protein oxidation 3.25 x 0.97 = 3.15 l/kg W per day.
Oxygen used for carbohydrate and fat oxidation 14.4 - 3.15 = 11.25 l/kg W per day.
Oxygen used for carbohydrate oxidation $^{2}/_{7}$ x 11.25 = 3.12 l/kg W per day.
Oxygen used for fat oxidation 11.25 - 3.21 = 8.04 l/kg W per day.
Carbohydrate oxidized 3.21/0.90 = 3.57 g/kg W per day.
Fat oxidized 8.04/1.50 = 5.36 g/kg W per day.

Metabolic water produced = [(3.25 x 0.4) + (3.57 x 0.5) + (5.36 x 0.81)]

= 7.43 ml/kg W per day

For a 60 kg W growing pig this is equal to 0.45 l of metabolic water produced per day. This is much lower than the expected daily production of metabolic water from the catabolism of feed estimated by ARC (1981) and Yang et al. (1984).

(iii) Urinary and faecal water losses

Water is the main constituent of urine (Table 1.5). It is the vehicle which carries the end products of catabolism, excess minerals and toxins filtered from the blood by the kidneys.

The minimum daily water requirements for eliminating the end products of catabolism, minerals and other filtrates in the urine are very difficult to assess. The minimum requirement for renal function will primarily depend on mineral intake, predominantly Na and K, dietary protein intake and protein quality .

Table 1.6 summarises ranges for daily urine production by a number of mammalian species including the pig. Assuming that urine is 95% water, a pig is expected to have a renal water loss of between 4.75 and 28.5 ml/kg W per day.

Table 1.5. Chemical composition of human urine

	per cent
Water	95
Na	0.35
Cl	0.6
Urea	2
Uric acid	0.05
K	0.15
NH_4	0.04
Ca	0.015
Mg	0.006
PO_4	0.15
SO_4	0.18

Similar proportions hold in general throughout the mammals

Cushny (1926)

Table 1.6. Volumes and specific gravities of urine produced by various mamalian species

Animal	Volume (ml/kg body wt/day)	Mean specific gravity
Cat	10-20	1.030
Cattle	17-45	1.032
Dog	20-100	1.025
Goat	10-40	1.030
Horse	3-18	1.040
Sheep	10-40	1.030
Swine	5-30	1.012
Man	8.6-28.6	1.020

Cited by Dukes (1984)

The renal pathway responds very quickly to short-term fluctuations in water intake. The volume of urinary water loss is thus largely dependent on the amount of water ingested.

For example Madec (1985) found that the density of urine from pregnant sows was inversely correlated with water consumption ($r = -0.66$) indicating an increased output of dilute urine with increased water intake.

Although the renal system can excrete large quantities of ingested water, when supply is severely restricted there is a limit to the amount of water that can be economised through renal reabsorption. This is because there is a finite limit beyond which the kidneys cannot increase urine concentration. In pigs the maximum concentration is 1 osmol/l urine while dogs and cats can achieve at least 3 osmol/l (McFarlane, 1976).

Faeces consist primarily of water and undigested feed residues. The amount of faeces produced and the volume of water lost through this route depends largely on nutrient digestibility and feed intake. For example if a growing pig weighing 60 kg W fed ad libitum consumes 2.7 kg/day of a diet with a dry matter content and digestibilty of 860 g/kg and 82% respectively, then the weight of faecal dry matter voided would be 0.42 kg/day. If the moisture content of fresh faeces is taken as 70% (Whittemore and Elsley, 1979) then the volume of water lost via this route would be 0.97 l/day. Faecal water loss will be increased when feed of low digestibility is consumed in large quantities.

Unlike urinary water loss, faecal water output is not affected by the amount of water ingested. This is apparent from Table 1.7 which summarises the results of four independent studies on the effects of feed moisture content on the dry matter content of faeces produced by growing pigs. It is apparent that there were only minor differences in percentage faecal dry matter content across a wide range of water to meal intake ratios investigated within independent studies. Differences in average faecal dry matter values between studies are probably due to variations in the digestibility and composition of the feed used.

(iv) Sweating and insensible water loss from the skin

Evaporative cooling resulting from active sweating and the passive diffusion of water through the skin, are important mechanisms of thermoregulation. For example the latent heat of vaporization of water from the body is about 2.4 J/g H_2O (Mitchell and Kelly, 1938) which represents a substantial cooling effect. Total moisture loss from the body surface is a function of the distribution and number of active apocrine glands, total skin surface area, the vapour pressure gradient between the skin and the surrounding air and ambient temperature.

It is difficult to determine the contribution of apocrine discharge to total skin moisture loss. An indication of potential output is an estimation of the number of glands present on the skin surface. In cattle, sheep and pigs the distribution of glands is associated with the location of hair follicles (Montagna and Yun, 1964; Roubicek, 1969). Whereas the sweat

Table 1.7. The effects of feed moisture content on the dry matter content of faeces produced by growing pigs

Moisture content of feed (%)	**Dry matter content of faeces (%)**	**Water provision***	**Reference No.+**
10	32.8-36.6	A	3
10	34.0-34.6	A	4
40	34.2	A	4
50	33.5-35.2	A	3
60	23.7	N	1
60	28.9	N	1
70	21.2-24.9	N	1
73	28.9	N	2
75	23.5	N	1
77	31.5	N	2
79	22.2	N	1
85	33.2-38.1	A	4
95	32.8	N	2

+ 1 Castle and Castle (1957)
2 Cooper and Tyler (1959)
3 Kornegay and Graber (1968)
4 Kornegay and Vander Noot (1968)

* Supplementary water not provided (N)
Supplementary water was provided _ad libitum_ (A)

glands of cattle and sheep are active, pig apocrine glands may be dormant as histological examinations by Ingram (1967) have shown that they are blocked by plugs of keratin.

The starch-iodine test, in which the skin surface is painted with 1 to 2% iodine in alcohol and then brushed over with a suspension of starch in oil, is a common method for detecting the response of active glands to stimuli. Using this test Ingram (1967) found that apocrine glands located on the back, flank, belly, face and legs of pigs showed little or no response to thermal or chemical stimulation. Only electrical stimulation of the cervical sympathetic nerves using 2 to 7 volts for 2 to 5 seconds evoked a positive response on the snout, neck and face. In a similar study Marzulli and Callahan (1957) observed a limited sweating response in pigs only in those areas which in man are well supplied with apocrine glands, namely the axilla, abdominal midline, perineum and perianal areas. Therefore in comparison to other species, the pig lacks the ability to lose evaporative heat through sweating (Table 1.8). This is further supported by Moritz and Henriques (1947) who demonstrated that water loss from living and dead pigs was similar (12 g/m^2 per h at 21°C and between 30 and 40% RH) and could only be due to the passive diffusion of water through the skin.

Independent determinations of insensible skin moisture loss have been made using sweat cups strapped over the body surface of pigs by Ingram (1964) and from placing individual animals in a moisture isolation unit by Morrison, Bond and Heitman (1967). In the study of Ingram (1964), moisture loss from the belly, flank

Table 1.8. Comparison of the pig, man and other animals in their ability to sweat following heat exposure (H) or intradermal injection of pilocarpine (P) on various areas of the body

	Skin sites tested and active glands per cmm.									
	Medial femoral		Abdominal		Ventral thoracic		Dorsal thoracic		Palms* or foot pads	
	P	H	P	H	P	H	P	H	P	H
Chester White swine+	0	0	0	6-11	0	6-9	0	10-20	0	0
Man	-	90-110	-	250-270	-	100-120	-	150-175	-	280-320
Rhesus monkey	16-29	46-55	4-12	20-25	6-27	25-30	9-24	40-42	10-80	80-120
Mongrel dog	15-20	30-48	9-30	30-45	10-32	60-65	5-10	45-50	0	10-50
Horse	-	-	-	-	-	-	-	> 1000	-	-
Milk goat	0	80-130	0	80-100	0	110-144	0	50-120	0	0

+Additional responses to heat were observed as follows: inguinal 6-10, perineal 14-30, axillary 12-30, superior femoral 10-15

Marzulli and Callahan (1957)

and back of young Landrace pigs increased with increasing temperature and averaged 7, 10, 16 and 32 g/m^2 per h at -5, 10, 25 and 30°C dry bulb (DB) respectively. Infra-red irradiation of these regions doubled the rate of loss at 10 and 25°C (DB) but had little effect at 30°C (DB). Morrison et al. (1967) obtained similar values using two gilts and reported a moisture loss of 13.4 and 25.4 g/m^2 per h at 15.6 and 29.4°C (DB) respectively, held at a constant dew point of 10°C. At a constant temperature of 29.4°C (DB)increasing the relative humidity from 50 to 90% had no consistent effect on skin moisture loss. Using Brody's (1964) equation $A = 0.10\ W^{0.63}$ (where A is total surface area in m^2 and W is body weight in kg) and assuming an insensible moisture loss of 13.4 g/m^2 per h at 15.6°C (DB) and 70% RH, as obtained by Morrison et al. (1967), a 60 kg W pig could lose about 0.42 l/day through this route.

Therefore sweating and insensible moisture loss are not important sources of water depletion in pigs. In fact Ingram (1965b) has demonstrated a net water gain through the pig's skin when the water vapour pressure of the environment exceeded 22 mm Hg. However insensible water loss may be of significance in predisposing suckling piglets to neonatal dehydration, especially where infra-red lamps are used as a source of heat in creep areas (Payne, 1977).

(v) Respiratory water loss

Moisture is continually lost from the respiratory tract through the normal process of breathing. The rate of loss depends on ambient temperature, the vapour pressure gradient between the incoming air and expired air and on the respiratory rate and tidal volume of the lungs. Incoming air is warmed and wetted as it passes over the moist lining of the respiratory tract and is then expired at about 90% saturation (Roubicek, 1969).

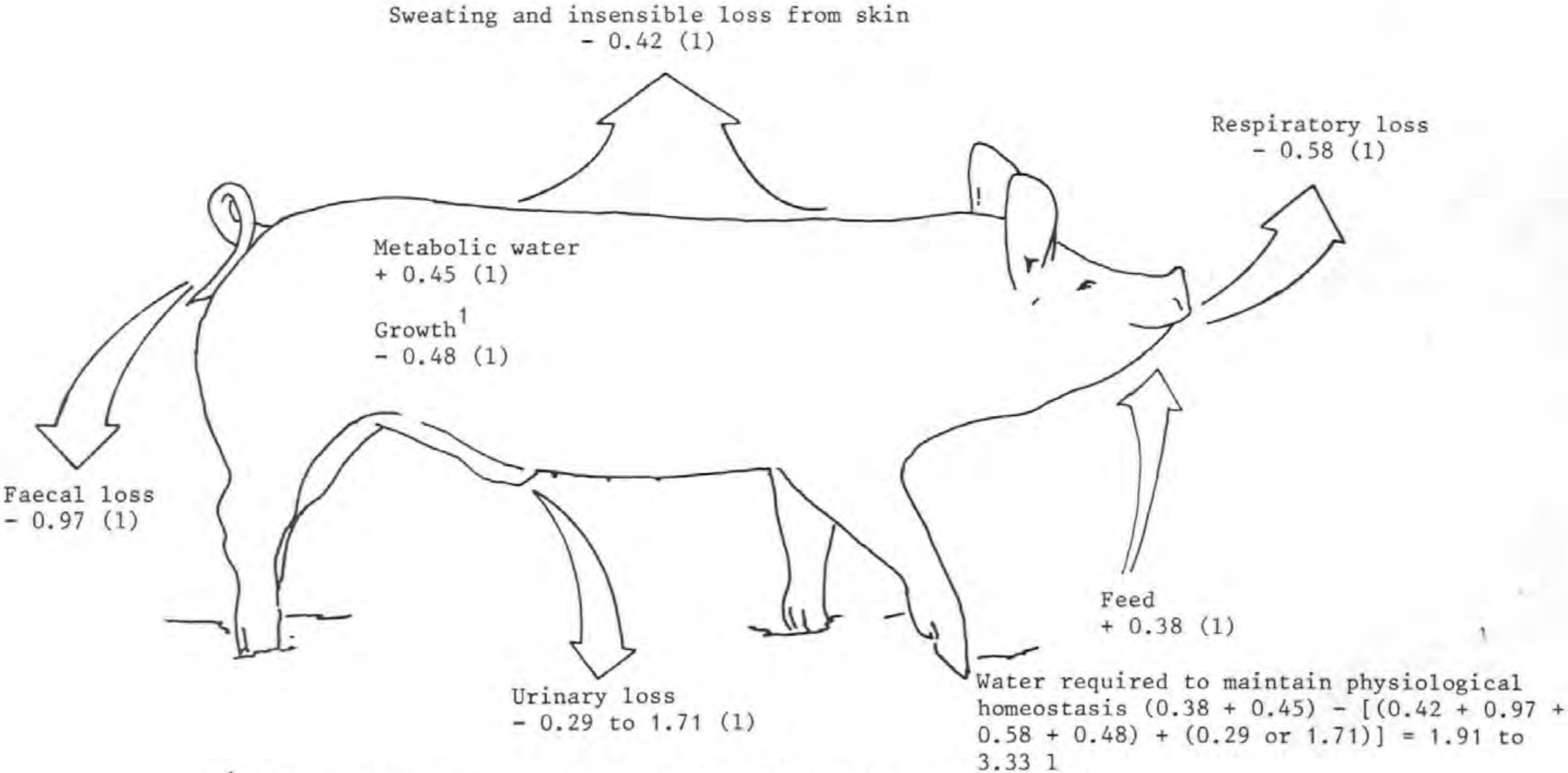
Morrison et al. (1967) studied the effects of ambient temperature and relative humidity on lung moisture loss from two gilts kept in a moisture isolation unit. At a constant dew point of 10°C, increasing the ambient temperature from 15.6 to 24.4°C (DB) rapidly increased the respiratory frequency from 15 to 86 breaths/minute. However since this was accompanied by a 50% reduction in tidal volume from 0.79 to 0.38 l, total lung moisture loss increased only three-fold from 0.28 to 0.87 g/pig minute. When ambient temperature was held at 29.4°C (DB) an increase in relative humidity from 50 to 90% increased the rate of breathing from 100 to 143 breaths per minute but again decreased the tidal volume from 0.53 to 0.33 l respectively. Consequently respiratory moisture loss decreased from 1.12 to 0.41 g/pig minute which represented only 2.9 mg water per breath under high ambient temperature and relative humidity conditions.

Ingram and Legge (1969/70) estimated the total respiratory water loss to be between 378 and 490 mg/pig minute for pigs of 20 to 26 kg W kept at 5°C (DB) and 4°C (WB). This represented a daily lung moisture loss of about 0.54 to 0.71 l/pig day. Taking the data on lung moisture loss reported by Morrison et al. (1967), Randall (1983) estimated a daily respiratory vapour loss of about 0.43 l/pig day from growing pigs. Holmes and Mount (1967) calculated a similar respiratory loss of 0.29 and 0.58 l/pig day for pigs of 20 and 60 kg W maintained at an ambient temperature of 20°C.

Respiratory evaporation is therefore a potential source of heat dissipation in pigs but only at low relative humidities and moderate ambient temperatures. At very high ambient temperatures any beneficial effects of respiratory cooling are offset by the added heat load from the metabolic effort involved in increased respiratory activity. Therefore respiratory cooling becomes increasingly inefficient with increasing temperature. For example Ingram and Legge (1969/70) showed that when ambient temperature was increased from 25 to 45°C although respiratory heat loss increased from about 0.42 - 0.67 to 2.1 kJ/pig minute rectal temperature rose from 39 to 40.5°C. The quantity of water lost due to respiratory ventilation is therefore of similar magnitude to that lost from passive diffusion and active sweating from the skin.

The amount of daily water required to maintain homeostasis can be calculated using the factorial method by adding all the losses, subtracting the contribution from metabolic water, and taking into account requirements for production. For a 60 kg W pig this is equivalent to a value of between 1.91 and 3.33 l/day (Figure 1.3). Assuming a 60 kg W fed to appetite consumes 2.72 kg of air-dry diet per day, containing 13 MJ DE/kg (ARC, 1981) with a moisture content of 14%, this represents a water to feed intake ratio of between 0.71:1 and 1.22:1. This supports the findings of Barber, Braude and Mitchell (1963), Holmes and Robinson (1965), Bowland

Figure 1.3 Obligatory water losses and inputs which determine the amount of water required per day by a growing pig of 60 kg body weight to maintain physiological homeostasis.



[1]Estimated from sequential slaughter data (Shields et al., 1983)

(1965) and Cunningham and Friend (1966) who showed that restricting the water to feed intake ratio of growing pigs to 1.5:1 had little adverse effect on growth and performance. The factorial method has also been used to calculate the daily water requirements of pregnant sows, lactating sows and boars and these are summarised with estimates for the growing pig in Table 1.9. Estimates of water requirement using the factorial method respresents the minimum daily intake required to maintain homeostasis.

Conclusions

This chapter has reviewed the subject of water metabolism in the pig by considering various published reports on the water content of the body, the internal regulation of water balance, thirst and on the rates of obligatory water losses and inputs.

Although the relationship between body water content and the composition of weight gain from birth to maturity have been accurately estimated from sequential slaughter experiments, the effects of changes in body composition on the amount of water required to maintain homeostasis have not been established.

The hormonal regulation of body water balance and the mechanics of the renin-angiotensin system have been widely documented, but the internal and external signals which initiate drinking in response to thirst remain unclear.

Table 1.9. Factorial estimates of the daily water requirements of various class of pig calculated[+] using values for obligatory water losses and inputs derived from published information

	Requirements to maintain body water balance (l/day)	Obligatory water inputs (l/day)		Obligatory water losses (l/day)				Required for production (l/day)		
		Water in feed[a]	Metabolic[b]	Urine[c]	Faeces[d]	Skin[e]	Lungs[f]	Growth	Milk[g]	Others[h]
Growing pig (60 kgW)	1.91 to 3.33	0.38	0.45	0.29 to 1.71	0.97	0.42	0.58	0.48	-	-
Pregnant sow (140 kgW)	2.63 to 5.95	0.36	1.04	0.67 to 3.09	0.94	0.72	1.4	0.17	-	0.13
Lactating sow (160 kgW)	8.05 to 11.75	0.73	1.16	0.74 to 4.45	1.87	0.78	1.56	-	4.99	-
Boars (200 kgW)	3.03 to 7.78	0.28	1.49	0.95 to 5.70	0.74	0.91	2.0	-	-	0.20

[a]Diet containing 140 g water/kg, digestibility of 0.82%; [b]7.43 ml/kgW per day; [c]5 to 30 ml/kgW per day, 95% water content; [d]70% water content; [e]13.2 ml/m^2 per h; [f]0.01 l/kgW per day; [g]80% water content; [h]products of conception, piglets, fluids, membranes, semen. [+]Details of calculations are given in Chapter 1 and in the Appendix.

The depletion of water from the body occurs by obligatory losses in the urine and faeces, from the respiratory tract and by perspiration from and passive diffusion through the skin.

Obligatory inputs include water derived from the moisture content of the feed and metabolic water produced from the catabolism of organic nutrients and body tissues.

The difference between obligatory inputs and losses, allowing requirements for growth, milk production, semen and products of conception determines the amount of water required to maintain homeostasis.

Information published in various reports on obligatory water losses and inputs have been used to calculate the amount of daily water required to maintain osmoregulation and the body water balance of a growing pig weighing 60 kg by the factorial method. This has been estimated to be between 1.91 and 3.33 l/day.

Estimates have also been calculated for lactating and pregnant sows and boars. The information used in these factorial calculations is of limited scope and does not take into account external factors which may influence the rate of obligatory losses and water requirements for production. These estimated values should be treated cautiously.

CHAPTER 2 FACTORS AFFECTING THE PIG'S DEMAND FOR WATER

2.1 Introduction

In the introduction to chapter 5 of The Nutrient Requirements of Pigs, ARC (1981) stated that the pig's requirement for water is determined by the magnitude of water depletion from the lungs, the skin, the intestines and the kidneys, together with the amounts which are included in milk or in new tissue formed during growth or pregnancy. This was followed by a short summary on the findings of 5 studies which reported effects of dietary dry matter digestibility and dietary salt, protein quality and intake on faecal and urinary water loss and on the water intakes of growing pigs.

However this factorial method for the estimation of water requirements was subsequently ignored, as recommendations on water allowances suggested as adequate to meet the requirements of breeding sows and growing pigs were based on various studies which assessed the demands of pigs offered unrestricted access to water or the effects of various degrees of water restriction on commercial performance criterion.

Recommendations for growing pigs were based on 5 studies of limited scope conducted about 25 years ago which showed that pigs offered restricted amounts of water with their feed in ratios of between 1.5 and 3.75 to 1 had no significant effects on the digestibility of dietary dry matter, growth, feed intake and conversion. Although 3 of these studies found improved daily weight gains, feed intake and conversion when pigs were offered an unrestricted water supply, ARC (1981) recommended an allowance of 2 parts of water per part of feed or 1.5 l/day at 15 kg W increasing to 6 l/day at 90 kg W for growing pigs.

Recommended allowances for non-pregnant sows were similar to those for growing pigs. Allowances for pregnant sows were based on production data published by Mitchell and Kelly (1938) which indicated a water to feed intake ratio of 2.5 to 1. Although the various studies on lactating sows reviewed by ARC (1981) showed considerable variations in the demands of individual sows with values ranging from 12 to 40 l/day, an allowance of between 15 and 20 l/day was recommended to meet their requirements for water. However, the provision of an unrestricted supply of water was advised for lactating sows offered dry feed. For lactating sows which received their water mixed with the feed in a wet-feeding system, an allowance of 3 litres of water per kg of feed dry matter was recommended, but ARC (1981) provided no reasons for presenting this discrete ratio. Allowances for boars and growing pigs above 90 kg W were not recommended because of the insufficient information available on this class of pig.

This chapter reviews published studies on the empirical estimates of water usage by various class of pig provided with unrestricted access to water and considers the various factors that may affect the pig's demand for water. In the first section the effects of age and physiological status of the breeding female are discussed and a summary of the literature on recommended water allowances for boars is included. This is followed by two sections which examine studies on the effects of diet composition and ambient temperature on water demand. In the next section, the drinking behaviour of sows, weaned and growing pigs in relation to different systems of housing and feeding has been discussed with reference to the findings of published ethological studies. Finally the various components of water delivery systems have been described and their reported effects on the usage of water by pigs have been considered.

2.2 Estimates of water usage by various class of pig

(i) Effects of age

The suckling piglet

Water consumption, or the need for water, by the suckling piglet has not received serious investigation. This has generally been due to the assumption that the water needs of suckling piglets are satisfied by the water content of sow milk. Therefore the provision of an independent water supply in early life has not been considered of great importance.

According to ARC (1981) the suckling piglet will consume about 856 g milk/day, corresponding to a milk-water intake of 700 g/day. This has been based on the assumption that sow milk has a water to dry matter ratio of about 4.5:1.

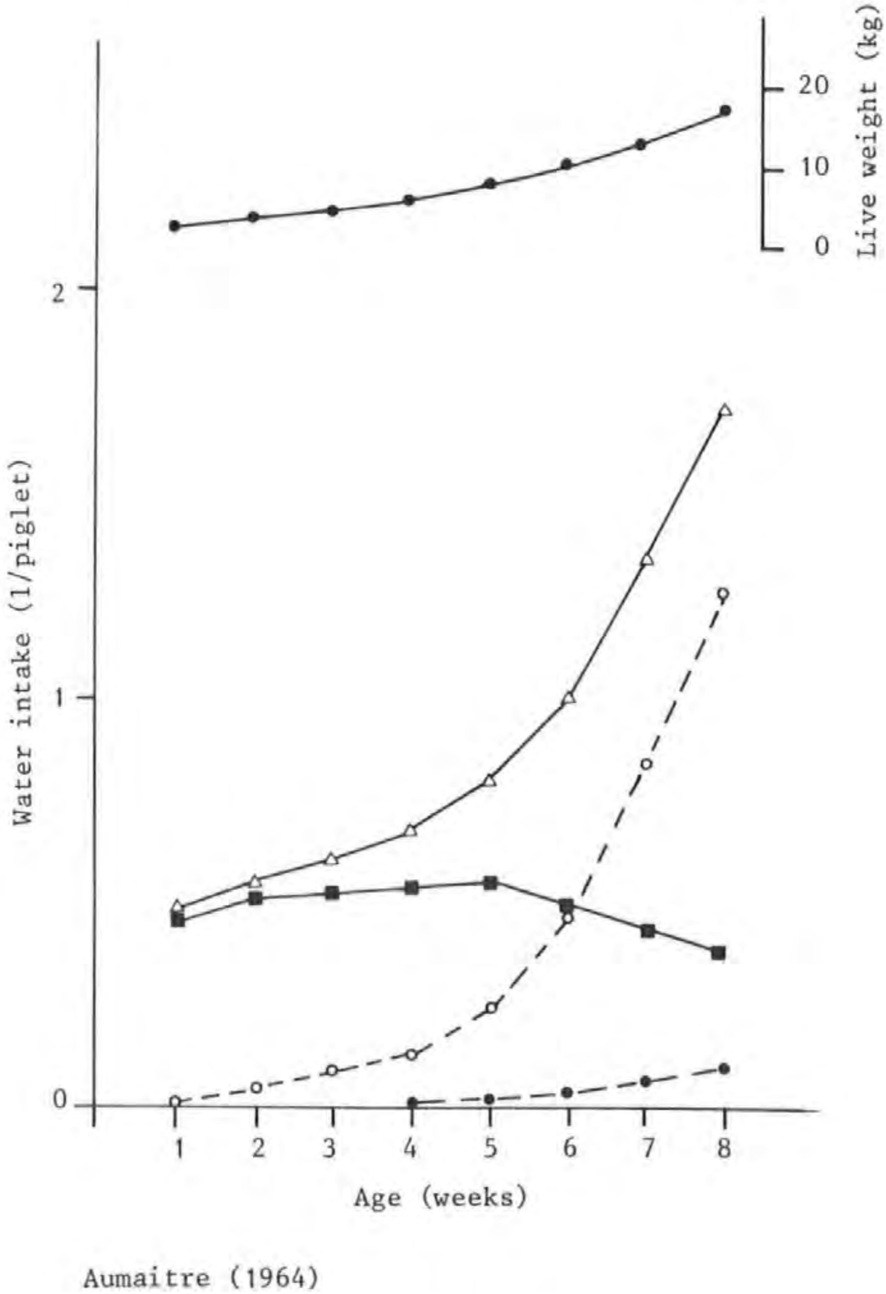
In a recent experiment White and Campbell (1984) estimated the milk yield of 15 sows nursing 10 piglets each. Milk yield was estimated by differences in the body weights of piglets before and after each hourly suckling for 6 consecutive hours per day. Milk consumption averaged 525, 595, 644 and 656 g/piglet day on days 7, 14, 21 and 28 of lactation respectively. Assuming that milk is 80% water (Elsley, 1970), this is equivalent to an average milk-water intake of 420, 476, 515 and 525 g/piglet day on each of the respective milking days. This is lower than the estimate proposed by ARC (1981).

An assessment of the amount of drinking water consumed by suckling piglets in addition to that supplied by the sow's milk has come from a detailed study by Aumaitre (1964). Figure 1.4 summarises the data from 33 litters offered ad libitum creep feed and drinking-water from birth to 8 weeks of age. The quantities of milk-water in the first 4 weeks of age are in close agreement with the results published by White and Campbell (1984). The contribution of sow milk-water to total daily water intake reached a maximum in week 4 of lactation and then decreased linearly until weaning. Changes in the supply of sow milk-water had no influence on the pattern of drinking-water consumed by piglets from birth to weaning. Drinking-water intake averaged 9 g/piglet day in week 5 and increased exponentially to 1.3 l/piglet day at 8 weeks of age. Creep feed was not consumed until week 4 and its moisture content contributed a maximum of only 95 g/piglet day by the end of the suckling period.

Aumaitre (1964) found that the relationship between piglet live weight and daily water intake from birth to weaning could be described by the following equation:-

$$I = 242.8/W + 78.7$$

Figure 1.4 Contribution of water in creep feed (●), sow milk (■) and drinking water (O) to total average daily water intake (Δ) by suckling piglets of between 1 and 8 weeks of age.



Aumaitre (1964)

Where I is daily water intake in g/kg and W is live weight in kg. This equation indicates that water intake per unit of live weight decreased with increasing body weight.

Barber, Braude and Mitchell (1964) compared the growth and creep feed intake of suckling piglets offered either drinking water or formalin treated skim milk from 2 to 8 weeks of age (Table 1.10). Skim milk was taken more readily than water and this slightly depressed creep feed consumption. There were considerable daily variations in the quantities of water, skim milk and creep feed consumed by piglets over the entire suckling period. There were no significant differences in the growth rate of piglets fed either skim milk or offered drinking water. Water consumption was much lower than that reported by Aumaitre (1964).

Although the studies by Aumaitre (1964) and Barber et al. (1964) provide information on the levels of drinking-water consumed by suckling piglets, they give no indication whether the provision of water per se had any beneficial effects on piglet performance.

In a limited experiment involving 9 litters, Friend and Cunningham (1966) used a split-litter experiment to determine the effects of providing suckling piglets with water or glucose solution on creep feed intake, weight gain and carcass composition. Table 1.11 gives the consumption of creep feed, water and glucose solution at weekly intervals from birth to weaning. Figures for average daily water intake were in closer agreement with the values reported by Barber et al. (1964) than those published by Aumaitre (1964). There was a greater

Table 1.10. Growth rate, creep feed and fluid intakes by suckling piglets offered either drinking water or skim milk from 2 to 8 weeks of age

Age (weeks)	Water intake	Creep feed intake	Skim milk intake	Creep feed intake
	(g/piglet day)		(g/piglet day)	
3	32.4	6.5	25.9	6.5
4	45.4	6.5	64.8	13.0
5	77.7	38.9	187.9	32.4
6	155.5	110.1	336.9	97.2
7	298.0	259.1	518.3	226.8
8	487.2	460.0	628.4	388.7
Total (s.d.)	1096.2 (801.2)	881.1 (521.5)	1762.2 (1511.7)	764.6 (461.1)
Total live weight gain from birth to 9 weeks of age kg/piglet (s.d.)		10.79 (2.3)		11.02 (2.4)

Barber _et al._ (1964)

Table 1.11. Consumption of water, glucose solution and creep feed by suckling piglets from birth to seven weeks of age

	Weekly feed intake (g) and proportion of total intake (%) per piglet						Weekly intakes of water and 10% glucose solution per piglet	
	Creep regimens							
	Control lot		Water lot		Glucose lot		Water	Glucose soln.
Week	g	%	g	%	g	%	g	g
1	-	-	-	-	-	-	84	34
2	22	0.01	28	0.01	20	0.01	234	102
3	42	0.19	36	0.11	30	0.10	326	611
4	95	4.38	125	3.89	77	2.69	576	1290
5	247	11.40	355	11.04	413	14.42	1104	2406
6	592	27.33	879	27.34	680	23.74	2159	3904
7	1168	53.92	1792	55.74	1644	57.40	3843	5280
Total	2166*		3215		2864		8326	13627

*Significantly ($P < 0.05$) different from total feed intake of piglets provided with water, but not different from that of the glucose lot.

Friend and Cunningham (1966)

preference for glucose solution than water but the difference was not significant. Water provision significantly increased creep feed intake. The effects of glucose solution and water provision on piglet performance and carcass composition at weaning are shown in Table 1.12. Both liquids significantly improved total body weight gain and carcass weights at weaning compared with control piglets receiving creep feed without supplementary fluids. The heavier carcasses from piglets fed glucose were attributable to a higher fat content whereas the effects of providing water were due to a greater carcass protein yield.

The weaned piglet

The suckling piglet obtains both its nutrients and water in a single package from the sow. Milk-water accounts for over 80% of a suckling piglet's daily water intake at 3 weeks of age and this remains as high as 80 and 68% during week 4 and 5 of lactation as indicated by the results of Aumaitre (1964). Weaning at around 3 to 4 weeks of age must represents an abrupt change where the piglet's supply of water is removed from its source of nutrients which are usually presented in the form of dry feed. Considering this abrupt change, it is surprising that there is so little published information on the water needs of the early weaned piglet.

In a recent study Brooks, Russell and Carpenter (1984) monitored the performance and daily water intake of weaned litter groups offered one of two commercial diets from 3 to 7 weeks of age. The results of this study are presented in Table 1.13. Weight gain and feed conversion improved with age, with concurrent increases in water and feed intake. The water to feed intake

Table 1.12. Weight gains and carcass composition of piglets provided with water or glucose solution from birth to seven weeks of age

	Liquid Supplement		
	Control (nil)	**Water**	**Glucose soln.**
Initial body weight (kg)	1.25	1.26	1.24
Body weight gain, total (kg)	11.05A	12.49B	12.29B
Body weight gain, 0-3 weeks (kg)	3.88	4.03	3.91
Body weight gain, 3-5 weeks (kg)	3.06a	3.48b	3.43b
Carcass weight (kg)	9.03a	9.85b	9.73b
Carcass gain (kg)	7.95a	8.83b	8.72b
Carcass composition (%)			
Dry matter	35.90A	35.69A	37.58B
Ash	3.73	3.69	3.60
Crude protein	18.09Aa	17.73Ab	16.88B
Fat	14.07A	14.27A	17.10B
Fat:protein ratio	0.78A	0.81A	1.02B
Carcass protein (kg)	1.62	1.75	1.64

Differences between means with different superscript letters are statistically significant at the 5% (a,b) or 1% (A,B) level of probability.

Friend and Cunningham (1966)

Table 1.13 Water intake, feed intake and performance of weaned piglets from 3 to 7 weeks of age fed two different commercial diets

	Weight gain (g/day)			**Feed conversion ratio**			**Feed intake (g/piglet day)**			**Water intake (litres/piglet day)**		
Week	**Diet A**	**Diet B**	**sed**	**Diet A**	**Diet B**	**sed**	**Diet A**	**Diet B**	**sed**	**Diet A**	**Diet B**	**sed**
1	92	109	45	2.18	2.67	0.80	164	187	29	0.71	0.74	0.04
2	237	263	26	1.50	1.43	0.20	340	375	31	1.09	1.31	0.14
3	366	370	27	1.57	1.61	0.07	567	594	34	1.63	2.16	0.39
4	478	430	33	1.61	1.75	0.20	762	704	59	2.15	2.58	0.44

None of the within week differences between treatments were statistically significant ($P > 0.005$).

Calculated chemical analysis of the commercial diets

Component	**Diet A**	**Diet B**
Protein (g/kg)	236	244
Oil (g/kg)	51.5	56.7
Crude fibre (g/kg)	37.0	35.5
Available lysine (g/kg)	12.0	13.5
Calcium (g/kg)	8.0	6.0
Phosphorus (g/kg)	6.0	6.0
Salt (g/kg)	3.5	3.5
Digestible energy (MJ/kg)	14.3	14.5
Moisture (g/kg)	130.8	130.0

Brooks _et al._ (1984)

ratio over the trial period averaged 3:1 which varied between 2.8 to 4.3:1 due to high between pen group variations in daily feed and water intake. Feed intake was related to water intake and was described by the following regression equation:

$$Y = 0.149 + 3.053X \ (P < 0.001; \ R^2 \ 0.65)$$

Where Y is water intake in l/piglet day and X is feed intake in g/piglet day, pooled for both diet types.

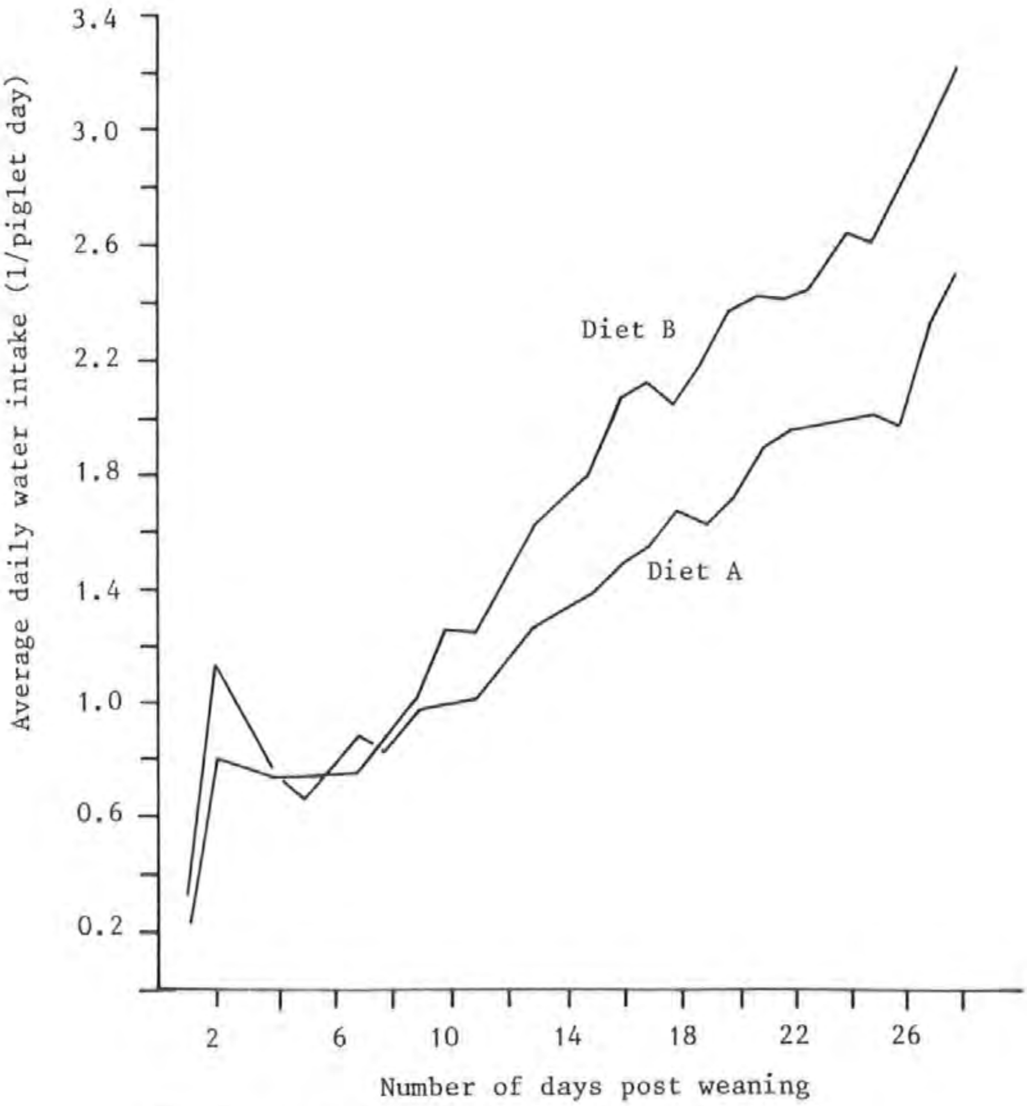
The relationship between average daily water intake and the number of days post weaning for the 2 diets is shown in Figure 1.5. Water consumption in the 24 hours after weaning was very low but this increased markedly on day 2. A normal pattern of water intake was not established until the second week of weaning.

Some additional data on water intake has come from a study conducted by Nienaber and Hahn (1984) on 4 week old weaned piglets. Water and feed intake averaged 3.72 l and 1.58 kg/piglet day respectively during 6 weeks after weaning.

<u>The growing pig</u>

A summary of data from various studies on the water intake of growing pigs of between 20 and 90 kg W is presented in Table 1.14. The relationship between water intake and live weight reported in some of these studies differ greatly. The study by Bauer, Ober and Schlenker (1978) indicated a linear relationship between water demand and live weight whereas the results reported by Antoni (1968) and Daelemans and Bekaert (1971) suggested curvilinearity.

Figure 1.5 Relationship between average daily water intake and number of days post weaning for piglets of between 3 and 7 weeks of age fed 2 different commercial diets.



Brooks et al. (1984)

Table 1.14 Summary of data from various studies on the water intakes of growing pigs of between 20 and 90 kg W

Live weight (kg)	< 20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	> 90	Reference No.+
		← 3.5 to 4.3 →								1
			7.5	10.1	11.1	10.2	9.3	9.0	10.1	2
	← 5.7 →									3
		4.9		4.9	5.9	6.4	7.2	7.6	6.4	4
	2.87									5
(Belgian Landrace)		3.01	3.44	3.53	3.84	4.39	4.71	5.13	4.63	6
(Pietrain)			2.42	2.86	3.69	4.27	4.3	4.11		6
		2.5	3.5		4.5	5.1	5.4	5.4	5.4	7
	3.4 to 5.3					6.3 to 8.1				8
		← 6.92 →								9
		← 5.4 to 5.8 →								10
			2.3 to 6.3							11
			← 5.5 →							12
			4.9					7.39		13
			2.3 to 6.3							14

+ 1 Alsmeyer et al. (1955); 2 Antoni (1968); 3 Barber et al. (1963); 4 Bauer et al. (1978); 5 Braude and Johnson (1953); 6 Daelemans and Bekaert (1971); 7 cited by Daelemans and Bekaert (1971); 8 Hagsten and Perry (1976); 9 Hepherd et al. (1983); 10 Lightfoot (1985); 11 Maigne (1985); 12 Mamede et al. (1982); 13 Mount et al. (1971); 14 Yang et al. (1981).

A curvilinear pattern of water demand was also apparent in the data obtained by Braude, Clarke, Mitchell, Cray, Franke and Sedgwick (1957) with growing pigs of between 10 and 36 weeks of age (Figure 1.6).

Antoni (1968) recorded a peak consumption of 11 l/pig day at about 56 kg W whereas Daelemans and Bekaert (1971) observed maximums of 5.1 l/pig day at 83.2 kg W and 4.3 l/pig day at 75.8 kg W for the Belgian Landrace and Pietrain breeds respectively. Braude et al. (1957) found that water intake reached a maximum of about 6.8 l/pig day between 16 and 20 weeks of age and thereafter decreased by about 0.13 l/pig week to a minimum of 4.7 l/pig day at 36 weeks of age.

As with water intake, the average water to feed intake ratio for growing pigs differs markedly between independent studies (Table 1.15). When water intake is expressed as a function of feed intake, the data published by Braude et al. (1957) suggests that water demand per unit of feed consumption decreases curvilinearly with increasing age. This is further supported by the results of Pieterse (1963) and Antoni (1968) and to a lesser extent from those produced by Daelemans and Bekaert (1971) with the Belgian Landrace but not with the Pietrain (Figure 1.7). In the Pietrain, the water to feed intake ratio increased curvilinearly reaching a maximum of 1.73 at 65.7 kg W then decreasing linearly to 1.54 at 86.4 kg W.

Figure 1.6 Relationship between age and water intake (□), feed intake (▲) and water to feed intake ratio (●) of growing pigs (Braude et al., 1957).

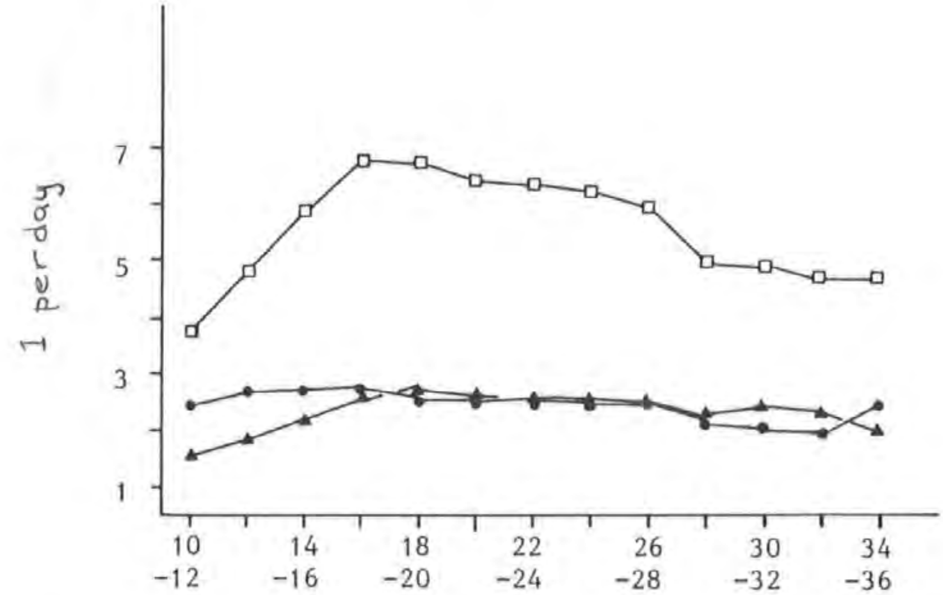
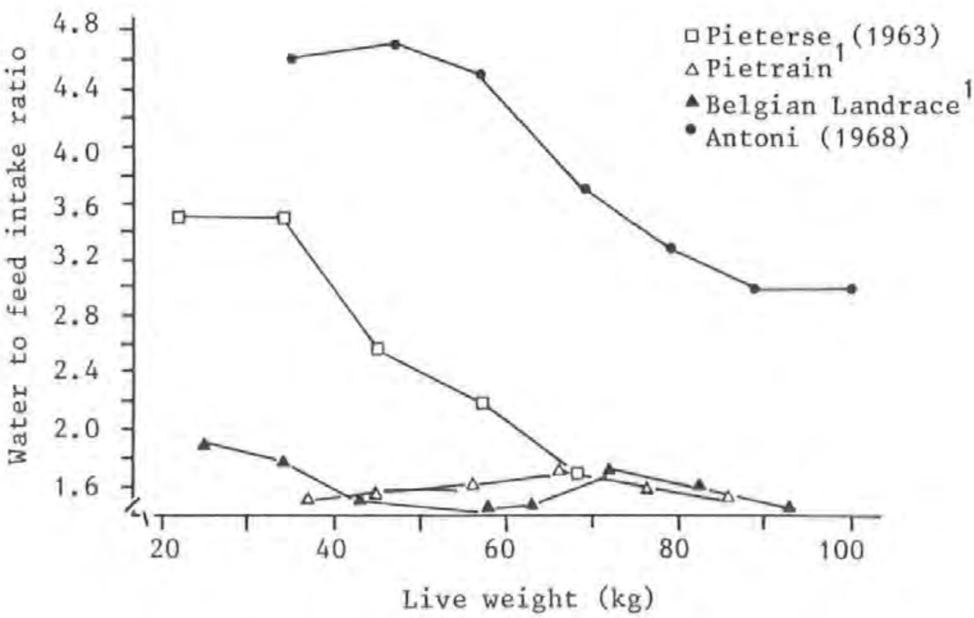


Figure 1.7 Relationship between the ratio of water to feed intake and live weight of growing pigs reported in 3 independent studies.



[1]Daelemans and Bekaert (1971)

Table 1.15. Average water to feed intake ratio of growing pigs reported in various published studies[++]

Live weight (kg)	Average water to feed intake ratio	Feeding regime	Reference No.[+]
35-100.5	3.86:1		1
18-95	2.4:1	3 kg/day, twice daily using 1 part of water per part of feed	2
(10-36 weeks of age)	2.46:1	2.72 kg/day maximum	3
20-90	3.3:1	2.1 kg/day, twice daily	4
16-91	3.0:1	1 to 3.6 kg/day	5
19-91	2.2:1	Wet fed using 1 part of water per part of feed	5
36-97	2.1:1	*Ad libitum*	6
37-73	2.2:1	*Ad libitum*	7
21-46	2.7:1	46.8 g/kg W per day	7
18-60	2.8:1	Fed to scale	8

[++]Pigs had access to an unrestricted supply of water in all these studies

[+]1 Antoni (1968)
2 Barber *et al.* (1963)
3 Braude *et al.* (1957)
4 Hepherd *et al.* (1983)
5 Holmes and Robinson (1965)
6 Mamede *et al.* (1982)
7 Mount *et al.* (1971)
8 Pieterse (1963)

(ii) Effects of physiological status

The pattern of voluntary water and feed intake by maiden gilts offered a free-choice ad libitum feeding system from which they could select either cereal or protein pellets was monitored for 22 weeks by Friend (1973). The results of this study are presented in Figure 1.8 which shows that water intake paralleled feed intake and both decreased gradually as animals approached mature weight. A decrease in growth rate with the advancement of maturity was the explanation given for the reduction in the requirements for feed and water. From Figure 1.8, mean water and feed intake of these gilts has been estimated to be 6.7 l and 2.9 kg/day respectively. This is equivalent to a water to feed intake ratio of 2.3:1. Distinct periodic depressions in dry matter and water intake were found to coincide with oestrus (Figure 1.9).

The effects of oestrus on water and feed consumption reported by Friend (1973) have also been observed in cattle (Roubicek 1969), Zebu type heifers (McFarlane, 1967) and in ewes (Tarttelin, 1968). Hormonal disturbances of the thirst mechanism and intense sexual excitement have been suggested as possible reasons for reducing drinking activity during oestrus. Furthermore Payne (1977) suggested that sex hormones may have a direct effect on water metabolism because females become alternately hydrated and dehydrated during the oestrous cycle.

The water intake of pregnant sows has been studied by a number of workers and their results are summarised in Table 1.16. A

Figure 1.8 Mean weekly intakes of water (●) and dry matter (▲) and body weight (■) changes of post-pubertal maiden gilts from 125 to 180 kgW.

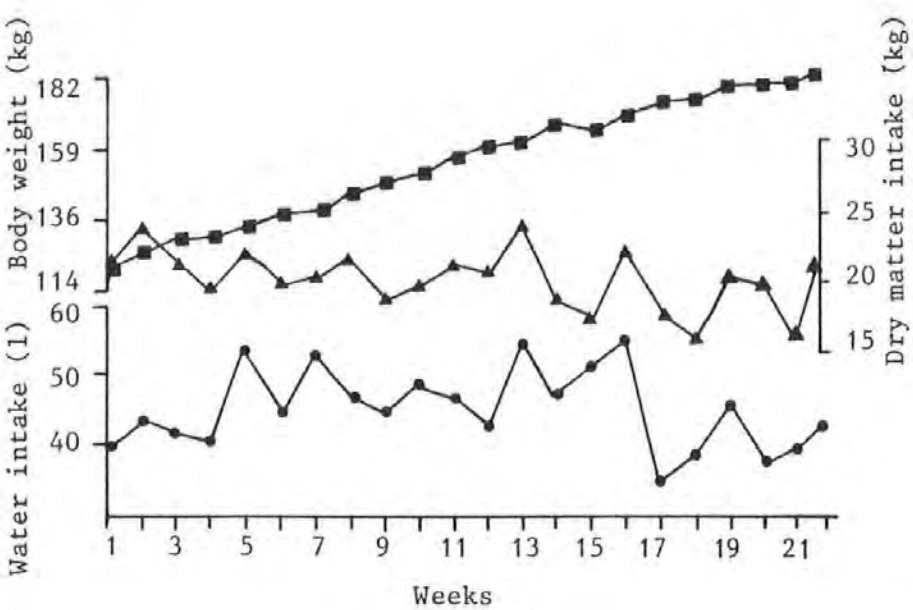
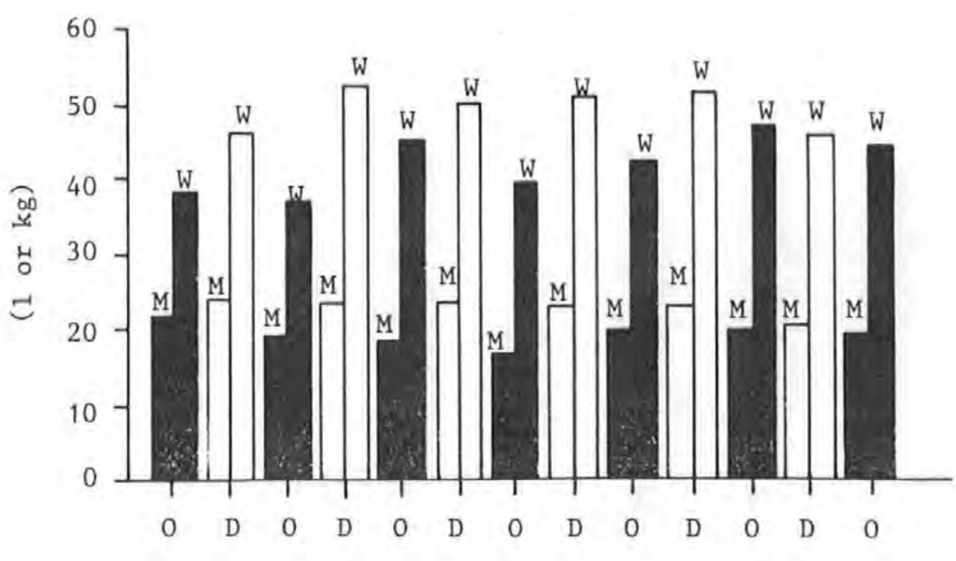


Figure 1.9 Mean weekly intakes of water (W) and dry matter (M) by post-pubertal maiden gilts during periods of oestrus (O) and dioestrus (D).



Friend (1973)

Table 1.16. Summary of the independent published values on the water intake of pregnant sows

No. animals	Age/weight	Feeding regime	Housing conditions	Water consumption	Reference No.[+]
19	Gilts (100 kg W at 1st service)	*Ad libitum*	Indoors in individual farrowing pens (18 to 19.2 °C)	2.3 or 7.6 water/ feed ratio	1
21	Sows	*Ad libitum*	At grass in huts (from Nov to Aug)	16.9 to 17.3 l/sow day last wk of pregnancy	2
24	155-233 kg W (12 gilts, 12 sows)	1.5-2.3 kg/sow d	In farrowing crates	10.1 (range 6.8 to 13.1) l/sow day last 3 wks of pregnancy	3
55	Sows	Unspecified	Housed	x = 20.6 l/sow day over 99 days (s.d. 2.83)	4
46	Sows	Unspecified	Housed	15.6 l/sow day over 100 days (s.d. 3.68)	4

[+]1 Friend (1971); 2 Garner and Sanders (1937); 3 Lightfoot and Armsby (1984); 4 Maigne (1985) notable feature of these results is the considerable variation in both the average and range of values for water consumption between different studies.

Friend (1971) recorded the water intake of 19 pregnant gilts and sows offered ad libitum cereal and protein pellets under a selective feeding system. The gilts were mated at about 100 kg W and their pattern of body weight change, water and dry matter intake were monitored over 2 reproductive cycles (Figure 1.10). In both cycles, water and feed intake increased rapidly during 2 to 3 weeks after conception, but then decreased towards parturition. As the rate of decrease in water intake was greater than feed intake, the water to feed intake ratio also decreased with advancing pregnancy (Figure 1.11). A similar observation was made by Madec (1985), who found that the average daily water consumption of pregnant sows decreased significantly from 7.9 to 5.6 l after week 11 of pregnancy.

Comparative data on the water intake and urine output of pregnant and non-pregnant gilts obtained by Elsley, Anderson, McDonald, MacPherson and Smart (1966) suggests that ingested water was metabolized with greater economy in pregnant animals. It was found that while pregnant gilts consumed significantly less water than non-pregnant controls (4.57 v 4.96 l/day), their urine output was also significantly lower (2.07 v 2.85 l/day), which showed that pregnant gilts retained 0.39 l water per day more than non-pregnant gilts. This increased water retention may be associated with increased protein retention in pregnancy and requirements for uterine growth and the products of conception.

Figure 1.10 Mean weekly intakes of water (●) and dry matter (▲) and body weight (■) changes of gilts and sows over 2 reproductive cycles.

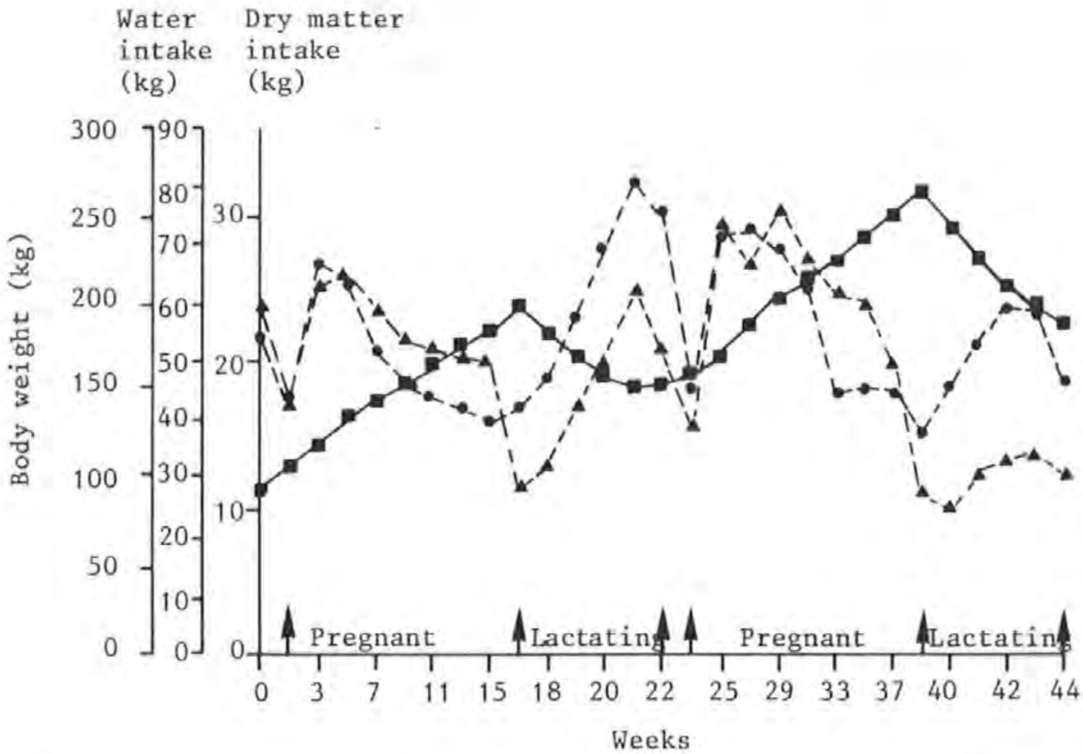
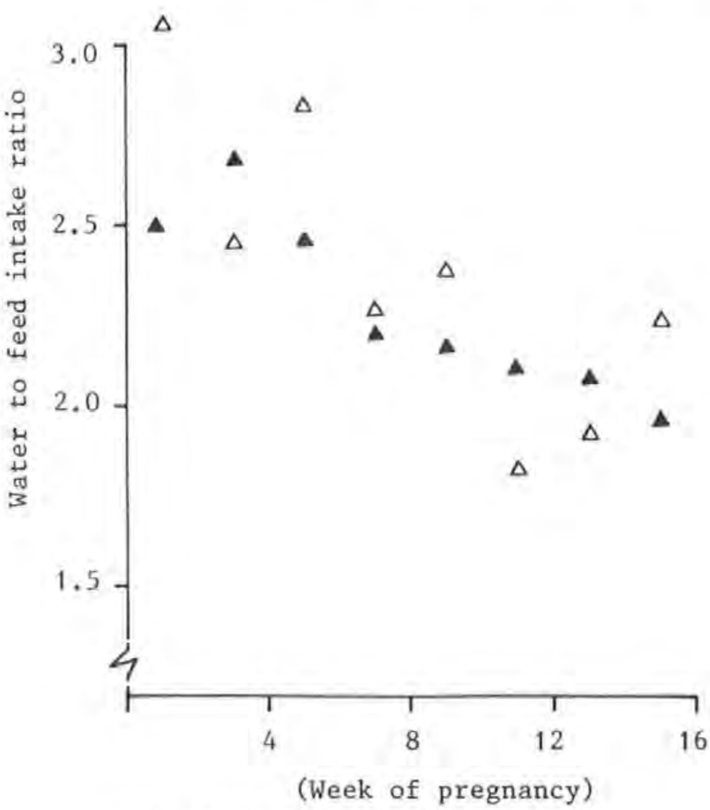


Figure 1.11 Relationship between stage of pregnancy and the ratio of water to feed intake for gilts (▲) and sows (Δ).



Friend (1977)

For example, in the same study Elsley et al. (1966) reported a significantly higher daily nitrogen retention by pregnant than by non-pregnant gilts (33.6 v 24.8%) on similar diets which provided 49.4 g N/day.

A part of the maternal weight gain during pregnancy could be accounted for by a net increase in water retention as indicated in the sow by Penzes (1961; cited by ARC 1981). Conversely Hovell, MacPherson, Crofts and Pennie (1977) found no significant differences in the moisture contents of carcasses from once-bred gilts and those from maiden gilts, both adjusted to an empty body weight of 116 kg. However carcass data relating to once-bred gilts was obtained from animals slaughtered 9 days post-partum which by then may have obscured any effects of pregnancy on body water retention.

Friend (1971) suggested that a decrease in water demand during gestation may be due to a reduction in uterine fluids in late pregnancy as demonstrated by the findings of Pomeroy (1960).

ARC (1981) indicated that a greater need for water due to an increased metabolic activity in late pregnancy may be offset to some extent by an improved feed conversion ratio. However in a recent study on sows, Bauer (1982) found that before mating water intake averaged 11.5 l per day, which increased to 15 l per day in late pregnancy.

According to Heap (1978), the increased retention of body water, protein and fat in the pregnant animal is hormonally regulated.

Progesterone is believed to play an important role but the mechanism by which it exerts its effects is not clear. In the mouse, progesterone induces water retention and increases protein anabolism. However in the mouse, but not in the sow, it also stimulates appetite and feed intake.

Water constitutes over 80% by weight of the milk of most species (Mepham, 1976). The comparative figure for sow milk calculated from a number of studies cited by Perrin (1953) is 81.2%. The increased metabolic activity of a lactating animal for milk synthesis therefore results in corresponding increases for water and nutrients requirements.

This is illustrated by Friend (1971) who showed that the onset of lactation in sows increased the demand for water and feed immediately after farrowing (Figure 1.10). The rate of increase in water intake was greater than feed intake resulting in a mean water to feed intake ratio of 3.9:1 after farrowing compared with 2.3:1 during pregnancy. A decline in daily water demand was found to occur around week 4 of lactation. This did not coincide with weaning at the end of week 5. Water intake during lactation averaged 8.1 l/day which is considerably lower than the 14 l/day estimated from heat and milk production data by Mitchell and Kelly (1938) and a range of 13 to 18 l/day observed by Lenkeit (1959).

In a series of experiments, Garner and Sanders (1937) recorded the water intake of 37 suckling sows at grass (Table 1.17). Water consumption increased after farrowing and averaged 19.4 l/day during a 6 week suckling period. Intake started to

Table 1.17. Water intake of sows at pasture before and after farrowing

Period	Mean temp. (°C)	No. of sows	Ave. no. of pigs per litter (weaned)	Av. wt. per pig at 6 weeks (kg)	Mean consumption per sow per day (litres)							Mean for weeks 1-6 after farrowing
					Week preceeding farrowing	Weeks after farrowing						
						1	2	3	4	5	6	
(1) Nov-Mar	7.14	10	7.6	10.2	16.9	18.9	18.4	17.9	18.3	17.9	17.0	18.0
(2) June-Aug	18.10	11	9.3	10.9	17.3	19.6	21.4	20.8	20.8	20.8	21.1	20.8
(3) Dec-Mar	2.24	8	7.9	11.1	-	20.6	19.9	19.7	20.5	18.5	18.5	19.6
(4) Apr-June	11.70	8	7.9	-	-	17.8	19.8	20.1	20.0	17.1	17.7	18.7
All periods	-	37	8.2	-	-	19.3	19.9	19.6	19.9	18.7	18.7	19.4

Garner and Sanders (1937)

decrease by week 5 of lactation, but as each sow received about 2.3 l water per day with the feed during the first week after farrowing, Garner and Sanders (1937) concluded that there was a tendency for water consumption to decrease throughout lactation. However, these results may be confounded by water supplied from the weight of fresh grass grazed by individual sows. There were considerable individual variations in daily water intake with values ranging from 2.3 to 43.1 l/sow.

Similar variations in the water intake of individual lactating sows have been reported by Lightfoot (1978). Although water intake averaged 18 l/day, this fell within a range of 12 to 40 l/day from day 5 of lactation to weaning at 3 weeks. In another study on sows weaned at 3 weeks, intake ranged from 14 to 21.3 l/day and averaged 17.7 l/day (Lightfoot and Armsby, 1984).

In a recent study Maigne (1985) obtained data on water intake using 2 groups of lactating sows in separate observations. Although no information was provided on weaning age, water consumption averaged 32.6 (s.e. 2.78) and 23.8 (s.e. 1.78) l/day in each of the respective groups. In another experiment involving lactating sows, Maigne (1985) reported a mean intake of 24.2 (s.e. 2.15) l/day which ranged from 6 to 47 l/day.

(iii) Water allowances for the boar

There have been very few published studies on the water requirements of working boars. Fevrier (1977) suggested that boars could be maintained on allowances which are adequate for growing pigs, as the provision of 2 parts of water per part of feed had no adverse effect on reproductive performance. Recently Suss (1985) suggested a more generous allowance of at least 8 l/day, whereas Menguy (1978) suggested an even higher value of 11 l/day. However it appears that these recommendations have been made without the support of experimental evidence.

The young working boar will require water for semen production in addition to that required for growth and maintenance. Since boar semen is 95% water (White, 1974) and a single ejaculate yields between 150 to 300 ml of semen (Foote, 1974) an adult boar which may be used 3 to 5 times a week will lose between 0.4 and 1.4 l of water per week via this route. Therefore the volume of water required for semen production does not represent a major proportion of the daily water requirements of boars.

2.3 Diet Composition

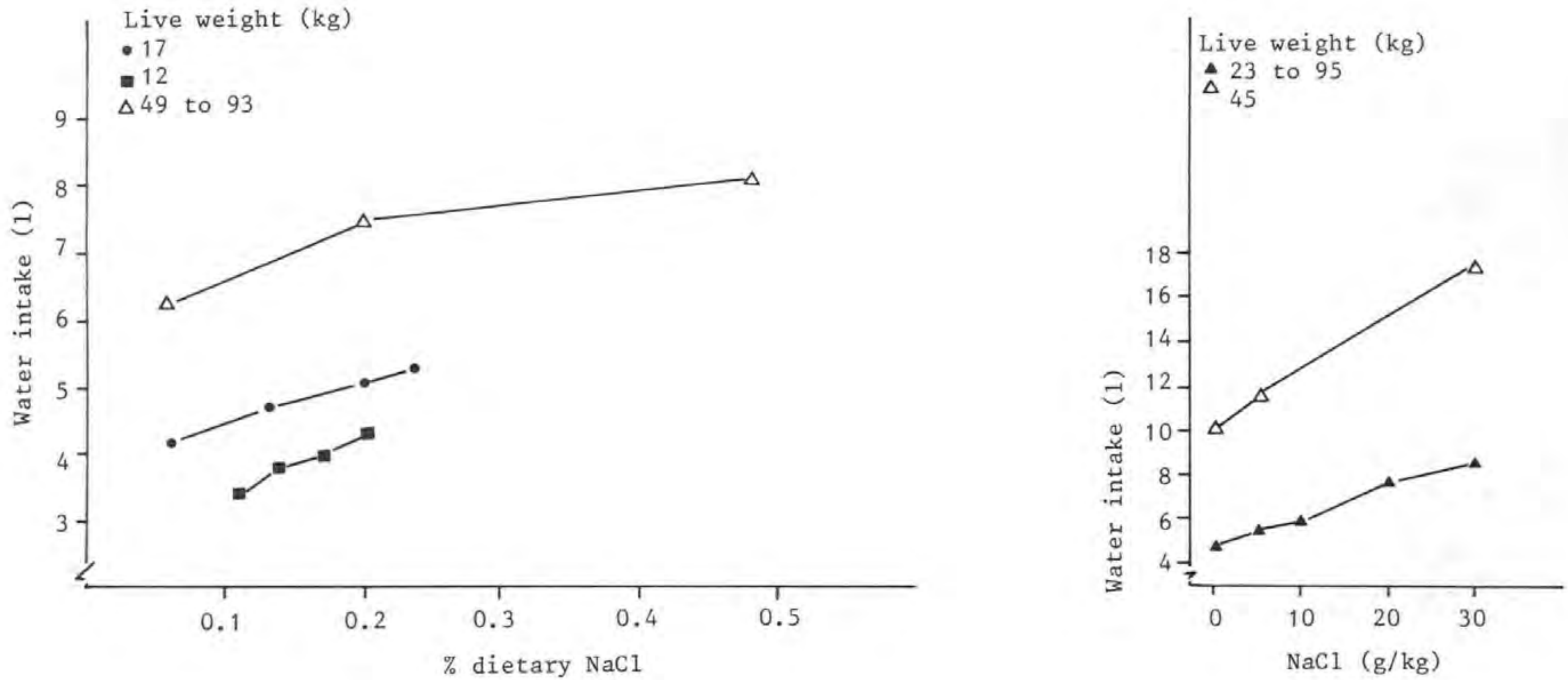
Water has rarely been studied as an integral part of nutrition, only a few workers have incorporated measurements of water intake into their research protocols. Consequently very little is known about the effects of specific nutritional factors on the water demands of pigs. Most of the information available relates water intakes to protein intake and mineral content of the diet with particular reference to sodium chloride. In addition a small number of studies have been published on the effects that antibiotics added to the feed have on water intake.

There is some evidence to indicate that the demand for water is positively correlated with dietary protein level. For example Wahlstrom, Taylor and Seerley (1970) found that the daily water intake of 48 growing pigs fed diets containing 12 and 16% crude protein (from 3 to 6 weeks of age) averaged 3.90 and 5.26 l/pig day respectively. Furthermore protein quality may be equally as important as protein quantity. Garrigus (1948) showed that when growing pigs were fed ad libitum and restricted to about 50% of their normal daily water demand, those receiving a good quality protein consumed more feed, had improved daily live weight gain but used less water per unit of feed intake than those given protein of poorer quality. This suggests that the deamination of the poorer quality protein may increase renal water demand for the excretion of increased urea production.

A few studies have produced dose-response data relating water demand with dietary sodium chloride concentration (Figure 1.12).

Hagsten and Perry (1976) found that when pigs of between 12 and 93 kg W were given unrestricted access to both water and feed, water usage was positively correlated with dietary NaCl concentration. In an extensive study Sinclair (1939) conducted dose-response experiments with growing pigs in order to determine a level of dietary NaCl supplementation which gave an optimum weight gain and performance from 19 to 95 kg W. Using ad libitum feeding and a watering regime which allowed consumption to appetite 3 times a day, 2 dose-response curves were produced for diets containing 0 to 3% supplemental NaCl. Alcantra, Hanson and Smith (1980) used much lower levels of NaCl and found that the addition of 0.08% common salt to a basal diet containing 0.9% NaCl increased the daily voluntary water intake of young pigs (10 to 25

Figure 1.12 Relationship between dietary NaCl and water intake by growing pigs reported in 2 independent studies.



Hagsten and Perry (1976)

Sinclair (1939)

kg W) from 1.45 to 1.71 kg/pig respectively. Additions beyond this level to a maximum of 0.24% NaCl produced no further increases in water demand.

Although these studies indicate that an increase in intake of common salt (NaCl) results in corresponding increases in the requirement for water, very little is known about the relative importance of the sodium cation (Na^+) or the chloride anion (Cl^-) and their specific role in thirst and water intake. The results of a study by Patterson (1984) suggest that the sodium ion **alone** can exert an influence similar to that produced by NaCl. It was found that growing pigs fed a diet containing 80% milled barley treated with 31% NaOH solution consumed significantly more water as compared with a group of controls which received a similar diet but with untreated barley (11.0 v 9.2 l/day). A calculated chemical composition showed that the 2 diets differed only in their sodium content which averaged 18.7 and 1.8 g Na/kg DM in the treated and untreated barley based feeds respectively.

There is some evidence to indicate that high concentrations of dietary potassium can also increase the water requirements of pigs. Farries (cited by ARC, 1981) studied the effects of increasing potassium intake (up to 1322 mg K/kg W) on the metabolism of growing pigs and pregnant sows and found a positive correlation between potassium intake and water demand.
The addition of fibrous material to the diets of growing pigs may increase water demand by increasing faecal water loss. Cooper and Tyler (1959) found that the addition of bran or fibrous

cellulose increased faecal moisture content, frequency of defecation and weight of fresh faeces produced by growing pigs. The laxative properties of the diet were markedly reduced when fibrous cellulose was replaced by powdered cellulose. This suggests that fibre quality is equally important as dietary fibre content. Unfortunately no data was provided on water intake.

A few reports suggest that dietary antibiotics may affect water balance. However results have not always been concordant. Pieterse (1963) found that the addition of 20 mg oxytetracycline per kg of feed increased the daily water demand of growing pigs by 13.7% without any corresponding increases in feed intake. Similarly Braude and Johnson (1953) reported an increased water intake with growing pigs fed a basal diet medicated with 20 g aureomycin per tonne compared with controls fed the same diet but without the antibiotic (2.92 v 2.87 l/pig day). Pigs fed dietary aureomycin had much higher urine output than unsupplemented controls (3.99 v 3.38 l/pig day). Conversely Robinson, Coey and Burnett (1953) recorded a reduction in water consumption but an increase in growth rate with pigs receiving penicillin in the feed. However in a later experiment Holmes and Robinson (1965) found no consistent differences in the water consumption of pigs fed diets with and without penicillin.

2.4 Ambient temperature

There is little quantitative information available on the effects of ambient temperature on the water consumption of pigs. Most of the published data has come from studies using calorimetery at the ARC Institute of Animal Physiology, Cambridge. Table 1.18 summarises the main findings of these reports and also presents results from other studies.

Mount, Holmes, Close, Morrison and Start (1971) used a large calorimeter to investigate the effects of several environmental temperatures between 7 and 33°C on water intake by growing pigs kept in groups of 3 to 6 and either fed ad libitum, 1.83 kg/day or on a scale related to body weight. They found no significant differences in water consumption within the temperature range of 7 to 20°C. A significant increase in water intake was reported with all three feeding levels when the temperature was raised to 30°C and above. In a similar experiment, Close, Mount and Start (1971) recorded water consumption by growing pigs averaging 33 kg W kept for up to 4 weeks in a calorimeter at temperatures of 7 to 30°C and fed according to a scale which provided between 39 and 52 g feed/kg W. Water intake was similar at temperatures between 7 and 20°C but increased markedly at 30°C.

In an earlier study Holmes and Mount (1967) exposed growing pigs of either 20 or 60 kg W in a calorimeter to ambient temperatures of either 9, 20 or 30°C for 2 weeks. Although water consumption per kg of feed intake was highest at 30°C they found that water requirements per kg body weight increased linearly with increasing temperature at both live weights.

Morrison and Mount (1971) measured water and feed intake of growing pigs fed ad libitum and subjected to 3 successive temperature changes of 22, 33 and 20°C at four weekly intervals

Table 1.18 The effects of ambient temperature on water usage of growing pigs reported in various published studies

Live weight (kg)	Feeding regime	Ambient temp (°C)	Water intake (litres/pig day)	Water intake (l/kg feed)	Water intake (l/kg W)	Reference No.+
25	39-52 g/kg W day	7		2.88	0.14	1
38		12		2.76	0.12	
35		20		2.74	0.12	
35		30		4.28	0.18	
73	<u>Ad libitum</u>	20	7.36	2.18		2
37		22	4.98	2.12		
50		33	8.45	5.00		
21-46	42-52 g/kg W day	7-12		2.60	0.12	3
		20		2.60	0.13-0.12	
		30		4.20	0.18	
	1.83 kg/day	20		2.2	0.09	
		30		2.8	0.12	
73	<u>Ad libitum</u>	20		2.2	0.1	
50		33		5.00	0.17	
23	<u>Ad libitum</u>	5	4.10			4
		35	7.33			
30	1.5 kg/pig day	27	4.60	3.10		5
		33	7.50	5.00		
	<u>Ad libitum</u>	27	4.00	1.60		
		33	610	2.40		

+ 1 Close <u>et al</u>. (1971) 4 Nienaber and Hahn (1984) 2 Morrison and Mount (1971)
3 Mount <u>et al.</u> (1971) 5 Yang <u>et al.</u> (1981)

in a large calorimeter. The water to feed intake ratio was similar when the temperature was maintained at 20 and 22^{o}C and averaged 2.2:1. The ratio increased to 5:1 when the temperature was raised to 33^{o}C, this was due to a reduction in feed consumption and an increase in water intake.

Although Yang, Howard and McFarlane (1981) showed an increased water consumption by young pigs at an air temperature of 33^{o}C, the water to feed intake ratios were considerably lower with ad libitum feeding and higher with restricted feeding than those reported by other workers.

Nienaber and Hahn (1984) used a factorial experimental design to investigate the effects of ambient temperature and water flow rates from nipple drinkers on water use by young pigs. There was a significant interaction between flow rate and ambient temperature. Water use increased with increasing flow rate but the rate of increase was considerably greater at an ambient temperature of 35^{o}C. On average pigs spent nearly twice as much time at the nipple drinkers at 35^{o}C than at 5^{o}C. It was suggested that this may be due to a behavioural adaptation resulting from thermal stress as pigs were found using nipple drinkers as showers for evaporative cooling. A similar behavioural response was observed by Close et al. (1971) who found that pigs kept at 30^{o}C made repeated efforts to spill water from drinking bowls and excreted urine and faeces over the entire pen area in an attempt to create a wallow for evaporative cooling.

Variations in ambient temperature within the thermal neutral zone are therefore unlikely to have any appreciable effects on the water demand of pigs. Only when temperatures reach 30°C and above are there notable increase in water consumption.

2.5 Housing and Feeding Systems

There have been very few comparative studies on the effects of different housing and feeding systems on the water demand and drinking behaviour of pigs. Current knowledge is based on behavioural studies using a limited number of animals, where observations on drinking activity have been subsidiary to the main objectives of the study and where measurements of water use have been rarely obtained. This section summarises and discusses the findings of these various reports in relation to the drinking behaviour and water demands of sows and weaned and growing pigs under differing systems of housing and feeding.

(i) Sows

Under contemporary systems of production pregnant sows are housed either individually or in groups. Individual housing usually confines sows in stalls with or without the use of tethers. Group housing may involve the use of stalls to feed sows individually at discrete times or computer controlled feeders which can provide rations for individual sows. The behaviour of sows housed under these varying degrees of confinement has received much interest but little is known about the effects of different housing systems on water demand and drinking activity.

Barnett, Cronin, Winfield and Dewar (1984) studied the effects of five diverse housing systems of differing levels of physical confinement on the behaviour of 30 non-pregnant sows. Although the occurrence of stereotypes such as excessive drinking activity, champing and biting was generally low, the frequency of these repetitive behaviours was higher in sows confined by tethers and stalls compared with sows housed in groups (Table 1.19). Pregnant sows confined in stalls restrained by tethers have been found to show many different kinds of behavioural stereotypes. In a recent study Broom (1986) found that stall housed sows spent between 33.3 and 114.4 minutes performing stereotypes during an 8-hour observation period after feeding. The proportion of this time spent drinker-pressing, bar-biting, nose rubbing and sham chewing varied considerably between individual sows and ranged from 7 to 65%; 0.3 to 9%; 0 to 22% and 0 to 78% respectively.

The behavioural characteristics of individual sows tethered in stalls has been comprehensively described by Cronin (1985) in a study of the development of stereotypes. Most sows were found to develop a basic sequence of stereotypes onto which they added extra components such as drinker associated stereotypes like mouth stretched over the drinker alternated with short drinking bouts. However each sow had its own characteristic sequence of stereotypes and for some sows drinker associated stereotypes were not a part of their sequence. Alternatively one sow incorporated excessive drinking into her sequence accompanied by frequent urination. This was subsequently modified to water spraying which was suggested as a means of reducing her water intake.

Table 1.19 The effects of 5 housing treatments on the behaviour patterns of sows (n/obs. period refers to the mean number of times particular behaviours were recorded, at 10-min intervals, during a 48-h observation period)

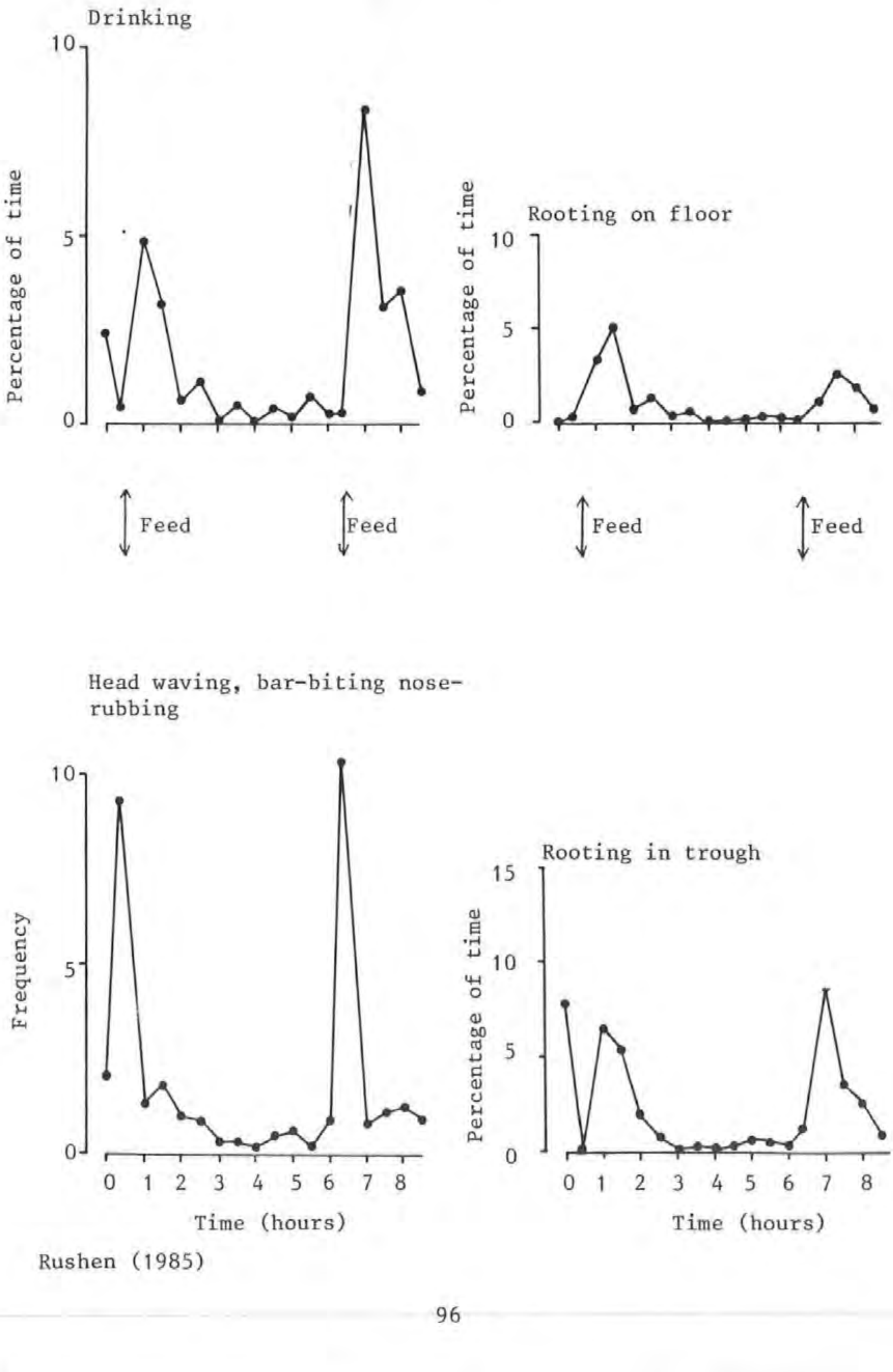
Parameter	Treatment					
	Tethers	Stalls	Group	Yard	Paddock	P
All active (n/obs. period)	41.5^{a}	44.3^{a}	35.8^{a}	45.1^{a}	79.0^{b}	< 0.001
Inactive (n/obs. period)	11.10^{ab}	13.87^{c}	15.57^{c}	5.16^{ab}	4.26^{a}	< 0.001
Resting (n/obs. period)	230.3^{b}	227.6^{b}	231.2^{b}	235.4^{b}	200.6^{a}	< 0.001
Resting alone (% of lying time)	-	10.8^{a}	3.0^{b}	7.4^{c}	7.4^{bc}	< 0.05
Breakdown of active behaviours						
Champing[2] (n/pig/day)	1.06^{a}	0.80^{a}	0.56^{ab}	0.08^{b}	0.0^{b}	< 0.05
Licking, biting and nosing (n/obs. period)	24.9^{a}	31.2^{a}	22.9^{a}	30.7^{a}	52.7^{b}	< 0.05
Biting[2] (n/obs. period)	2.23^{a}	2.80^{a}	0.39^{bc}	0.34^{b}	0.71^{c}	< 0.05
Feeding (n/obs. period)	5.89^{ab}	5.43^{a}	7.78^{c}	7.43^{ab}	8.13^{c}	< 0.001
Use of drinker (n/obs. period)	5.24^{a}	2.55^{ab}	2.56^{ab}	1.50^{ab}	1.32^{b}	< 0.05
Other active inc. champing (n/obs. period)	1.94^{ab}	2.02^{ab}	0.60^{a}	4.28^{bc}	8.70^{c}	< 0.001

a,b,c Means with the same superscript within the same row did not differ significantly (P > 0.05).
Barnett et al. (1984) .

The interaction between feeding time and drinking activity together with the occurrence of stereotypes in tethered pregnant sows has been studied by Rushen (1984 and 1985). In the earlier study, the behaviour of sows was observed one hour before and one hour after feeding. Lying, bar-biting, head-waving and snout-rubbing were more common before feeding whereas frequent manipulation of the drinker and extended drinking activity occurred after feeding. Individual sows which spent a large amount of time manipulating the drinker after feeding spent a similar amount of time rooting in the feed trough. In the subsequent study behavioural observations were extended to nine hours spanning two feeding periods. Drinking and rooting behaviour were again found to occur more frequently two hours after feeding while head-waving, bar-biting and nose-rubbing occurred immediately prior to the delivery of feed (Figure 1.13). It was suggested that the occurrence of persistent post-prandial drinking behaviour and behaviour related to food searching in these sows was motivated by hunger because feed allowance did not satisfy the needs for gut fill.

Grouping of animals allows social interaction which is otherwise restricted by confinement in individual stalls or by the use of tethers. There have been many recent studies on the behaviour of sows housed in groups but limited information is available on the drinking behaviour and water demands of animals under such conditions. Hunter, Broom, Edwards and Sibly (1988) studied social hierarchy in two groups of 20 sows offered unrestricted access to water from two drinkers and fed once a day using a computer controlled feeding station. Social interactions at the

Figure 1.13 Effect of time since feeding on the percentage of time spent drinking, rooting and frequency of head waving, bar-biting and nose rubbing activities by multiparous sows.



Rushen (1985)

drinkers were infrequent and non aggressive. The most common interactions occurred at the feeder queue which generally involved displacement without resistance.

Andersson, Schaar and Wiktorsson (1984) found that social hierarchy was positively correlated with water consumption from a single bowl shared by cows tied up in pairs. As a result of the competition over water supply submissive cows spent less time per drinking bout (31 v 44 seconds) but showed an increased daily drinking frequency (38 v 28/24 h).

The drinking behaviour of group housed sows fed individually in stalls at discrete feeding times has not been studied in detail. Increased post-prandial water demand reported in tethered sows may be an important factor which could modify the behaviour of sows at the drinkers following release from feeder stalls in this type of housing system. As a consequence the incidence of antagonistic social interactions at the drinkers may be much higher than the lack of such behaviour reported by Hunter et al. (1988) in sows fed using an electronic feeder.

(ii) Weaned and growing pigs

Flat-deck cages are widely used to rear piglets weaned at about 3 to 4 weeks of age. However, the water demand and drinking behaviour of these early weaned piglets have not been studied in detail and no known comparisons have been made with less intensive systems used to house piglets weaned at an older age.

Wood-Gush and Csermely (1981) studied the behaviour of three week weaned piglets in flat-deck cages immediately following and 21 days after weaning. Observations were made on 8 litters at 2 minute intervals from 08.30 h to 20.30 h during two successive days. At 3 and 6 weeks of age time spent drinking, feeding, lying, exploring and in aggressive behaviour averaged 2.7%, 3.7%; 8.8%, 10.7%; 68.7%, 67.9%; 11.3%, 13% and 1.9%, 0.7% respectively. The proportion of time spent drinking may have been underestimated as Brooks et al. (1984) found that water intake by piglets weaned into flat-deck accommodation at three weeks of age occurred throughout the 24 h cycle with an estimated 36% of total daily consumption taking place between 17.00 and 05.30 h. Continuous lighting was used in both these independent studies. Alternatively weaned piglets exposed to a 12 h light (06.00 to 18.00 h) and 12 h dark cycle have been reported to confine most of their drinking, feeding and other activities during the period of light (Ingram, Walters and Legge, 1980). This circadian activity collapsed when the lighting regime was switched to continuous exposure. These studies suggest that weaned piglets do not display strong circadian rhythms of water and feed intake under continuous exposure to light and will consequently drink and eat during the hours of night.

There are a diversity of housing and feeding systems currently used for growing pigs in the UK. In general animals are group housed either using effluent or straw based systems. Feeding can be either 'wet' which involves the mixing of meal with water before feeding at discrete time intervals or 'dry' either in the form of meal or pelleted feed offered ad libitum to slaughter or restricted at some point during the finishing stage. The effects of these different combinations of production systems on the water demand and drinking behaviour of growing pigs have not been extensively investigated.

A recent study by Shillito Walser, Hague and Parrott (1988) suggests that there may be an interaction between feeding regime and the availability of bedding material on water use. The provision of straw was found to significantly reduce the water use of growing pigs on restricted feed allowances but not with ad libitum feeding. Conversely Lightfoot (1985) found no significant differences in the water use of growing pigs provided with and without straw and fed on a scale related to days on trial.

In pipeline wet feeding systems, the mixing of large quantities of fresh water with the dry meal ration prior to delivery increases the contribution of dietary water to total daily water intake by a significant amount. When no other drinking water supply is available for wet fed pigs, which is common in commercial practice, the entire daily water intake of pigs is derived from the liquid diet. The total quantity of water ingested would be determined by the amount of liquid feed consumed and the ratio of water to meal in the liquid diet.

The water demands over and above that provided in the liquid diet of wet fed pigs have not been studied in detail. Roller, Teague, Grifo and Cahill (1965) compared the water consumption of growing pigs of between 54 and 95 kg W fed a meal offered ad libitum or at the rate of 2.27 kg/day given either dry or as a liquid feed containing between 60 and 63% moisture. Total daily water consumption on these feeding regimes averaged 4.24, 3.70 and 4.31 l/day respectively. Liquid fed pigs consumed 1.48 l/day in addition to the water added to the meal. There were no consistent treatment effects on pig performance. Smith (1983) found marginal but non-significant improvements in the growth and feed conversion of growing pigs fed a liquid diet containing 75% water and provided with and without a supplementary water supply. A higher proportion of the pigs offered supplementary water graded with a backfat thickness of less than 19 mm (89.7 v 88.6%).

Hansen, Hagelso and Madsen (1982) studied the behaviour of group housed growing pigs (21 to 70 kg W) fed ad libitum either from 1 or 4 individual feeder space allowances per pen of 8 animals and offered unrestricted access to water from 3 or 4 drinkers. No differences were found in total daily drinking activity, however dominant pigs in groups restricted to a single feeder space allowance showed a tendency to drink and eat more frequently than subordinate pigs. Although eating activity and aggression were positively correlated in pigs provided with a single feeder space allowance, there were no incidences of aggressive encounters at the drinker valves.

Aggressive competition at drinking points may occur in groups of growing pigs on restricted feed allowances. For example Hepherd, Hanley, Armsby and Hartley (1983) found that growing pigs in commercial bacon herds fed 2 or 3 times daily showed a peak demand for water immediately after feeding. Furthermore Yang et al. (1981 and 1984) found that a restriction in daily feed allowance increased the water consumption of young pigs by an amount equal to the reduction in feed intake. This behaviour was attributed to hunger as feed allowance was considered insufficient to satisfy gut fill. These findings support the conclusions made by Rushen (1984 and 1985) from studies on pregnant sows on restricted feed allowances.

2.6 Water delivery systems

Under dry feeding systems, where no water is added to the feed, the water demand of pigs must be satisfied by the supply of drinking water. In the UK, livestock are usually provided with water from the public supply. Other potential but less common water sources include wells, boreholes and water springs.

In order to protect the quality of public water supply, the statutory requirements of water authorities demand that the distribution of water to commercial livestock must be carried out by the use of self-refill header tanks connected to the high pressure mains system (Water Research Centre, 1986). The provision of water to pigs is achieved by the use of drinking devices fitted along a low pressure piped system.

The components of a water delivery system which may vary according to different commercial conditions include; (1) the type of drinker fitted, (2) location of drinkers within pens, (3) number of drinkers per pen, (4) rate of water flow from drinkers.

There are many different types of drinkers on offer to commercial producers and a number of them have been described in detail by MacCormack (1972) and Olsson (1983). New innovations and modifications are continuously made to the range of drinkers available from manufacturers attempting to secure a share of the sales market. Most drinkers fall into one of the following categories; bowls, bite drinkers and nipple drinkers.

Not much information is available on the effects of different types of drinkers on the water usage and performance of pigs. In a study involving 467 growing pigs Fiedler (1982) found that water usage was higher from a nipple drinker than from a bowl drinker (16.2 v 14.2 l/pig day). More recently Lightfoot (1985) reported no significant differences in the water usage and performance of 90 growing pigs offered unrestricted access to water from three different types of bite drinker. Danielson (1973) also failed to detect any differences in the daily weight gain or feed conversion of growing pigs supplied with water from either a self-refill bowl drinker or a bite drinker. Diblik (1986) found that the water intake of 9 lactating sows from either an open water surface, bowl, a nozzle-type drinker or a sucking drinker averaged 14.1, 13.6, 12.4 and 10.8 l/sow day with ranges of 9-18, 9-20, 8-16.7 and 8-14 l/sow day respectively. Conversely a study on a commercial herd by Maigne (1985) found no significant differences in the water usage by lactating sows from either a nose-operated push-button drinker or a similar mechanism fitted with a lever (25.1 v 24.9 l/sow day).

Studies by Olsson (1983) suggested that the location of bite drinkers within the dunging area of growing pig pens influenced the amount of water wasted. When the position of the drinker was changed from the wall facing the lying area to a place on the partition between the dunging area and lying area, the amount of water wasted was reduced from 2.33 to 1.44 l/pig day and this also improved pen hygiene.

The effects of number of pigs per drinker on water demand and drinking behaviour have not been systematically investigated. Practical experience has been the basis of recommendations made by manufacturers and those published in the literature. Simonsson, Olsson and Gustafsson (1977) showed a reduced water use when the number of bite drinker per pen group of 10 growing pigs was increased from 1 to 2 (8.45 v 7.84 l/pig day). It was suggested that this was probably due to less competition for water and consequently reduced spillage after feeding in pens having two drinkers. Using a 2 x 2 factorial experimental design Barber, Brooks and Carpenter (1988a) found no significant interactions between the number of drinkers per pen (1 v 2/pen group of 8) and water delivery rate (300 v 900 cm^3/min) on the use of water by growing pigs fed twice daily on a scale related to metabolic body weight. Water use was significantly higher at the higher delivery rate (3.8 v 1.85 l/pig day) but there were no differences in water use between pen groups with either 1 or 2 drinkers. There were no significant effects of delivery rate or number of drinkers per pen on feed intake, growth rate and feed conversion.

Manufacturers of drinkers usually provide recommendations on the minimum flow rates for different classes of pigs. These recommendations are often given in an effort to reduce water spillage without adversely restricting water availability. However these suggested flow rates are not based on the findings of research but are made from commercial knowledge and practical experience. The comprehensive study made by Nienaber and Hahn (1984) which was based on two separate experiments is one of the few available on the effects of water flow rates from nipple drinkers on the water use and performance of early weaned and young pigs. The first experiment involved three water flow rates (100, 600 and 1,500 ml/min) and two ambient temperatures (5 and 35°C) as a 3 x 2 factorial design using 10 week old pigs. Water use increased linearly with flow rate at both temperatures (3.26, 4.43 and 4.62 l/day at 5°C and 3.13, 8.02 and 10.83 l/day at 35°C). The correlation between flow rate and live weight gain was positive at 35°C but negative at 5°C. The frequency of drinking activity decreased as flow rate increased at both ambient temperatures (3.23, 1.83 and 1.56 drinks/h at 5°C and 3.48, 3.36 and 2.45 drinks/h at 35°C). In the second experiment with 4 week old weaned piglets reared at 30°C, water use increased with increasing flow rate (1.57 l/day at 100 ml/min to 5.20 l/day at 1,100 ml/min) but there were no significant effects on performance. Excessive water use at high flow rates and ambient temperatures was attributed to water wastage and deliberate spillage for evaporative cooling. Similarly Carlson and Peo (1982) found that water usage by growing pigs from nipple drinkers with a inlet valve size of 3 mm diameter was higher than from drinkers with narrower openings of 1 mm diameter (1.12 v 0.79 l/day). This agrees with the findings of Stansbury, Hancock, Tunmire, Tribble and Orr (1981) who showed that water use by growing pigs from nipple drinkers with inlet valve sizes of 0.89, 1.17 and 2.54 mm in diameter averaged 6.46, 9.64 and 10.14 l/day respectively. Unlike Hancock et al. (1981), Carlson and Peo (1982) reported some improvements in the growth rate of pigs provided with water from drinkers with the larger inlet valve size.

CONCLUSIONS AND RATIONALE FOR THE RESEARCH PROGRAMME

For each class of pig the quantity of daily water required to maintain physiological homeostasis, has been calculated using the factorial method. The derived values are compared in Table 1.20 with recommended allowances published by ARC (1981) and in The Codes of Recommendations for the Welfare of Livestock, Pigs (1983). For comparison the range and average values for water use by each class of stock obtained from studies published in the various reports reviewed in Chapter 2 are also presented.

When access to water has been unrestricted, independent studies on the same class of pig have shown wide differences in water use. Variations in water use between individual animals have also been found to be very high. Furthermore the average quantities used are considerably higher than the values calculated to maintain physiological homeostasis.

The maximum rates of daily water use reported in the literature are between 1.5 and 5 fold higher than the maximum recommended allowances published by ARC (1981) and in The Codes of Welfare (1983).

In order to investigate these discrepencies systematically there is a need to address the following questions:-

1. **Why do individual pigs show wide variations in water consumption when offered unrestricted access to water?**

Table 1.20. Comparison of factorial estimates of the water requirements by different classes of pig with recommended allowances published by ARC (1981) and The Codes of Welfare (1983) and values of water use reported in various studies

Class of pig	Factorial estimates	ARC (1981) recommendations	Codes of Welfare Pigs (1983)	Values of water use from various studies Mean	Min	Max
Sows (l/day)						
Pregnant	2.65 to 5.97	5 to 8 (2.5:1)[a]	5 to 8	13.8	6.8	22.7
Lactating	8.05 to 11.75	15 to 20 (3:1)	15 to 30	19.7	6.0	47.0
Suckling piglet (l/day)		b	b			
0-3 weeks of age				0.03	0.005	0.05
3-8 weeks of age				0.30	0.03	0.59
Weaned piglets (l/day)		b	b			
3-7 weeks of age				2.6		
Growing pigs (l/day)		(2:1)	(2.5:1)			
15-50 kgW		1.5 to 2.0		4.7	2.0	10.1
50-90 kgW	1.91 to 3.33	6.0		6.4	2.0	11.3
Boars (l/day)	3.03 to 7.78	b	b	9.5	8	11

[a]Recommended values have also been expressed as a function of feed allowance. Ratios given in parenthesis are parts of water per part of feed allowance.
[b]Not provided.

In their conclusion on water requirements, the ARC Working Party acknowledged that pigs show considerable variations in individual water consumption when offered unrestricted access to a supply of drinking water. The Agricultural Research Council could not decide nor were able to explain whether these variations represented "unimportant idiosyncrasies or physiological needs which should be met". These needs have obviously not been given important consideration as the discrete water allowances recommended for growing pigs and sows make no provision for pigs to satisfy their individual needs and factors which may influence their demand for water. Furthermore these allowances do not support the statement made by Braude in the preface to The Nutrient Requirements of pigs which defined requirement as "the amount of a nutrient that must be supplied in the diet to meet the needs of the normal healthy animal given an otherwise adequate diet in an environment compatable with good health." This definition appears to suggest that the supply of a nutrient below the specified requirement may have an adverse effect on the physical health of the animal although "needs" could be extended to include behavioural requirements. Similarly the water requirements of the pig could be described as the minimum requirement for physiological homeostasis **and** needs which satisfy behavioural requirements expressed under conditions of unrestricted access to water. Pigs which do not have unrestricted access to water may fulfil their requirements for the maintenance of homeostasis but under such conditions the expression of demand for behavioural needs could be suppressed, although this would be difficult to assess.

Given that these individual variations in water consumption have been acknowledged by ARC (1981), the justification for publishing discrete recommended water allowances based on insufficient information is difficult to support. These variations require investigation in order to determine whether they represent needs which should be satisfied.

2. **Why are there considerable differences in the average and range of values for water use reported between independent studies on the same class of pig?**

Although The Agricultural Research Council Working Party on The Nutrient Requirements of pigs (1981) have made considerable efforts to determine the factors which influence the requirements for energy, protein, vitamins and minerals by various class of pig, they give no detailed information on factors which may modify the pig's requirement for water.

From the various reports considered in Chapter 2, it is apparent that differences in the water demands of sows, boars, early weaned and growing pigs are primarily associated with differences in age, live weight, feed intake and physiological status. In the breeding sow evidence suggests a progressive decrease in water demand with advancing pregnancy. This is followed by an increase after parturition. The suckling piglet has been found to utilise small but increasing quantities of water from an early age, however the effects of water provision on the performance of piglets of less than three weeks of age have not been extensively investigated. Although the early weaned piglet has been found to show disturbed patterns of water use immediately after weaning, the extent to which these influence post-weaning growth and performance have not been thoroughly researched. In the growing pig there are indications that water intake increases curvilinearly with live weight but when expressed as a unit of feed intake or body weight water demand appears to decrease with age. Although age, live weight, feed intake and physiological status are factors which explain the fundamental differences in the water demands of different classes of pig, few studies have attempted to quantify the relationship between these variables and water intake.

It is unclear why there are such wide differences in the values for water use reported between independent studies on the same class of pig. These differences may be attributable to differences in diet composition, feeding regime and systems of housing, although the extent to which these factors influence water needs have not been quantified.

Very few studies have been conducted on the effects of diet composition on the water requirement of pigs. The main dietary constituents which have been found to influence water demand are the salts of sodium and to a much lesser extent those of potassium. When pigs are given unrestricted access to water, increases in the intakes of either sodium or potassium salts have been shown to result in corresponding increases in water intake for the elimination of these minerals in the urine. Although this physiological response has been widely documented for common salt (NaCl), there is very little information available for potassium.

This is surprising considering the fact that the concentration of potassium in vegetable protein supplements such as soyabean meal are some 50 times higher than sodium and both these minerals are present in similar concentrations in animal protein supplements such as fish meals.

Because the effects of variations in the mineral content of feedstuffs on water requirements have not been given serious consideration, the use of novel ingredients containing high levels of either Na or K in the diets of pigs on restricted water allowances have in certain cases proved disastrous (Braude, Jones and Houseman, 1977; Hanrahan, 1980) even though their water allowances had satisfied the recommendations published by ARC (1981) and in The Codes of Welfare (1983). Therefore there is a need to quantitatively investigate the effects of variations in dietary mineral content within the ranges found in commercial practice on the water demands of pigs.

A number of ethological studies suggest that different feeding and housing system combinations can modify the drinking behaviour of pigs. However very few studies have taken measurements of water use and consequently provide no quantitative information relating these effects to water demand. In growing pigs recent studies indicate that water serves as a substitute for food when feed allowances are insufficient to satisfy the needs for gut fill. This behavioural response has also been attributed to the high levels of post-prandial drinking and rooting activities observed in stall housed pregnant sows on restricted feeding regimes.

3. Are the large differences in water intake reported between independent studies attributed to inaccuracies of measurement and water losses?

It is important to differentiate between "water intake" and "water use". Intake should strictly refer to that quantity of water recorded which is consumed by the pig and should not include losses resulting from spillage during drinking or wastage through play. Water use represents the total quantity of water registered from the delivery system and this includes losses which cannot be distinguished from intake. Intake has often been indiscriminately applied to measurement of water use and it is questionable whether these reported values represent actual or apparent consumption.

Some of the large differences in water intake reported between independent studies may be due to differences in water wasted from drinkers. Using TOH dilution, Yang et al. (1981) found that intake accounted for 80 to 90% of the volume registered from bowl drinkers. These differences were presumed to be a measure of spillage. Olsson (1983) estimated that water spillage accounted for 20% of the total volume of water used by growing pigs from bite drinkers. The delivery of water to intensively housed pigs is now commonly achieved by the use of many different types of drinker. The amount of water wasted may be influenced by drinker type and this may explain inconsistencies in the values of water intake estimated for similar classes of stock in previous studies.

Commercial manufacturers have made substantial claims for the ability of certain types of drinkers to reduce water wastage. However these claims have not been systematically investigated through objective comparisons of water use from different types of drinker under controlled test conditions.

Inaccuracies can also occur when water use is recorded by the use of turbine flow meters attached directly to the mains supply or to the low pressure piped delivery system. According to Carpenter (personal communication, 1983) conventional turbine flow meters are not suitable for measuring water use as they only respond accurately at a relatively high and consistent rate of flow. Water consumption by animals is intermittent and generally provokes only low rates of flow which can result in inaccuracies of measurement of up to 30%. This problem was avoided by the development at Seale-Hayne College of a water metering device which eliminated sporadic flow rates, thus ensuring that turbine flow meters used to record water usage operated at maximum rates of efficiency (see Appendix).

4. Do the ARC (1981) recommended water allowances based on research conducted some 15 to 50 years ago satisfy the water needs of modern genotypes managed under contemporary systems of production?

Modern genotypes have been continuously selected for improved growth rates, feed conversion efficiency and a higher percentage of carcass lean content. For example from 1975 to 1986 the average daily gain to feed intake ratio of growing pigs of between 20 and 80 kg W has improved from 3.4 to 1.75. In the same period backfat thickness has been reduced by 8 mm (MLC 1985 and 1987). Since the daily rate of body water turnover is positively correlated with carcass lean content (McFarlane, 1976) and higher rates of protein accretion involve increased levels of water retention, water requirements for maintenance and production may have changed significantly during the last 15 to 20 years.

Over the same period systems of management, housing and feeding have become increasingly specialised. For example, earlier weaning has resulted in the development of environmentally controlled buildings in which young pigs are reared using high nutrient density diets. Earlier weaning and increased confinement at farrowing has also placed greater demands on the breeding sow.

It is questionable whether water allowances based on the finding of research conducted between 15 and 50 years ago satisfy the water needs of modern genotypes selected for increased biological efficiency and reared under current systems of production.

Therefore a programme of research was initiated with the aim of obtaining quantitative information on the water use by pigs managed under various conditions of feeding, nutrition and housing. The programme of research had 3 specific objectives, namely:-

1. To assess the effects of age, live weight, feed intake and physiological status on the water demand of the pig.

2. To evaluate the effects of drinker type on water use and pig performance.

3 To investigate the effects of dietary mineral concentration on water demand.

THE RESEARCH

PART I WATER DEMAND OF VARIOUS CLASSES OF PIG IN RELATION TO AGE, LIVEWIGHT, FEED INTAKE AND PHSIOLOGICAL STATUS

Introduction

Present published recommendations on the water requirements of pigs are usually presented as means calculated from the results of the very few studies reported in the literature on the water use by various classes of pig. These recommendations provide no indication of biological variation and give no information on the quantitive relationship between water demand and age, live weight, feed intake and physiological status for each of the various classes of pig.

The objective of this section was to investigate the water demands of lactating sows, suckling and weaned piglets and to establish whether variations in daily water use could be quantitatively explained by age, feed intake, live weight and physiological status.

The study on sows investigated the effects of parturition, lactation, litter size suckled, litter weight gain and feed intake on daily water demand. The interactions between water and creep feed provision on the daily water use and performance of suckling piglets from birth to 3 weeks of age was investigated in conjunction with the study on lactating sows. The transition from suckling to weaning represents an abrupt change in the fluid and nutrient sources of the young pig. This change of environment and its effect on the water use by early weaned piglets in relation to feed intake, live weight and age was quantitatively investigated.

Experiment 1 Water use by lactating sows

Thirty-two Large White x (Large White x Landrace) primi- and multiparous sows were used to investigate the effects of stage of lactation on daily water use.

Materials and methods

Animals and housing

Pregnant sows were taken from dry sow accommodation 6±1 days before their expected date of parturition, weighed and transferred to the College farrowing house (see Appendix) which operated a commercial three week weaning system with continuous occupation, using fresh straw as bedding. Sows were placed in farrowing crates and drinking water was available ad libitum from a nose operated drinker located in the corner of each feeding trough (see Appendix).

Sows and their litters were moved from farrowing crates to mothering pens one week after farrowing. The feeding regime was not changed. Drinking water was available ad libitum from a single wall mounted bowl drinker (Alvin 78[R], Fisher Foundries Ltd.) fitted in the dunging area of each mothering pen.

Sows were fed once daily a commercial meal (Ultra Breed 16 [R], Dalgety Agriculture Ltd) with wheat bran (Table 2.1) at a level which provided 2 kg meal + 0.5 kg wheat bran/sow day prior to farrowing. The meal allowance was increased after farrowing at the rate of 0.5 kg/sow day until sows reached maximum appetite. Wheat bran was withdrawn on the third day after farrowing. The daily feed allowance was given with an equivalent weight of water

Table 2.1. Proximate and mineral analyses of the meal and wheat bran used in experiment 1

	Meal	Wheat bran
Dry matter (%)	88	86.7
Digestible energy (MJ/kg DM)$^{+}$	14	13.0
Crude protein (g/kg DM)	188	194.0
Crude fibre (g/kg DM)	77	111.0
Neutral detergent fibre (g/kg DM)	250	335.0
Ether extract (g/kg DM)	80	51.0
Total ash (g/kg DM)	85	65.0
Calcium (g/kg DM)	10.6	11.3
Phosphorous (g/kg DM)	7.8	9.5
Magnesium (g/kg DM)	3.3	1.6
Sodium (g/kg DM)	2.5	4.3
Potassium (g/kg DM)	16.1	12.2
Chloride (g/kg DM)	3.0	0.3

$^{+}$DE (MJ/kg DM) = 17.5 + 0.016 EE + 0.008 CP - 0.03 Ash - 0.015 NDF (Whittemore, 1987) and sows were allowed 30 minutes within which to clear their troughs. If feed was left then the daily allowance was decreased by 0.5 kg meal/sow day until trough clearance was resumed. Uneaten feed was removed, weighed and oven dried at 100°C for 24 h to determine the unconsumed fractions of meal and water. Maximum appetite was defined as the point when sows could no longer consume their daily feed allowance within 30 minutes after feeding. Water use was recorded daily from each drinker before feeding at 0700 h, using a water metering device (see Appendix).

Litters from these sows were used in experiment 2.

Results

The health of the sows was good. Piglets born per litter averaged 11.03 (s.e. 0.51) alive and 0.5 (s.e. 0.23) dead. Sow No. 31 which produced 5 alive but 7 dead piglets was given 3 foster piglets from Sow No. 34. Six piglets were fostered from other sows not used in the experiment onto Sow No. 32 which produced only 3 born alive. Mortality of piglets born alive averaged 12.5%. The incidence of crushing was high and accounted for over 83% of all preweaning deaths. Litter size at weaning averaged 9.66 (s.e. 0.33). Some problems were encountered weighing sows with a newly installed electronic platform weigher. The digital read-out showed occasional errors when a reference weight was used to check its accuracy following each weighing. Suspect live weight data was subsequently eliminated from statistical analyses. Six sows refused to enter the weigher.

The pattern of average daily total water use (water added to the feed plus drinking water) and feed intake before and after farrowing is illustrated in Figure 2.1. Water use increased linearly over the week before farrowing and reached 12.2 l/sow the day before parturition. This is described by the following linear equation which was fitted following the analysis of regression of total daily water use by each sow against the number of days before farrowing (NDBF):-

$$Y = 12.5 - 0.823X \text{ (r.s.d. 5.75; } R^2 \text{ 0.55; } P < 0.01)$$

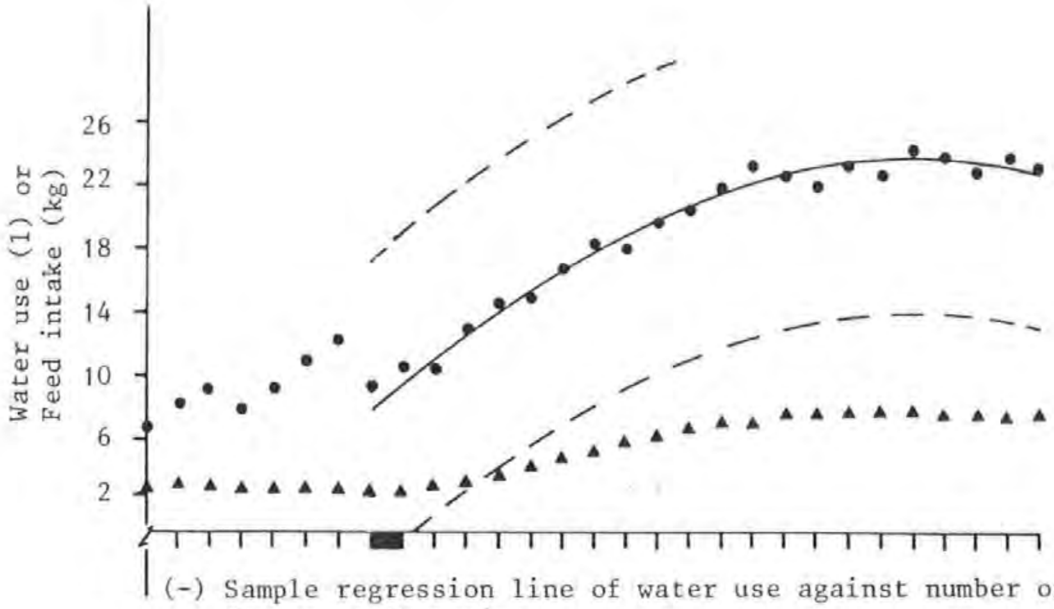
Where Y is litters per sow day and X is NDBF

On the day of farrowing, water use significantly ($P < 0.001$) decreased to 9.3 (s.e. 0.84) l/sow. After farrowing water use increased curvilinearly and reached a plateau in week three of lactation.

In lactation maximum feed intake was reached about two weeks after farrowing. The ratio of total daily water use to daily feed intake was calculated for each sow. Average values and their standard errors are presented in Figure 2.2.

Daily data was used to calculate the regression of total water use against the number of days post farrowing (NDPF), feed intake, and number of piglets suckled. The relationship between water demand during lactation and sow body weight and piglet growth was studied using the regression of total water use by each sow from farrowing to weaning against sow live weight and against litter weight gain from day 1 to weaning. The results of these regression analyses are summarised in Table 2.2.

Figure 2.1 Mean daily water use (●) and feed intake (▲) of sows before and after farrowing



(-) Sample regression line of water use against number of days post farrowing

(---) 95% confidence limits for individual values of water use

Figure 2.2 Mean daily water use to feed intake ratio (± s.e.) of sows before and after farrowing.

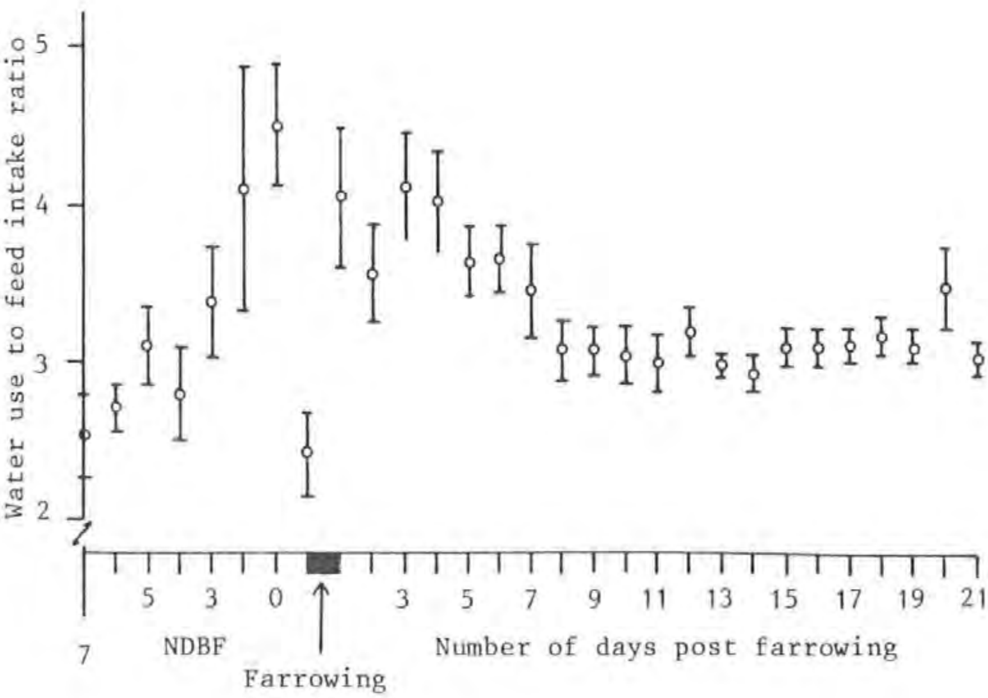


Table 2.2. Regression of total daily water use by lactating sows against daily feed intake, live weight, stage of lactation and litter size suckled

Regression equation	P	r.s.d.	R^2	Standard error of:		
				intercept	b_1	b_2
$Y = 4.22 + 2.52X_1$	<0.001	4.80	0.532	0.565	0.092	
$Y = 16.1 + 0.01X_2$	<0.05	7.12	0.01	1.26	0.01	
$Y = 7.63 + 1.81X_3 - 0.05X^2{}_3$	<0.001	4.91	0.515	0.518	0.116	0.005
$Y = 16.7 + 0.22X_4$	<0.05	7.02	0.04	1.40	0.14	
$Y = 18.1 + 4.89X_5$	<0.01	2.31	0.234	0.449	0.046	

Where: Y = Total water use (l/sow day)
X_1 = Feed intake (kg/sow day)
X_2 = Sow live weight (kg)
X_3 = NDPF
X_4 = Litter size suckled
X_5 = Litter weight gain (kg/day)

The relationship between water use and number of days post farrowing was described by a quadratic function ($P < 0.001$). According to the fitted equation, the point of maximum water use averaged 24 l/sow day (when $dY/dX_3 = 0$) which occurred 18 days post partum. Litter weight gain from day 1 to weaning accounted for 23.4% of the variation in total water use during lactation ($P < 0.01$). The regression against live weight and litter size showed that only 1 and 4% of the variation in water use was explained by those independent variables.

Discussion

The results obtained from this study indicate that physiological changes during parturition and lactation had a marked influence on the pattern of daily water demand by sows.

In domestic animals, parturition has been described by 3 stages of development which relate to the physiological and behavioural events occuring under the influence of maternal and fetal hormones (McDonald, 1980). In the sow, English, Smith and MacLean (1982) defined the first set of events before parturition as the preparatory stage, the second during which the piglets are born and the final stage during which the placenta is expelled.

The preparatory stage begins about 2 days prior to farrowing. During this time there is a decrease in plasma progesterone and a rapid rise in plasma oestrogen which causes the relaxation of the cervix and vagina to assist the expulsion of piglets at parturition (Hughes and Varley, 1980). According to English et al. (1982) sows show several physiological and behavioural responses during stage 2 which indicate that farrowing is imminent. These include increased restlessness, signs of discomfort, nervousness and frustration, increased frequency of drinking and urination and defecation, bed-making activity and increased levels of vocal noise. Sows also experience swelling of the vulva, an increase in body temperature and milk secretion which can begin some 12 hours prepartum. In the present study, sows showed a linear increase in water use in the week before parturition and it is probable that this is associated with the physiological and behavioural events characteristic of the preparatory stage.

Stage two normally takes between 1 and 4 hours (Hughes and Varley, 1980). Plasma oestrogen reaches a peak at the time of delivery and this is accompanied by a rapid surge in oxytocin and prostaglandin which mark the onset of uterine contractions (McDonald, 1980). Although sow activity may remain generally high during this stage, some sows can become very peaceful (Marrable, 1971; English et al., 1982).

Expulsion of the placenta is usually accomplished within 1 to 4 hours after the last birth. In contrast with stages 1 and 2, this phase is marked by a considerable reduction in sow restlessness and activity. English et al. (1982) made observations on 31 sows in different stages of farrowing and found the number of total movements per hour in stages 2 and 3 averaged 5.1 and 1.04 respectively. This may explain the reduction in average water use immediately following farrowing found in the current study. Friend (1971) has also reported trends indicating a decrease in voluntary water use as well as feed intake after farrowing. Any effect of parturition on voluntary feed intake cannot be evaluated in the present study due to the imposition of a fixed feeding scale before farrowing and the daily increment in feed allowance used after farrowing which did not permit the expression of appetite in early lactation. Feed intake from farrowing to day 11 increased at a rate which was similar to the increment in daily feed allowance used in this study. The rate of increase in daily feed intake may have been higher under ad libitum feeding conditions.

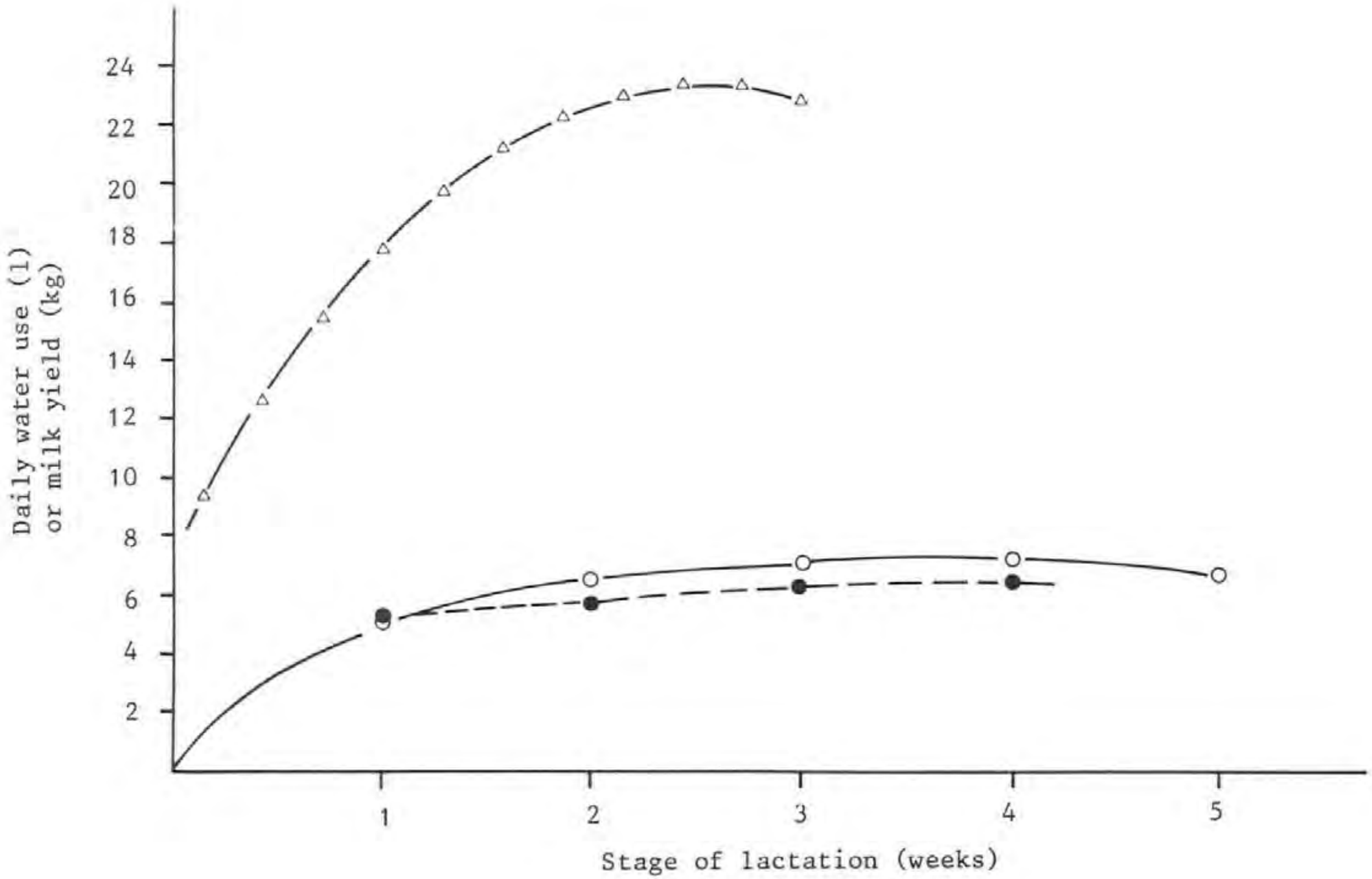
Total daily water use from farrowing to weaning averaged 18.9 (s.e. 0.27) l/sow day which is in close agreement with estimates published in four previous studies (Garner and Sanders, 1937; Lenkeit 1959; Lightfoot, 1978; Lightfoot and Armsby, 1984). However, this value is considerably higher than the mean of 8.1 l/sow day reported by Friend (1971) and considerably lower than the means of 24.2 and 32.6 l/sow day obtained from 2 studies by Maigne (1985). These differences could be attributable to a combination of factors such as the technique used to measure water usage, water wastage, diet composition, feed allowance, housing and the environment.

The pattern of daily water use from farrowing to weaning presented in the current study is dissimilar to that established in the study of Lightfoot (1978) where intake increased linearly from 0.8 l/sow at farrowing to 18 l/sow on day 9, which then remained constant up to weaning at 21 days. On the other hand Friend (1971) found that water use continued to increase until 3 to 4 weeks after farrowing, followed by a rapid decrease to weaning at 5 weeks (Figure 1.10, page 79).

Figure 2.3 compares the shape of the water use curve from farrowing to weaning obtained in this experiment with sow milk yield curves published by Elsley (1970) and White and Cambell (1984). This comparison indicates that maximum water use in this study did not coincide with the time of peak milk yield which occurred between 3 and 4 weeks post-partum in these reports. It would appear that in this study feed intake was a more important factor which determined the pattern of water use rather than milk yield. This is supported by the analysis of regression which showed that 53.2% of the variation in total daily water use was explained by feed intake and only 23.4% by total litter weight gain from day 1 to weaning which provides an indirect estimate of milk production. Furthermore in the multiple regression of total daily water use against daily feed intake and NDPF, only feed intake was the significant independent variate ($P < 0.001$; see Appendix). This indicates that the relationship between stage of lactation (NDPF) and water use was confounded by the feeding regime which was time dependent.

Under ad libitum feeding conditions the sow can express her requirements for feed to sustain optimum milk production. For example Friend (1971) showed that voluntary feed intake paralleled voluntary water use which both closely resembled the characteristic shape of the sow milk yield curves reported in the literature. This suggests that milk production is an important factor which influences the requirements for food which in turn

Figure 2.3 Comparison of water use by lactating sows △ (experiment 1) with milk yield curves reported in 2 previous studies; ○ Elsley (1970); ● White and Cambell (1984).



influences water demand. However, day to day fluctuations in water demand before and after farrowing are likely to represent transient changes required to maintain osmoregulation and to satisfy other needs above those required for milk production.

As daily feed allowance before farrowing was held constant, the water to feed intake ratio increased in proportion to the increase in water use. The ratio decreased sharply at farrowing corresponding to the decrease in water demand but with feed intake remaining equal to the level of daily allowance. The ratio subsequently increased from 2.4:1 to 4:1 indicating a change in proportionality in favour of water intake. As sows were not fed to appetite after farrowing, the increased demand for water at this stage may satisfy the needs for gut fill since milk yield in early lactation is generally no more than 5 to 6 l/day.

The close relationship between the stage of lactation (NDPF) and water use reported in this experiment can be explained by the fact that the feeding increment after farrowing was time dependent. The width of the 95% confidence limits either side of the sample regression line of total daily water use against daily feed intake and against the NDPF indicates that the accuracy of prediction was relatively poor. This is due to the high degree of variation found in the daily water use data both within and between individual sows.

Although heavier sows and sows with larger litters had increased water use, sow live weight and litter size suckled per se accounted for less than 5% of the variation in daily water use.

Inaccurate output from the digital read out fitted to the platform weigher used in this experiment is probably responsible for the weak relationship between water use and sow live weight. Consequently it would be sensible to reject this relationship as it could be based on inaccurate data.

Experiment 2 The effects of water and creep feed provision on the performance of suckling piglets.

Materials and methods

Experimental design and treatments

Thirty-two litters were randomly allocated at birth to one of the following 2 x 2 factorial treatments:-

A Drinking water provided from birth to 21 days of age
No creep feed provided

B Drinking water provided from birth to 21 days of age
Creep feed provided from 7 to 21 days of age

C No drinking water provided
No creep feed provided

D No drinking water provided
Creep feed provided from 7 to 21 days of age

Treatments were replicated in time according to a Randomised Complete Block Design.

Animals and housing

The management and housing of litters and nursing sows has been previously described in experiment 1.

Experimental procedures

Piglets were individually weighed and ear tagged for identification 24 h after birth. Piglet weights were recorded thereafter at 7, 11, 16 and 21 days of age. All losses were recorded.

Drinking water was provided *ad libitum* to litters on treatments A and B from a nose operated bowl drinker (see Appendix) located at the rear of each farrowing pen and in the creep area of each mothering pen. Each bowl drinker was supplied with water from a 5 litre calibrated plastic bottle. To ensure a fresh supply of drinking water, all bottles were routinely emptied, cleaned and refilled to the 3 litre mark every 2 days. Water readings were taken daily at 0700 h.

A commercial pelleted creep feed (Ultra Start R, Dalgety Agriculture Ltd) was offered to litters on treatments A and C from a clean trough placed in the creep area of the mothering pen. Uneaten creep feed was removed, weighed and replaced with 250 g of fresh feed daily at 0800 h. Proximate and mineral analyses of the creep feed are presented in Table 2.3.

All litters remained on trial until they were weaned at 21 days of age.

Results

Average daily water use from birth to 7 days of age and from 8 to 21 days of age for litter groups provided with, or without creep feed is illustrated in Figure 2.4. Litter groups offered creep feed had a significantly lower ($P < 0.001$) average daily water use than those not offered creep feed [0.22 (s.e. 0.019) v 0.53 (s.e. 0.035) l/litter]. Average daily creep feed intake from 8 to 21 days of age by litter groups provided with or without drinking water is compared in Figure 2.5. The provision of drinking water had no significant effect on creep feed intake

Table 2.3 Proximate and mineral analyses of the creep feed used in experiment 2

Dry matter (%)	92.2
Digestible energy (MJ/kg DM)	18.0
Crude protein (g/kg DM)	242.0
Crude fibre (g/kg DM)	20.0
Neutral detergent fibre (g/kg DM)	77.0
Ether extract (g/kg DM)	110.0
Total ash (g/kg DM)	64.0
Calcium (g/kg DM)	10.0
Phosphorous (g/kg DM)	16.3
Magnesium (g/kg DM)	5.6
Sodium (g/kg DM)	0.1
Potassium (g/kg DM)	19.1
Chloride (g/kg DM)	6.4

DE calculated using equation given on page 120 .

Figure 2.4 Mean daily water use (± s.e.) from birth to 7 days of age (O) and from 8 to 21 days of age by litter groups provided with (Δ) and without creep feed (▲).

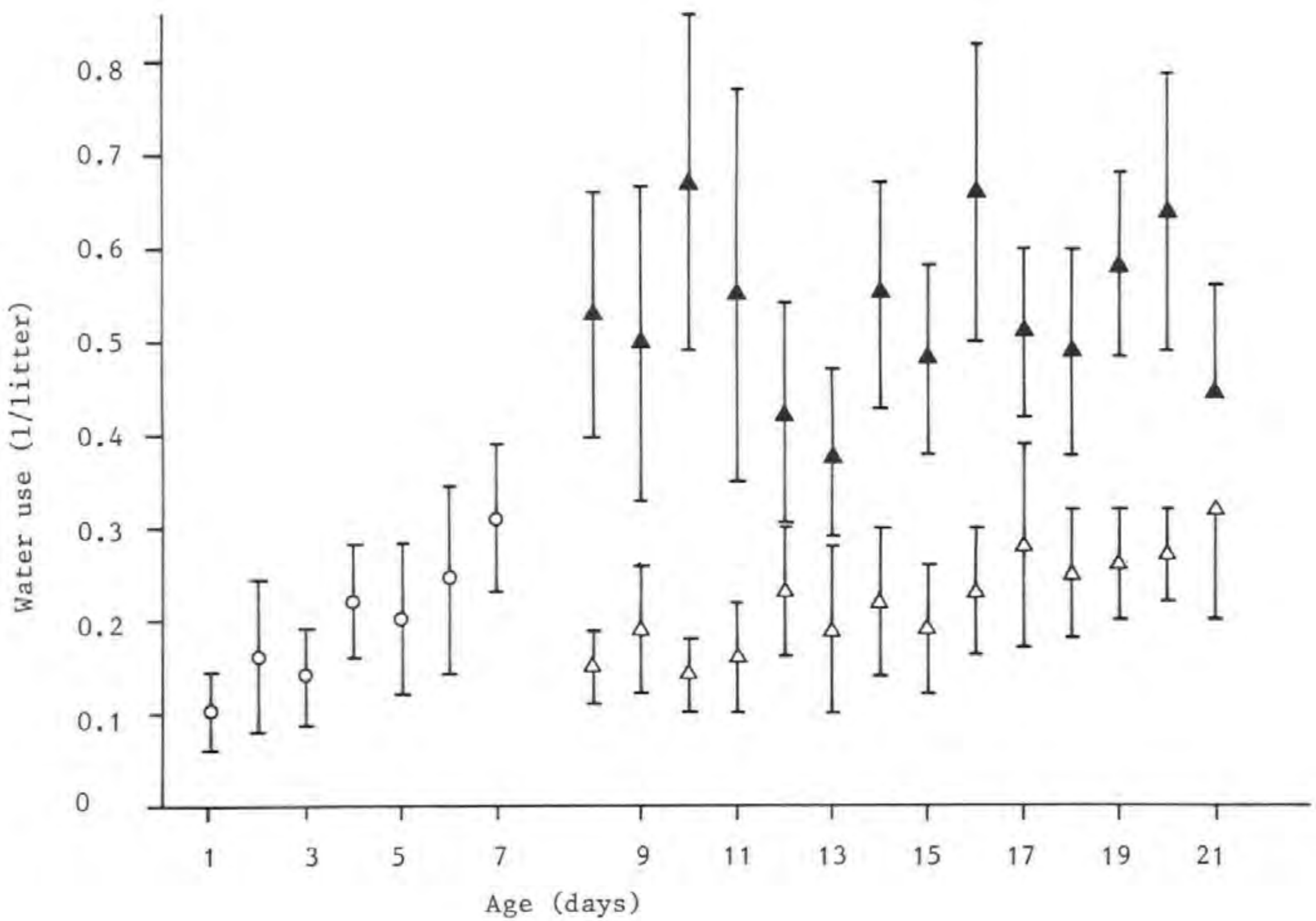
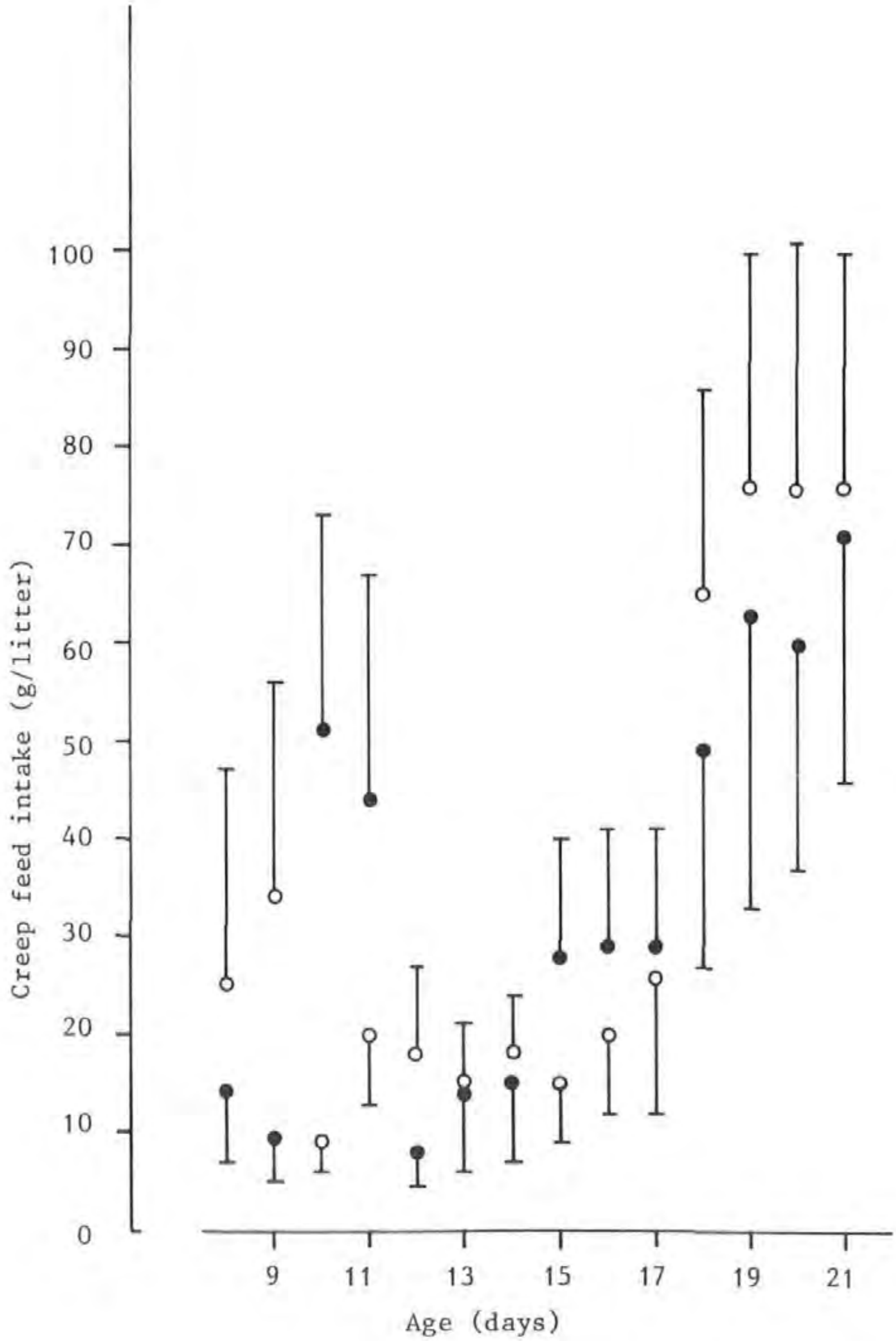


Figure 2.5 Mean daily creep feed intake (+ s.e.) from 8 to 21 days of age by litter groups provided with (●) and without (O) a supply of drinking water.



which averaged 34.7 (s.e. 3.4) g/litter day. There were considerable day to day variations within and between litter groups in both creep feed intake and water use.

Performance of piglets from litter groups provided with or without drinking water in the first week of life is compared in Table 2.4. There were no significant differences. Treatment and main factorial effects of water and creep feed provision on piglet performance from 7 to 21 days of age are summarised in Tables 2.5 and 2.6 respectively. No significant treatment or main effects were found. There were no significant creep feed x water interactions on piglet performance.

Discussion

In this experiment, 8 out of 16 litters presented with drinking water were found to have used their supply within 24 h after birth. This supports the finding of Aumaitre (1964) and Friend and Cunningham (1966) who showed that suckling piglets will utilise small quantities of drinking water in early life.

Although there were considerable between litter variations in daily water use, mean usage was found to increase linearly from 0.01 to 0.03 l/piglet day from birth to 7 days of age. This suggests that water demand in the first week of life is not entirely ad hoc and that there may be underlying physiological and/or behavioural factors involved.

The total amount of water used in week 1 averaged 0.13 l/piglet which was marginally higher than the value of 0.084 l/piglet

Table 2.4 Performance of suckling piglets from litter groups provided with or without drinking water from birth to 7 days of age

		Water provided		No water provided	
		Mean	**s.e.**	**Mean**	**s.e.**
	Age(d)				
Live weight (kg/piglet)	1	1.26	0.064	1.31	0.051
	7	2.35	0.129	2.43	0.162
Within litter variation in piglet live weight ($\sigma n - 1$)	1	0.25	0.023	0.25	0.027
	7	0.49	0.046	0.47	0.041
Litter size	1	11.0	0.5	11.3	0.55
	7	10.4	0.49	9.8	0.52

Means within the same row did not differ significantly ($P > 0.05$).

Table 2.5 Treatment effects of water and creep feed provision on piglet performance from 7 to 21 days of age

Treatment		A		B		C		D	
Water		Yes		Yes		No		No	
Creep feed		No		Yes		No		Yes	
		Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
	Age(d)								
Live weight	7	2.41	0.129	2.32	0.089	2.42	0.129	2.43	0.098
(kg/piglet)	11	3.19	0.165	3.12	0.058	3.23	0.198	3.28	0.122
	16	4.30	0.235	4.41	0.160	4.39	0.204	4.41	0.148
	21	5.35	0.225	5.60	0.161	5.50	0.328	5.50	0.214
Within litter	7	0.47	0.046	0.50	0.082	0.45	0.053	0.48	0.067
variation in	11	0.71	0.063	0.69	0.111	0.55	0.084	0.61	0.106
piglet live	16	0.92	0.096	0.87	0.107	0.85	0.121	0.79	0.124
weight (σn-1)	21	1.11	0.123	1.02	0.116	1.03	0.162	1.06	0.163
Litter size	7	11.6	0.5	9.3	0.6	10.1	0.8	9.5	0.7
	11	11.4	0.5	8.8	0.5	10.0	0.7	9.5	0.7
	16	11.1	0.5	8.6	0.5	10.0	0.7	9.4	0.7
	21	11.0	0.5	8.6	0.5	9.8	0.8	9.4	0.7

Means within the same row did not differ significantly ($P > 0.05$).

Table 2.6 Main factorial effects of water and creep feed provision on piglet performance from 7 to 21 days of age

		Water				Creep feed			
		Yes		No		Yes		No	
		Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
	Age(d)								
Live weight (kg/piglet)	7	2.36	0.077	2.43	0.078	2.38	0.066	2.41	0.088
	11	3.15	0.085	3.26	0.113	3.20	0.069	3.21	0.124
	16	4.35	0.124	4.40	0.122	4.41	0.086	4.34	0.151
	21	5.48	0.138	5.50	0.189	5.55	0.130	5.43	0.193
Within litter variation in piglet live weight (σ_{n-1})	7	0.49	0.046	0.47	0.042	0.49	0.051	0.46	0.034
	11	0.70	0.062	0.58	0.066	0.65	0.075	0.63	0.055
	16	0.90	0.069	0.82	0.084	0.83	0.080	0.88	0.075
	21	1.06	0.083	1.05	0.111	1.04	0.097	1.07	0.099
Litter size	7	10.4	0.5	9.8	0.5	9.4	0.5	10.9	0.5
	11	10.1	0.5	9.8	0.5	9.1	0.4	10.7	0.5
	16	9.9	0.5	9.7	0.5	9.0	0.4	10.6	0.4
	21	9.8	0.5	9.6	0.5	9.0	0.4	10.4	0.5

Means did not differ significantly ($P > 0.05$).

reported by Friend and Cunningham (1966). However in that study, daily access to water was limited to 9 h between 8 am and 5 pm. This may have restricted piglets an opportunity to satisfy their maximum demand for water. However Aumaitre (1964) published a much lower value and found that total consumption averaged 0.009 l/piglet in week 1.

Water provision has often been suggested as a means of encouraging suckling piglets to consume more creep feed. For example Friend and Cunningham (1966) found that water provision from birth significantly increased total creep feed consumption from 2 to 8 weeks of age (3.23 v 2.17 kg/litter). However appreciable differences in creep feed intake between piglets provided with, or without a water supply did not emerge until four weeks of age. In the present study there were no indications to support the belief that water provision had any net beneficial effects on creep feed intake before three weeks of age. Creep feed consumption from 2 to 3 weeks of age by litter groups with and without a water supply was very similar and averaged 0.034 and 0.035 kg/litter day respectively.

A suitable water supply could be an important means of encouraging creep feed intake with weaning ages beyond three weeks since the contribution of milk-water to total daily water intake begins to diminish around 4 to 5 weeks (Aumaitre, 1964). Creep feed consumption could therefore be increased where an additional water source can satisfy the increased water requirements for osmoregulation, digestion and metabolism by suckling piglets older than three weeks of age.

Although creep feed consumption was not influenced by the availability of a water supply, water use was significantly higher ($P < 0.001$) when no creep feed was provided. This suggests that the quantity of water consumed in addition to milk and creep feed may be a function of milk yield and gut capacity. This is supported by calculations on total daily volumetric intake presented in Table 2.7. Total daily volumetric intake as a percentage of mean piglet weight was marginally higher when both creep feed and water were provided. However differences between treatments became reduced towards the end of the suckling period. When creep feed is not provided, piglets may consume extra water to satisfy the needs for gut fill.

From a review of literature, Fowler (1985) concluded that creep feeding even using the most expensive diets confers little if any advantages in piglet performance under a three week weaning system. The results from this study support this. However under some situations provision of both creep feed and water could produce beneficial responses in piglet performance in three ways. Firstly there may be a case for providing creep feed and water when sow milk output is insufficient to meet the daily nutrient and fluid requirements of piglets. Secondly provision of creep feed in the suckling period may facilitate dry matter intake after weaning but Lightfoot (1987) found no evidence to support this under a 3 week weaning system. Finally piglets which have been familiarised with a water supply during suckling, may adapt more easily to an identical supply after weaning.

Table 2.7. Total average daily volumetric intake (milk intake + creep feed intake + water use) expressed as a percentage of mean piglet live weight from 8 to 21 days of age

Age (days)	**8 to 11**	**12 to 16**	**17 to 21**
Treatment A			
Water (l/piglet d)	0.048	0.044	0.049
Milk (l/piglet d)[a]	0.7	0.7	0.7
Live weight (kg)	2.8	3.75	4.83
% Total Vol/lw[b]	26.71	19.84	15.57
Treatment B			
Water (l/piglet d)	0.018	0.024	0.032
Creep (kg/piglet d)	0.003	0.002	0.006
Milk (l/piglet d)	0.8	0.8	0.8
Live weight (kg)	2.72	3.77	5.01
% Total Vol/lw	30.18	21.91	16.73
Treatment C			
Milk (l/piglet d)	0.8	0.8	0.8
Live weight (kg)	2.83	3.81	4.95
% Total Vol/lw	28.27	21.00	16.16
Treatment D			
Creep (kg/piglet d)	0.002	0.002	0.007
Milk (kg/piglet d)	0.8	0.8	0.8
Live weight (kg)	2.86	3.85	5.00
% Total Vol/lw	28.04	20.83	16.12

[a]Milk production estimated from Elsley (1970), cited by ARC (1981)
[b]Total volumetric intake as a percentage of live weight

Furthermore there are trends in the data from this experiment which lend some support to the practice of providing creep feed and water to suckling piglets. For example litter groups allocated to both water and creep feed showed the highest (though non significant) weight gains from 7 to 21 days of age. This is in line with the findings of Friend and Cunningham (1966) who observed increased weight gains from birth to three weeks of age by piglets offered creep feed and water compared with those given only creep feed (192 v 185 g/piglet day). In addition there was an underlying trend for both water use and creep feed intake to increase with increasing age. This suggests that sow milk may not provide the entire nutrient and fluid requirements of piglets under three weeks of age.

Experiment 3 Water use by weaned piglets from 3 to 6 weeks of age.

Materials and methods

Animals and housing

Twenty-eight litters were weaned at 21 ± 1 days of age and reared as litter groups in flat-deck pens from weaning to 6 weeks of age. Each pen in the flat-deck weaner house (see Appendix) was fitted with a single Arato 76 nipple drinker (Figure 2.18, page 188). Each drinker was supplied with water from a 40 litre calibrated plastic tank. Piglets were routinely medicated with 110 ml of lincomycin (Lincocin [R], Upjohn Ltd) stock solution mixed with the first 40 litres of drinking water, as a precautionary measure against swine dysentery and post weaning coliform scours. The stock solution provided 33.3 mg of lincomycin per litre of drinking water according to the manufacturer's recommendations. Water was available ad libitum and the tanks were manually refilled daily to the 40 litre mark if there was insufficient volume left for the next day. A commercial meal (Ultra Wean [R], Dalgety Agriculture Ltd) was offered ad libitum, but daily additions to troughs were controlled to prevent the accumulation of stale feed. The proximate and mineral analyses of the diet are presented in Table 2.8.

Experimental procedures

All feed inputs were recorded and soiled feed was removed and weighed when necessary. Residual feed was weighed back weekly.

Table 2.8. Proximate and mineral analyses of the diet used in experiment 3

Dry matter (%)	86.5
Digestible energy (MJ/kg DM)	15.1
Crude protein (g/kg DM)	254.0
Crude fibre (g/kg DM)	51.0
Neutral detergent fibre (g/kg DM)	165.0
Ether extract (g/kg DM)	35.0
Total ash (g/kg DM)	75.0
Calcium (g/kg DM)	12.8
Phosphorus (g/kg DM)	8.1
Magnesium (g/kg DM)	2.7
Sodium (g/kg DM)	2.3
Potassium (g/kg DM)	12.1
Chloride (g/kg DM)	2.9

DE calculated using equation given on page 120.

Water use was recorded daily at 0900 h. Piglets were individually weighed weekly and each pen group of littermates remained on trial for three weeks after weaning.

Results

The health of the piglets was good. Litter size averaged 9.86 (s.e. 0.35) at weaning. Live weight at weaning and at six weeks of age averaged 5.69 (s.e. 0.15) and 10.72 (s.e. 0.31) kg/piglet respectively. Water use, feed intake and performance data for each weekly interval after weaning are presented in Table 2.9.

Weekly data was used in the regression of water use against feed intake and against live weight. Daily data was used in the regression of water use against the number of days post weaning (NDPW). Residual plots from the linear regressions against feed intake and against live weight indicated that square-root transformation was necessary to stablise the variance for water use (Sokal and Rohlf, 1981). The results of these regression analyses are summarised in Table 2.10. The sample regression equations with their respective 95% confidence limits for predicted individual values of water use have been illustrated with scatter plots in Figures 2.6 and 2.7.

Table 2.9 Water use, feed intake and performance of piglets over 3 weekly intervals from weaning to 6 weeks of age

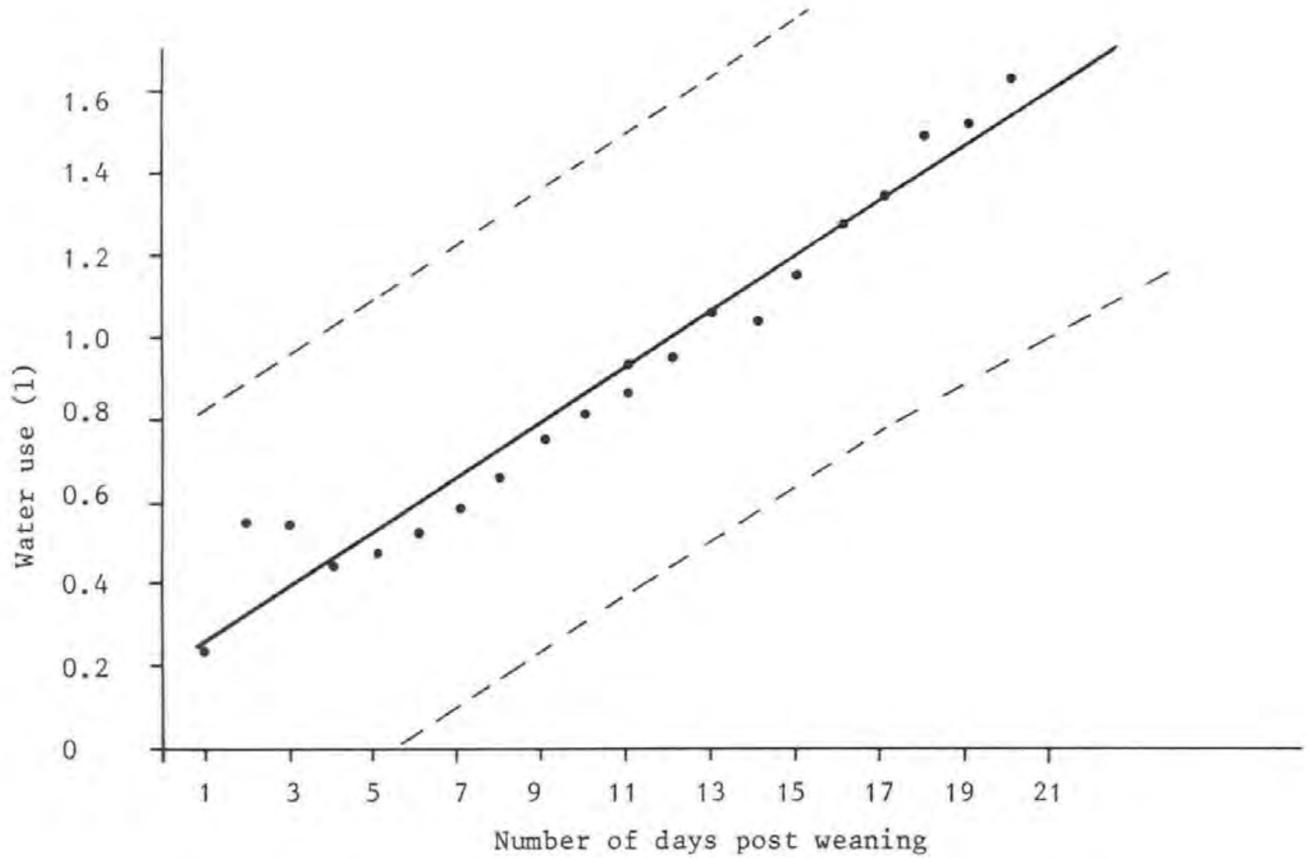
Week post weaning	Water use (l/piglet day)		Feed intake (kg/piglet day)		Live weight gain (kg/piglet day)		Mean live weight (kg)		Feed conversion ratio		Water use: feed intake ratio		Water use: live weight ratio	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
1	0.49	0.022	0.20	0.008	0.09	0.010	6.00	0.153	3.67	0.760	2.48	0.111	0.08	0.003
2	0.89	0.043	0.41	0.015	0.22	0.011	7.10	0.187	1.90	0.072	2.21	0.104	0.11	0.005
3	1.46	0.060	0.63	0.017	0.41	0.015	9.34	0.257	1.56	0.040	2.33	0.081	0.14	0.005

Table 2.10. Regression of daily water use by weaned piglets against feed intake, live weight and number of days post weaning from 3 to 6 weeks of age

Regression equation				**Standard error of:**	
	P	**r.s.d.**	R^2	**intercept**	**slope**
$Y = [0.48 + 1.13X_1]^2$	<0.001	0.097	0.83	0.026	0.057
$Y = [0.13 + 0.11X_2]^2$	<0.001	0.137	0.665	0.066	0.009
$Y = 0.19 + 0.07X_3$	<0.001	0.286	0.674	0.024	0.002

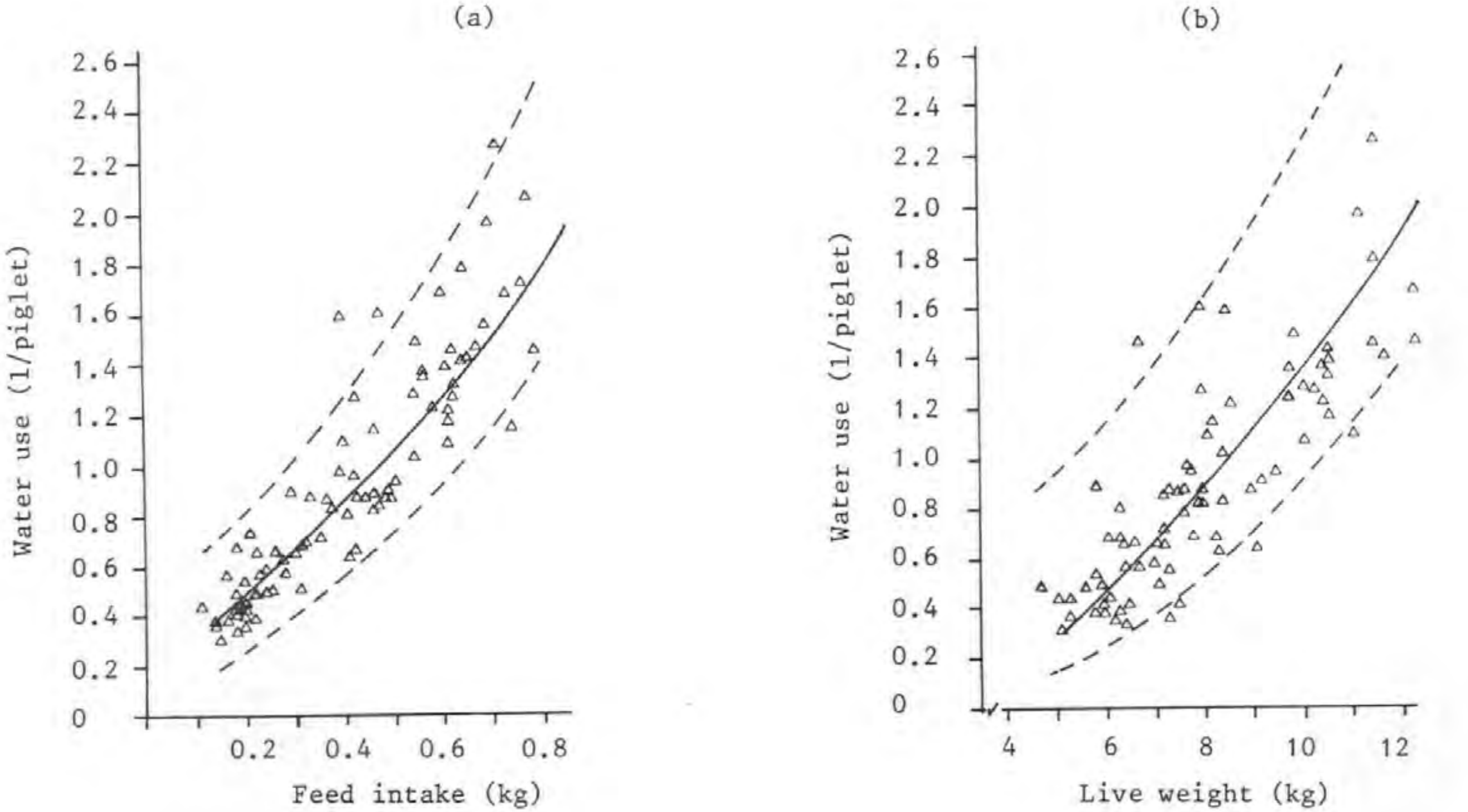
Where: Y = Average daily water use (l/piglet)
X_1 = Average daily feed intake (kg/piglet)
X_2 = Mean live weight (kg)
X_3 = NDPW

Figure 2.6 Regression of average daily water use against the number of days post weaning for piglets of between 3 and 6 weeks of age.



(-) Sample regression line.
(---) 95% confidence limits for individual values of water use.

Figure 2.7 Regression of average daily water use against (a) average daily feed intake and (b) mean live weights of weaned piglets of between 3 and 6 weeks of age.



(-) Sample regression lines.
(---) 95% confidence limits for individual values of water use.

Discussion

The replacement of sow milk-water with drinking water and sow milk-nutrients with dry feed at weaning represents a very significant change in the life of a young pig. In the current study this change was seen to have a profound influence on the biological performance of piglets following weaning. For example performance in the first week post weaning was characterised by poor feed conversion and little or no weight gain as a result of low feed intake and a disturbed pattern of water use.

The pattern of daily water use immediately following weaning showed that piglets required a long time to adapt to their new environment. Water use in the first 24 h after weaning was consistently low amongst all litter groups. This indicates that piglets may have experienced difficulty in locating and operating the nipple drinkers when first introduced to flat-deck pens. It is highly likely that water intake during this period may have been insufficient to meet the requirements for osmoregulation. The increased water usage on days 2 and 3 suggest that this response may be an over compensation as a result of the dehydration incurred on day 1. A consistent pattern of water use was not established until the end of week 1.

These results are in close agreement with the findings of a similar study conducted by Brooks et al. (1984). However, despite the fact that both studies were conducted under identical weaning, feeding and housing conditions, water use reported in the earlier study was considerably higher which averaged 0.73, 1.2 and 2.37 l/piglet day in weeks 1, 2 and 3 after weaning.

This disparity could be accounted for by a number of factors. The most important of which could be that the two studies used different types of drinker. Brooks et al. (1984) used a bite drinker which minimised losses from leakage, but they did not provide a detailed illustration of the article. However, attention was drawn to the point that water losses were still possible with this type of drinker from the mouth of piglets while drinking or through play. Conversely manufacturers of the nipple drinker used in the current study have claimed that their product reduces water losses by directing a correct stream of water to the rear of the piglet's mouth. Although water use was monitored accurately in both studies, it was not possible to determine the proportion of that water which was lost or wasted. Therefore differences in the values for water use could be attributable to differences in water wastage from the two types of drinker as a result of leakage and spillage during drinking and play.

Diet composition may also influence water demand. Brooks et al. (1984) used two different commercial diets within the same study and found that piglets fed the higher protein diet had increased growth rates, feed and water consumption. The commercial diet used in the present experiment had a higher protein, digestible energy, mineral and salt content than the diets used by Brooks et al. (1984), but water use remained consistently lower. Although diet composition may result in variations in water intake within a study this is an unlikely explanation for the large differences in water use between these two studies.

The results from the current experiment show that water use was closely correlated with feed intake, live weight and NDPW and that these variables could be used to predict water demand from regression equations.

Initially the relationship between water use and feed intake and live weight was studied using independent linear regression analysis. However, examination of the residuals from the sample linear regression lines showed that the variance increased proportionally with water use. Using the procedure outlined by Sokal and Rohlf (1981), it was found that the regression of the square root transformation of water use against feed intake and against live weight yielded equations which were significantly more accurate than their respective linear models ($P < 0.001$). This can be seen from the differences in the coefficients of determination and the residual variances between the linear and curvilinear regressions compared in Table 2.11.

The curvilinear relationship between water use and feed intake presented in this study differs from the following linear regression equation produced by Brooks et al. (1984):-

$$Y = 0.149 + 3.053\,X_1 \pm 0.522 \quad (P < 0.001;\ R^2 = 0.550)$$

Where Y is mean daily water intake (l/piglet day) and X_1 is mean daily feed intake (kg/piglet day).

However, since the average water to feed intake ratio did not remain constant over the length of the trial period in either of

Table 2.11 Comparison of linear and curvilinear regressions of average daily water use (Y) against average daily feed intake and mean live weight of weaned piglets of between 3 and 6 weeks of age

Independent variable (X_n)		**Regression equation**	**P**	**r.s.d.**	R^2	**Standard error of:- intercept**	**slope**
Feed intake (X_1) (kg/piglet day)	Linear	$Y = 0.05 + 2.18\ X_1$	< 0.001	0.207	0.79	0.054	0.120
	Curvilinear	$Y = [0.48 + 1.13\ X_1]^2$	< 0.001	0.097	0.83	0.026	0.057
Live weight (X_2)	Linear	$Y = -0.66 + 0.21\ X_2$	< 0.001	0.270	0.66	0.014	0.002
	Curvilinear	$Y = [0.13 + 0.11\ X_2]^2$	< 0.001	0.137	0.66	0.066	0.009

Curvilinear regression equations produced significantly ($P < 0.001$) better fits than linear regression equations (see Appendix).

these 2 studies, this suggests that the relationship between water and feed intake is not intrinsically linear. The curvilinear equation derived from this experiment probably represents a more accurate description of the quantitive relationship between water use and feed intake in early weaned piglets reared under these conditions of housing and feeding.

Aumaitre (1964) presented the following linear equation for the relationship between live weight and water intake from a study with suckling piglets of between 1 to 8 weeks of age:-

$$I = \frac{242.8}{W} + 78.7$$

Where I is total water intake (drinking water + milk-water + moisture obtained from creep feed) in g/kg live weight per day and W is live weight in kg.

However, closer examination of the data reported by Aumaitre (1964) as illustrated in Figure 1.4 (Page 62) suggests that a curvilinear equation would have produced a better fit. This can be seen by studying Table 2.12 which compares curvilinear and linear regression equations fitted to Aumaitre's (1964) data. Similarly in the current study the relationship between water use and piglet weight was more accurately ($P < 0.001$) described by a curvilinear equation (Table 2.11).

Using multiple linear regression analysis, Brooks et al. (1984) found that feed intake and metabolic body weight ($W^{0.6}$) accounted for more of the variation in water intake than any other

Table 2.12 Comparison of linear and curvilinear regression of total daily water intake against mean live weight of suckling piglets of between 1 and 8 weeks of age in the study of Aumaitre (1964)

	Regression equation	P	r.s.d.	R^2	Standard error of: intercept	slope
Linear	$Y = 0.175 + 0.0889\ X_2$	< 0.001	0.069	0.987	0.044	0.004
Curvilinear	$Y = [0.58 + 0.042\ X_2]^2$	< 0.001	0.014	0.997	0.009	0.001

Curvilinear regression equation produced a significantly ($P < 0.001$) better fit than linear regression equation (see Appendix)

Where:-

Y = Average daily water use (l/piglet day)
X_2 = Mean live weight (kg)

combination of factors according to the following equation:-

$$Y = 1\ 0.788 + 2.23\ X_1 + 0.367\ X_2\ (P < 0.001;\ R^2 = 0.69)$$

Where Y is mean daily water intake (l/piglet day), X_1 is mean daily feed intake (kg/piglet day) and X_2 is the metabolic body weight ($W^{0.6}$).

In the present study neither live weight nor metabolic body weight (${X_2}^{0.6}$) significantly reduced the residual error in the multiple regression analysis of water use against feed intake and live weight. This was because feed intake, and live weight were auto-correlated and only feed intake was found to be the significant independent variable in the multiple regression equation (see Appendix).

Table 2.13 compares predicted values for water use by piglets of similar weight and feed intake using the equations obtained from the present study and those reported by Brooks et al. (1984) and Aumaitre (1964). Estimations of water use differ markedly according to the equation used. Furthermore the independent variable used to establish a preditive equation for water use also has a significant effect on the value of an estimation.

Although statistical methodology and interpretation of the results can influence the type of predictive equation produced from experimental data, the conditions under which an investigation is conducted may be of greater importance. For example the type of drinking equipment used, water measuring techniques, water leaks and wastage, diet composition, housing, feeding and management could be amongst the many other factors

Table 2.13 Prediction of water use by piglets from regression equations published in 2 independent studies and in experiment 3

X_1[a] Feed intake (kg/piglet per d)	X_2[b] Live weight (kg)	Experiment 6		Brooks *et al.* (1984)		Aumaitre (1964)
		$Y=[0.48 + 1.13X_1]^2$	$Y=[0.13 + 0.11X_2]^2$	$Y=0.149 + 3.053X_1$	$Y=0.788 + 2.23X_1 + 0.367X_2^{0.6}$	$Y^1=0.2428 + 0.0787X_2$[+]
0.20	6.00	0.50	0.62	0.76	0.73	0.72
0.41	7.10	0.89	0.83	1.40	1.32	0.80
0.63	9.34	1.42	1.34	2.07	2.02	0.98

Where:

Y = Average daily water use (l/piglet per day), Y^1 includes estimate for milk-water intake and moisture obtained from creep feed.
X_1 = Average daily feed intake (kg/piglet per day)
X_2 = Mean live weight (kg)
[+] = Original equation rearranged
[a,b] = Values for X_1 and X_2 used are those obtained in experiment 3

which may account for differences in the estimation of water use from different studies.

PART II WATER USE BY EARLY WEANED AND GROWING PIGS FROM DIFFERENT TYPES OF DRINKER MANAGED UNDER VARIOUS CONDITIONS OF FEEDING AND HOUSING

Introduction

Some of the differences in water use reported between independent studies on the same class of pigs could be due to differences in water wastage attributable to the type of drinker used. For example although experiment 3 in the current study was conducted with the same age of weaned piglet using identical conditions of housing and feeding to those reported in a study by Brooks et al. (1984), average daily water use was 51% lower. However the type of drinker used in these two studies was different.

There are many different types of pig drinking devices and a number of them have been described by MacCormack (1972) and Olsson (1983).

Most drinking devices fall into one of the following categories:-

Bite drinkers

These drinkers have acquired this name because a biting action is required by the pig to unseat a spring loaded valve from an 'O' ring rubber washer. This biting action opens the valve releasing fresh water from the drinker. The valve assembly is protected by a strong metal shell and the whole unit is usually small enough to be taken completely into the mouth. Most types have a sieve on the entry side which protects the valve from abrasive water borne particles such as rust and grit. A number of designs have adjustable flow rate controls which can be used to reduce spillage when the flow rate is too high.

Nipple drinkers

These are similar to bite drinkers but they require no biting action. Instead these drinkers have a small teat, nipple or a tube which when pushed or displaced opens a valve causing the release of fresh water. The valve can be of two different types, either a spring loaded one, as found in bite drinkers, or a simple stainless steel ball bearing which is held in the closed position by the combined forces of gravity and water pressure. The latter are very simple in construction and require no maintenance. Nipple drinkers with spring loaded value assemblies are more complicated and have protective sieves like bite drinkers. Most nipple drinkers do not have adjustable flow rate screws.

Bowls

Bowl drinkers can be subdivided into two further groups; the self-refill and the pig-operated types.

Self-refill bowl drinkers provide a drinking reservoir of a given volume. The volume is held constant by the use of a float valve assembly unit. The valve mechanism operates like a ball valve assembly in a header tank and ensures that any quantity of water removed from the bowl reservoir is immediately replenished. The float valve is protected by an enclosed chamber connected to the bowl reservoir or a removable cover which facilitates repair and cleaning. Reservoir volume may range from 1 to 3 litres depending on bowl size. In some self-refill bowl drinkers the volume can be adjusted simply by raising or lowering the float on the assembly arm.

Pig-operated bowl drinkers have a rigid metal flap or lever which must be pushed against a spring loaded valve to allow the release of fresh water into a collecting basin. In some models the collecting basin may be quite large, in others it can be very shallow and serve only as a lip to hold back a small quantity of fresh water. Water is continuously replenished as long as the spring loaded valve is held open by the pig. The aim is to ensure a fresh supply of drinking water since there is a continuous turnover of water in the basin during each drinking bout. Some manufacturers incorporate a water flow regulator into the valve assembly as a way of reducing the flow rate to avoid excessive spillage.

Recently certain manufacturers of new types of bite and nipple drinkers have claimed substantial reductions in water usage due to savings in wastage and spillage during operation. However these claims have to date not been systematically investigated.

The following experiments were conducted to investigate whether the type of drinker used had any significant effects on the water use and performance of early weaned and growing pigs.

Experiment 4 A comparison of water use from two different types of drinker by growing pigs fed to a scale based on metabolic body weight.

Materials and methods

In a feeding trial, 32 growing pigs were reared in groups of 8 in 4 pens fitted with either a Mono-flo nipple drinker (Figure 2.8) or an Arato 80 bite drinker (Figure 2.9).

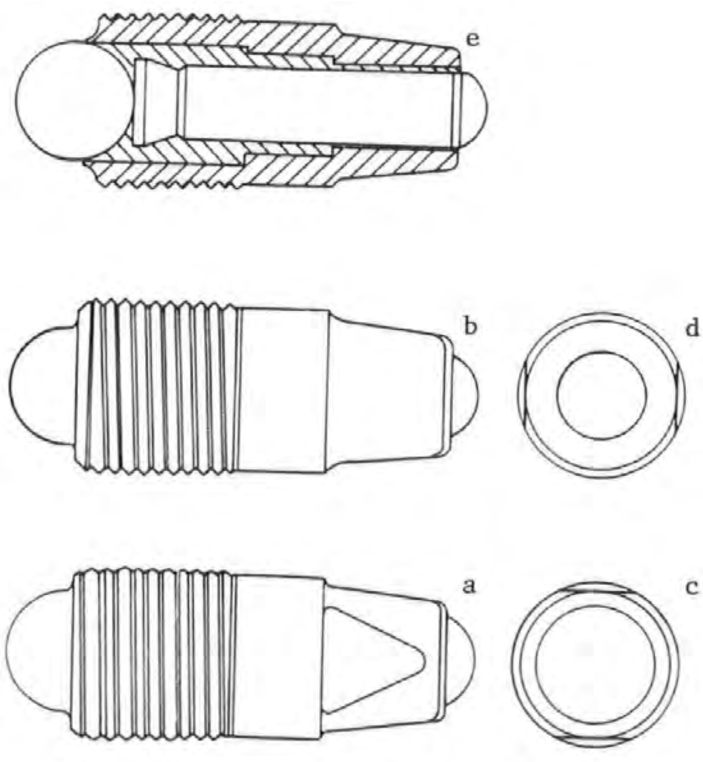
Animals and housing

Sixteen entire males and 16 females were selected with a mean initial weight of 26.5 (s.e. 0.45) kg W and transferred to a performance testing house (see Appendix). Pigs were ear tagged for identification, individually weighed on entry to the house and allocated to four pens on the basis of initial weight and balanced for sex. Water was available ad libitum to each pen group from a single drinker, either an Arato 80 bite or a Mono-flo nipple drinker. Water was supplied to each drinker from a water metering device (see Appendix). Pigs were allowed one week for adaptation. During this time a commercial pelleted feed (Ultra Wean^{R}, Dalgety Agriculture Ltd) was offered ad libitum and all pigs were wormed using fenbendazole (Panacur^{R}, Hoechst UK Ltd) according to the manufacturer's recommendations.

Experimental procedures

Pigs were weighed at the start of the experiment to determine their ration allowance which provided 100 g feed/kg $W^{0.75}$ per

Figure 2.8 Mono-flo[1] nipple drinker. (a) Side elevation; (b) top elevation; (c) end elevation; (d) front elevation; (e) cross section (½" BSP drawn to full scale).



[1]Mono-flo Lister; Halifax, Yorkshire.

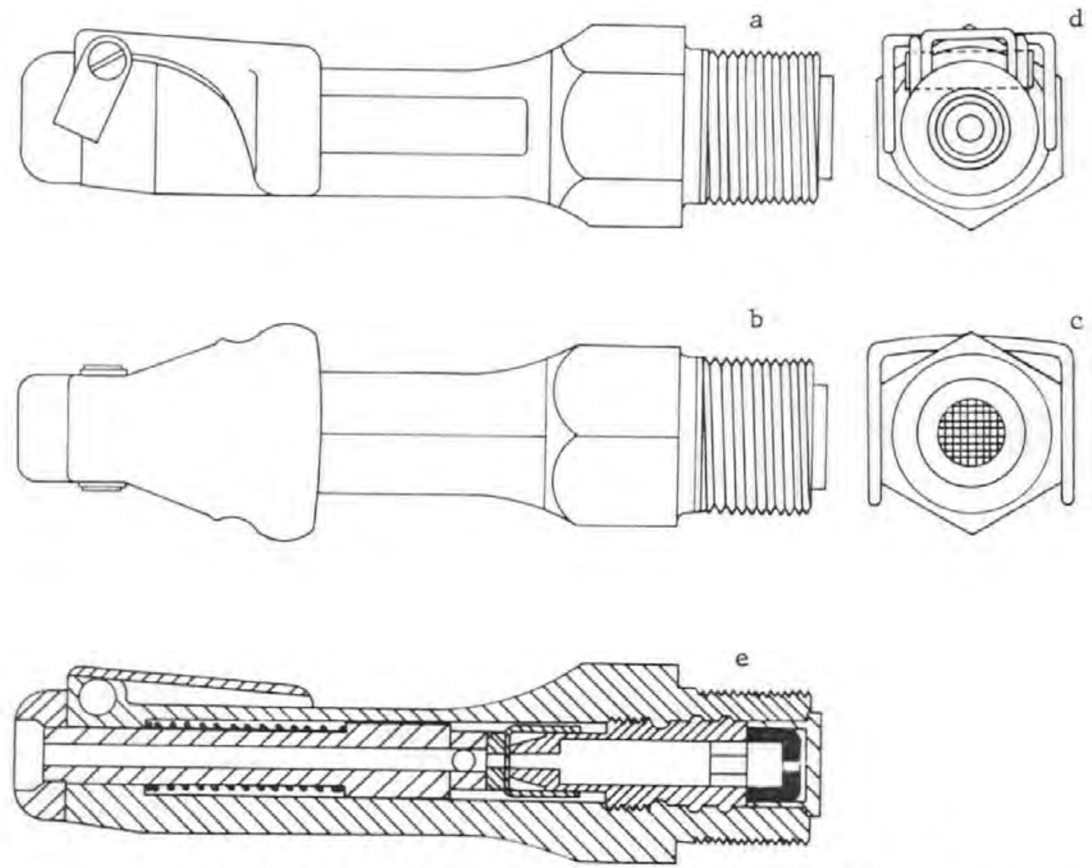


Figure 2.9 Arato[1] 80 bite drinker. (a) Side elevation; (b) top elevation; (c) end elevation; (d) front elevation; (e) cross section (drawn to full scale).

[1]Arato; Weeley Heath, Essex.

day. The pigs were individually fed once daily a meal formulated from commonly used raw materials, using published composition values to meet ARC (1981) nutrient requirements for growing pigs. The composition and proximate analyses of the diet are given in Table 2.14. The daily meal allowance was mixed with an equivalent weight of water immediately before feeding. Pigs were allowed 30 minutes within which to clear feeding troughs. Rejected feed was removed from troughs after each feeding time, weighed and oven dried at 100^{o}C for 24 h to determine the unconsumed fractions of meal and water. Pigs were individually weighed each week and their meal allowance was increased accordingly.

Water use was recorded daily after feeding at 0900 h.

Results

Water use, feed intake and pig performance data for the two drinker types is summarised in Table 2.15 . Water use was significantly higher (74%) from the Mono-flo nipple drinker ($P < 0.001$). There were no significant differences in feed intake, live-weight gain and feed conversion between pigs using the two different types of drinker. Differences in the ratio of average daily total water use (water use from drinkers plus water added to the feed) to feed intake and average daily total water use to live weight between pigs using the two drinker types were the result of a difference in voluntary water use.

Total daily water use was averaged for each week and regressed against feed intake (Figure 2.10) and live weight (Figure 2.11) for both drinker types. The results of the regression analyses

Table 2.14. Composition and proximate and mineral analyses of the diet used in experiment 4

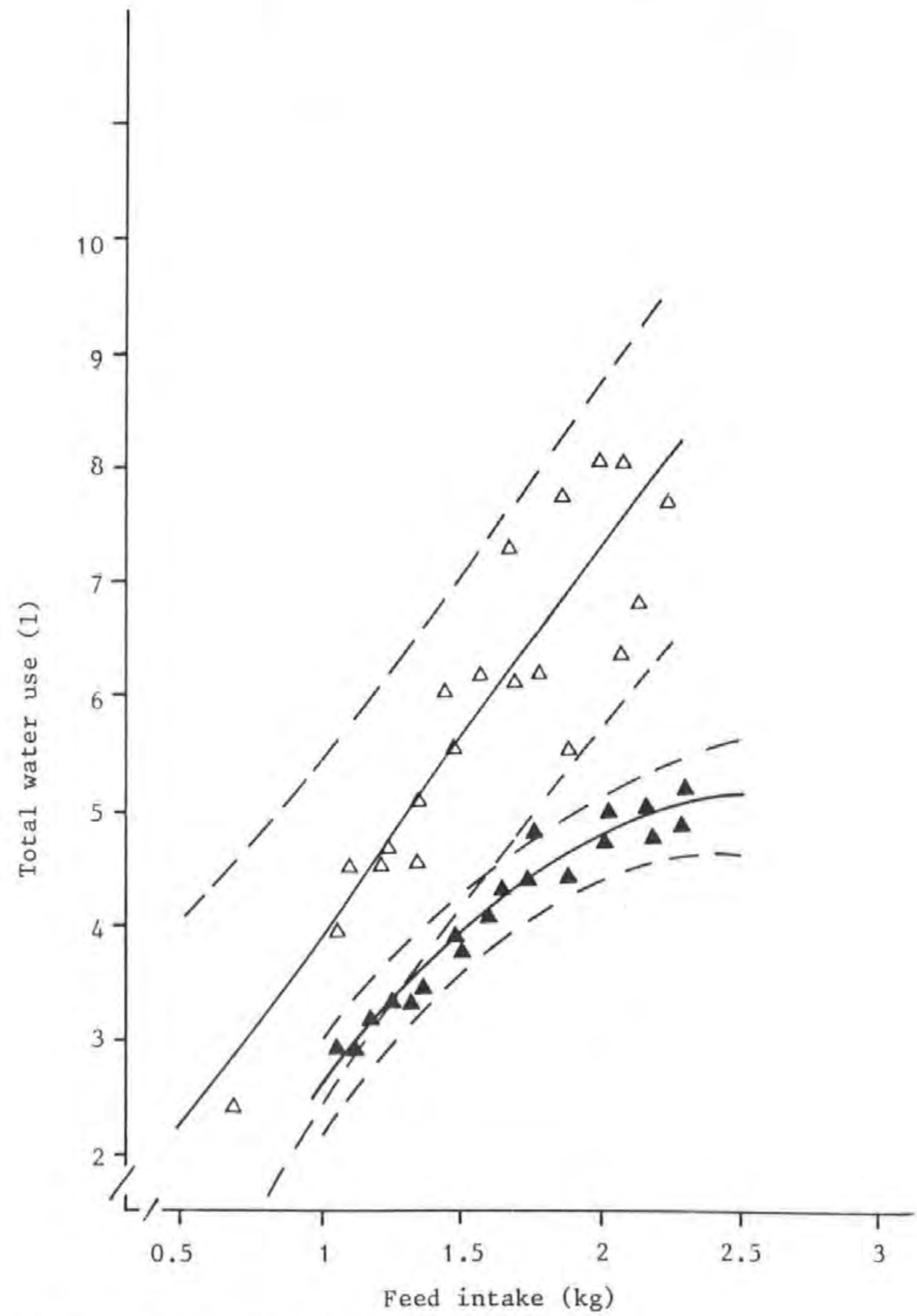
Ingredient	**% inclusion**
Wheat	81.0
Wheat feed	4.1
Herring meal	7.8
Blood meal	5.0
Limestone flour	1.0
Vitamin/mineral supplement	1.0
Salt	0.2
Proximate analysis	
Dry matter (%)	85.0
Digestible energy (MJ/kg DM)	16.1
Crude protein (g/kg DM)	244.0
Crude fibre (g/kg DM)	39.0
Neutral detergent fibre (g/kg DM)	132.0
Ether extract (g/kg DM)	22.0
Total ash (g/kg DM)	56.0
Mineral analysis	
Calcium (g/kg DM)	13.1
Phosphorous (g/kg DM)	7.2
Magnesium (g/kg DM)	15.6
Sodium (g/kg DM)	2.5
Potassium (g/kg DM)	7.4
Chloride (g/kg DM)	2.8

DE calculated using equation given on page 120 .

Table 2.15 Water use, feed intake and performance of growing pigs offered water from 2 different types of drinker

	Treatment				
	Mono-flo		Arato 80		
	Mean	**s.e.**	**Mean**	**s.e.**	**P**
Live weight (kg)					
Initial	29.0	0.76	31.2	0.63	
Final	76.3	0.54	76.3	0.50	
Voluntary water use					
(l/pig day)	4.30	0.245	2.47	0.086	< 0.001
Total water use					
(l/pig day)	5.89	0.322	4.16	0.168	< 0.001
Feed intake					
(kg/pig day)	1.59	0.089	1.69	0.089	NS
Live-weight gain					
(kg/pig day)	0.61	0.026	0.67	0.032	NS
Feed conversion ratio	2.60	0.083	2.54	0.071	NS
Total water use: feed intake	3.72	0.082	2.50	0.040	
Total water use: live weight	0.13	0.004	0.09	0.002	

Figure 2.10 Regression of average daily total water use against average daily feed intake for growing pigs offered water from 2 different types of drinker: △ Mono-flo, ▲ Arato 80.



(-) Sample regression line.
(---) 95% confidence limits for individual values of water use.

Figure 2.11 Regression of average daily total water use against mean live weight of growing pigs offered water from 2 different types of drinker: △ Mono-flo, ▲ Arato 80.

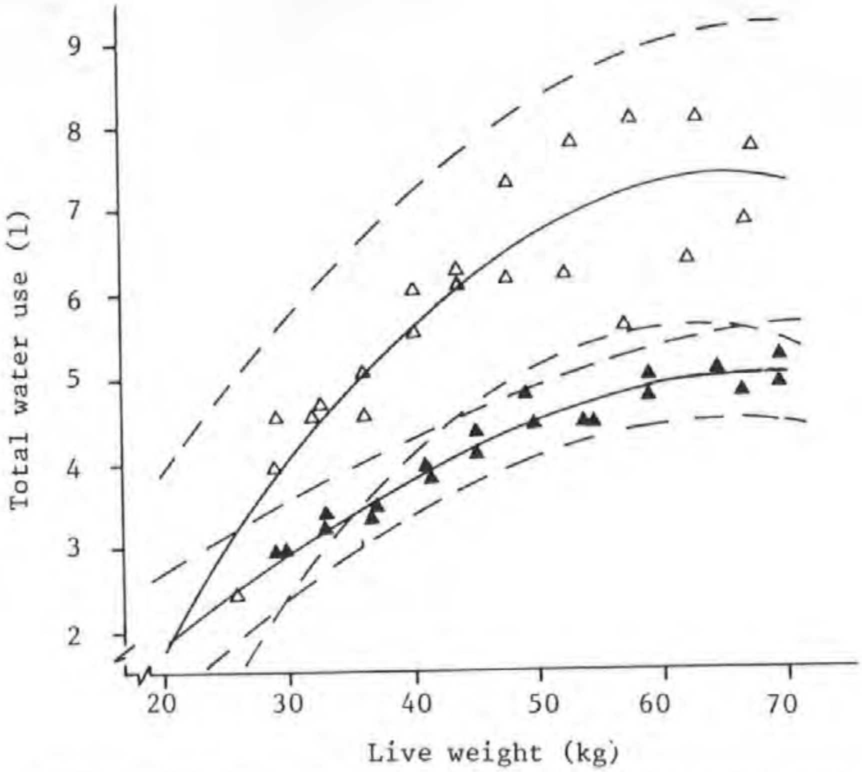
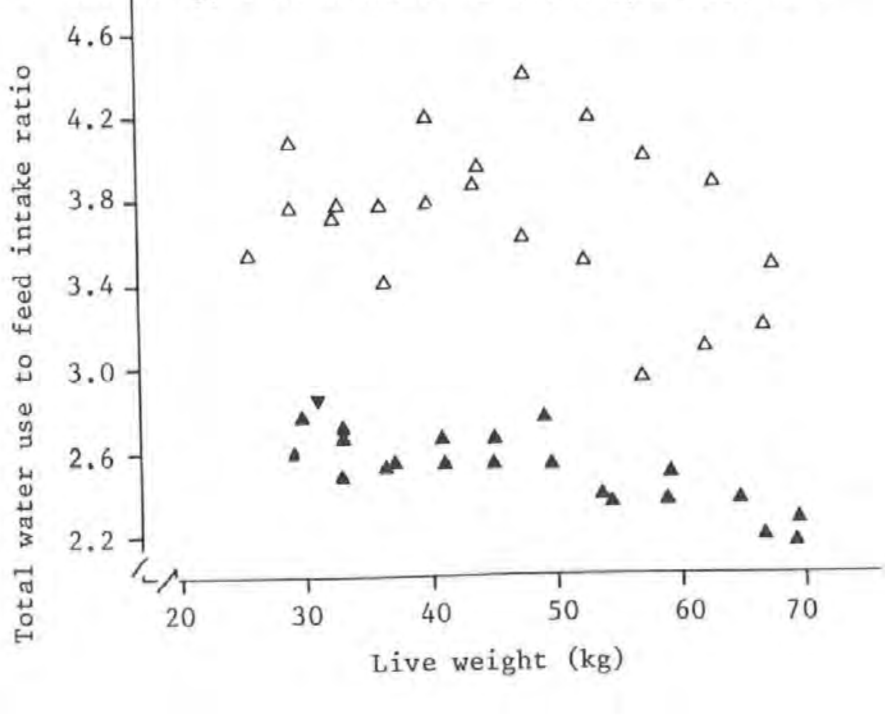


Figure 2.12 Relationship between live weight and total water use to feed intake ratio for growing pigs offered water from 2 different types of drinker: △ Mono-flo, ▲ Arato 80.



are summarised in Table 2.16. All regression equations were highly significant ($P < 0.001$). The relationship between feed intake and total water use for the Mono-flo nipple drinker was found to be linear. A curvilinear equation produced a significantly better fit ($P < 0.01$) than a linear equation in the regression of average daily total water use against feed intake for the Arato 80 bite drinker (see Appendix). For both drinker types, the total water use to feed intake ratio did not remain constant but decreased linearly with increasing live weight (Figure 2.12).

The analyses of regression showed that quadratic equations produced significantly better fits than linear equations for the relationship between live weight and total water use for both the Mono-flo nipple and Arato 80 bite drinkers ($P < 0.05$; $P < 0.001$; see Appendix). According to the fitted equations, the point of maximum average daily total water use (when $dY/dX_2 = 0$) was reached at 65.6 kg W and 72.4 kg w for the Mono-flo nipple and Arato 80 bite drinker respectively. Total water use at these weights averaged 7.3 and 5.0 l/pig per day respectively.

Table 2.16. Regression of total average daily water use against average daily feed intake and mean live weight of growing pigs provided with water from two different types of drinker

Treatment	Regression equation	P	r.s.d.	R^2	Standard error of: intercept	b1	b2
Mono-flo	$Y = 0.55 + 3.37X_1$	<0.001	0.674	0.814	0.606	0.369	
Arato 80	$Y = -1.45 + 4.98X_1 - 0.935X^2_1$	<0.001	0.169	0.955	0.788	0.964	0.283
Mono-flo	$Y = -3.96 + 0.345X_2 - 0.00263X^2_2$	<0.001	0.732	0.793	2.302	0.103	0.001
Arato 80	$Y = -1.04 + 0.168X_2 - 0.00116X^2_2$	<0.001	0.176	0.951	0.626	0.027	0.0003

Where: Y = Average daily total water use (l/pig)
X_1 = Average daily feed intake (kg/pig)
X_2 = Mean live weight (kg)

Experiment 5 A comparison of water use from four different types of drinker by growing pigs fed ad libitum (trial 5a) and according to a scale based on metabolic body weight (trial 5b).

Materials and methods

Experimental design and treatments

In two 12 week feeding trials, growing pigs were reared in pens fitted with one of four different types of drinker namely ;

Mono-flo nipple drinker, 1/2 inch BSP	(Figure 2.8)
Arato 80 bite drinker	(Figure 2.9)
Lubing bite drinker, type I	(Figure 2.13)
Lubing bite drinker, type II	(Figure 2.14)

The drinkers were randomly allocated as treatments to 4 pen groups of pigs within each trial according to a 4 x 4 Balanced Latin Square design, in which each pen group received its water from each drinker type once only for a period of three weeks.

Animals and housing

Twenty-four pigs, 12 entire males and 12 females, with a mean initial weight of 18.2 (s.e. 0.47) kg W were selected for trial 5a. Thirty-two pigs, 16 entire males and 16 females, with a mean initial weight of 19.1 (s.e. 0.34) kg W were selected for trial 5b. The two groups were transferred to separate performance testing houses (see Appendix). Pigs were ear tagged for identification, individually weighed and allocated to 4 pens within each house on the basis of initial weight and balanced for sex and numbers.

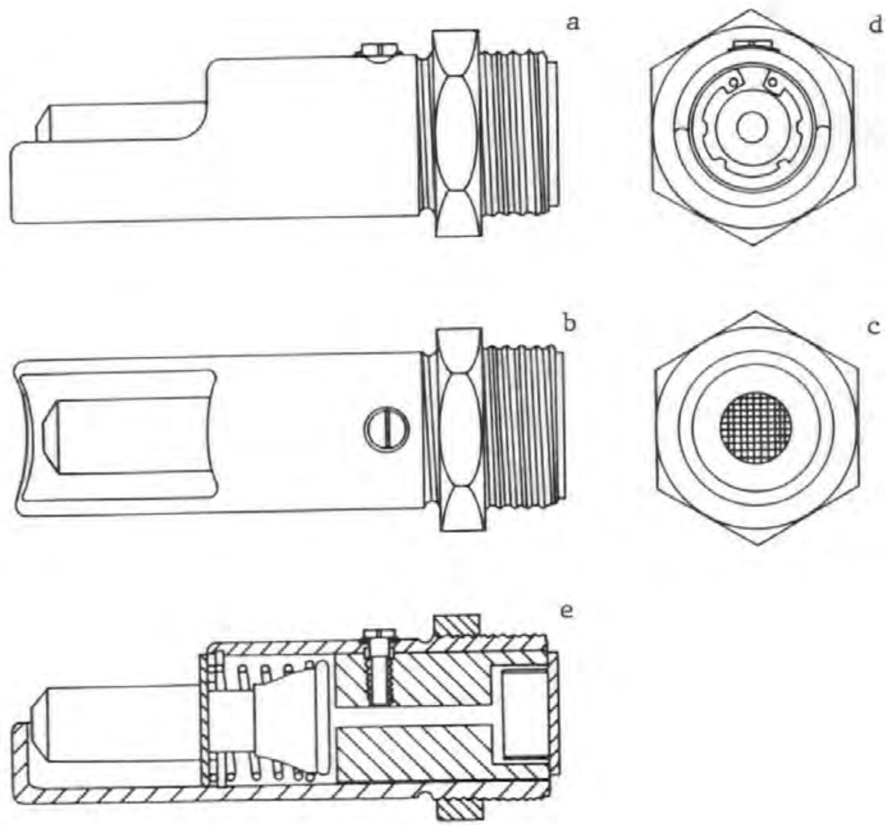
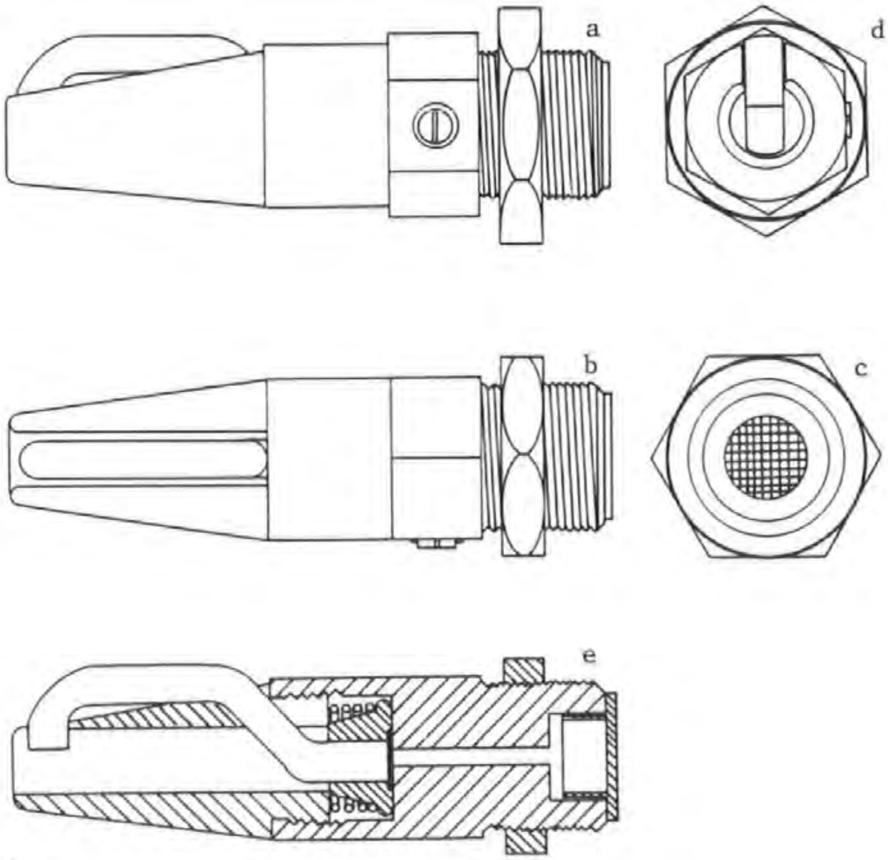


Figure 2.13 Lubing[1] type I bite drinker. (a) Side elevation; (b) top elevation; (c) end elevation; (d) front elevation; (e) cross section (drawn to full scale).

[1]Lubing Equipment (UK) Ltd., Knutsford, Cheshire.

Figure 2.14 Lubing[1] type II bite drinker. (a) Side elevation; (b) top elevation; (c) end elevation; (d) front elevation; (e) cross section (drawn to full scale).



[1]Lubing Equipment (UK) Ltd., Knutsford, Cheshire.

Water was available *ad libitum* to each pen group from a single drinker. Water was supplied to each drinker from a water metering device (see Appendix). Pigs were allowed one week for adaptation. During this time, a commercial pelleted diet (Ultra Wean[R], Dalgety Agriculture Ltd) was offered *ad libitum*. All pigs were wormed using fenbendazole (Panacur [R], Hoechst UK Ltd) according to the manufacturer's recommendations.

Experimental procedures

Trial 5a

Pigs were individually weighed and fed *ad libitum*, as pen groups, a commercial pelleted diet from a single feed hopper located in the lying area of each pen. Pigs were individually weighed and residual feed was removed from the hoppers and weighed each week.

Trial 5b

Pigs were weighed and individually fed a commercial pelleted diet according to a scale which provided 700 g feed/kg $W^{0.75}$ per pig per week. The calculated weekly feed allowance for each pig was divided into 13 equal feeds such that pigs were fed twice daily at 0900 and 1600 h except on Sundays when only the morning feed was given. Water was not added to the dry pellets and any rejected feed was removed from troughs and weighed after each feeding time. Pigs were individually weighed weekly and their feed allowance was increased accordingly.

In both feeding trials water use was recorded daily at 0900 h. The proximate and mineral analyses of the diets used in trials 5a and 5b are given in Table 2.17.

Table 2.17. Proximate and mineral analyses of diets used in trials 5a and 5b

	Trial 5a diet	**Trial 5b diet**
Dry matter (%)	88.0	87.5
Digestible energy (MJ/kg DM)	15.4	14.1
Crude protein (g/kg DM)	220.0	172.5
Crude fibre (g/kg DM)	72.0	24.6
Neutral detergent fibre (g/kg DM)	166.0	170.1
Ether extract (g/kg DM)	60.0	24.6
Total ash (g/kg DM)	74.0	85.1
Calcium (g/kg DM)	10.2	8.8
Phosphorous (g/kg DM)	8.2	6.5
Magnesium (g/kg DM)	2.7	2.3
Sodium (g/kg DM)	1.6	1.2
Potassium (g/kg DM)	16.1	12.1
Chloride (g/kg DM)	2.4	1.8

DE calculated using equation given on page 120 .

Results

The health of the pigs remained satisfactory, with the exception that in week four of trial 5b pig 5 started to refuse large amounts of feed for no apparent reason and lost weight. It was not removed from the experiment but data related to this animal was omitted from the statistical analyses of feed intake, live weight gain and feed conversion data. Water use data was lost in weeks 1 and 12 of trial 5b. This was due to unforeseen maintenance work on the College water tank in week 1 and freezing weather conditions in week 12 which ruptured external water pipes supplying the experimental house. The disruption in week 1 required the readjustment of water metering devices as the experimental house was temporarily transferred to the high pressure public mains supply. All the data for weeks 1 and 12 of trial 5b were ommitted from statistical analyses. Water supply of trial 5a was not affected as the two trials did not run concurrently.

Initial and final live weight averaged 20.9 (s.e. 0.60) and 26.0 (s.e. 0.52); 88.6 (s.e. 1.95) and 84.9 (s.e. 1.86) kg W for trials 5a and 5b respectively. Water use, feed intake and pig performance data according to drinker type treatment are summarised for both trials in Table 2.18. Under both feeding regimes, water use was significantly higher ($P < 0.001$) from the Mono-flo nipple drinker than from the Arato 80, Lubing type I and type II bite drinkers. Water use was higher with ad libitum than for scale fed pigs for the three types of bite drinker, but from the Mono-flo nipple drinker a greater volume was used when the pigs were fed on a scale related to metabolic body weight.

Table 2.18. Water use, feed intake and performance of growing pigs fed _ad libitum_ or according to a scale related to metabolic body weight and provided with water from four different types of drinker

Drinker	Treatment / Feeding regime	Mono-flo nipple Mean	Mono-flo nipple s.e.	Arato 80 bite Mean	Arato 80 bite s.e.	Lubing bite type I Mean	Lubing bite type I s.e.	Lubing bite type II Mean	Lubing bite type II s.e.	P
Water flow rate (l/min)		1.32		0.67		0.57		0.67		
Water use (l/pig day)	Ad libitum	8.32[a]	0.726	5.63[b]	0.491	4.98[b]	0.451	5.21[b]	0.435	<0.001
	Scale	10.25[a]	1.071	5.00[b]	0.439	4.94[b]	0.151	5.06[b]	0.313	<0.001
Feed intake (kg/pig day)	Ad libitum	1.97	0.191	2.16	0.206	2.21	0.174	2.10	0.159	NS
	Scale	1.85[a]	0.055	1.83[a]	0.048	1.92[b]	0.045	1.95[b]	0.047	<0.001
Live-weight gain (kg/pig day)	Ad-libitum	0.82	0.026	0.79	0.032	0.82	0.029	0.79	0.028	NS
	Scale	0.76[a]	0.021	0.77[a]	0.027	0.83[b]	0.025	0.86[b]	0.025	<0.001
Feed conversion ratio	Ad libitum	2.62	0.194	2.92	0.345	2.57	0.136	2.66	0.168	NS
	Scale	2.47	0.281	2.71	0.286	2.40	0.056	2.35	0.062	NS
Water use: Feed intake ratio	Ad libitum	4.02	0.200	2.54	0.096	2.50	0.078	2.53	0.139	
	Scale	5.50	0.403	2.81	0.275	2.71	0.203	2.73	0.186	
Water use: Live weight ratio	Ad libitum	0.17	0.01	0.11	0.007	0.10	0.006	0.11	0.01	
	Scale	0.21	0.022	0.11	0.015	0.10	0.012	0.11	0.011	

[a,b]Means with the same superscript within the same row did not differ significantly (P > 0.05)

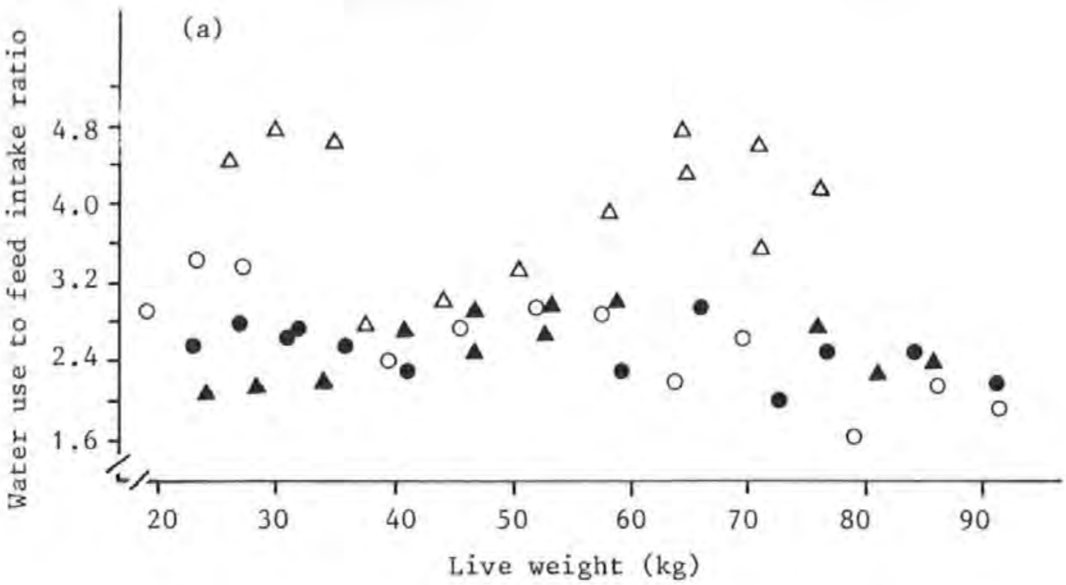
For *ad libitum* fed pigs, type of drinker had no significant effect on feed intake, daily live-weight gain and feed conversion. However, with scale fed pigs, average daily feed intake and live-weight gain were significantly affected by drinker type. Daily feed intake and weight gain were significantly higher ($P < 0.001$) in the periods when pigs were offered water from Lubing type I and II bite drinkers.

Irrespective of drinker type, feed intake was higher with *ad libitum* feeding but feed conversion was consistantly superior with scale feeding. Although there were large differences in the average feed conversion of pigs using the different drinker types, these differences failed to reach statistical significance.

Although both water use and feed intake tended to be higher with *ad libitum* feeding, more water was used per unit of feed intake by pigs fed on the scale related to metabolic body weight. For both feeding regimes the ratio of water use to feed intake decreased with increasing live weight (Figure 2.15). The ratio of average water use to live weight showed a high degree of constancy between the three types of bite drinkers both within and between the two feeding regimes. Water use averaged 11% of body weight.

The relationship between daily water use and feed intake for trials 5a and 5b is presented in Figure 2.16. Similarly the relationship between water use and live weight is illustrated in Figure 2.17. Under both feeding regimes, water use from the

Figure 2.15 Relationship between mean live weight and water use to feed intake ratio of growing pigs fed either (a) ad libitum or (b) to a scale related to matabolic body weight and offered water from 4 different types of drinker: △ Mono-flo, ▲ Arato 80, ● Lubing type I, ○ Lubing type II.



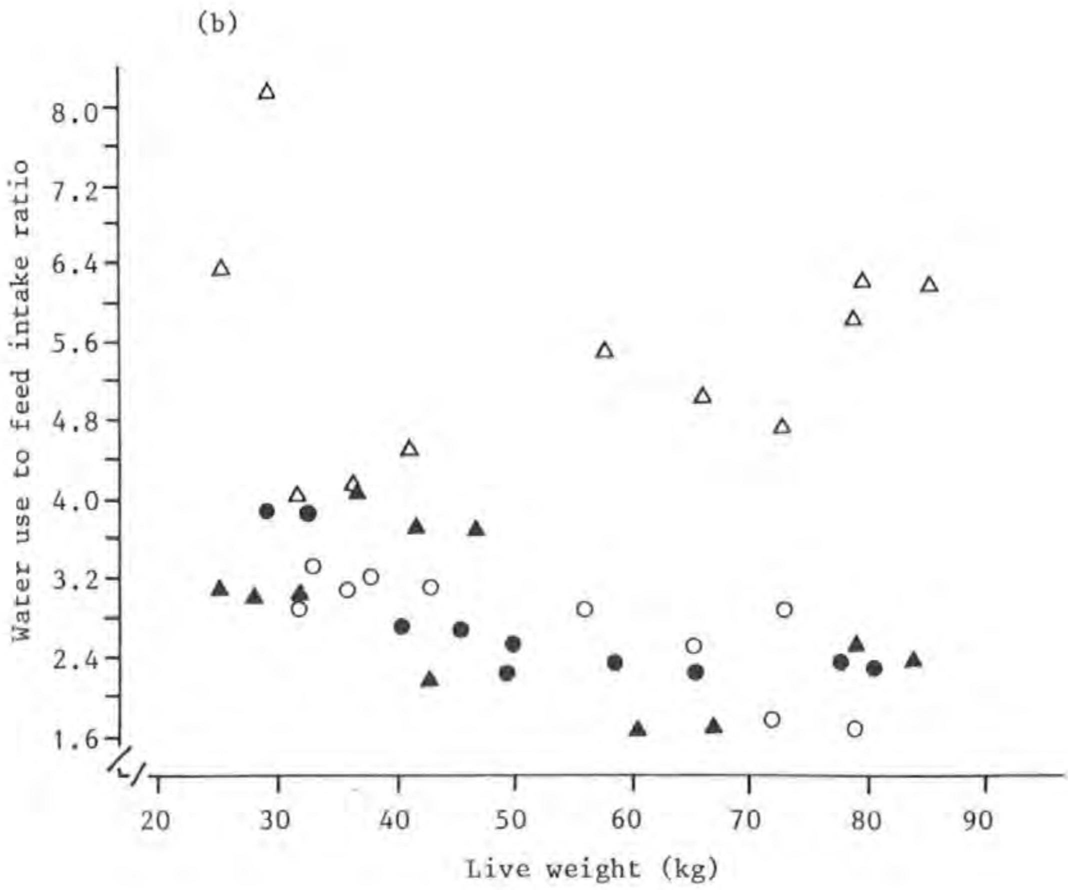


Figure 2.16 Relationship between average daily feed intake and water use of growing pigs fed either (a) ad libitum or (b) on a scale related to metabolic body weight and offered water from 4 different types of drinker: △ Mono-flo, ▲ Arato 80, ● Lubing type I, ○ Lubing type II.

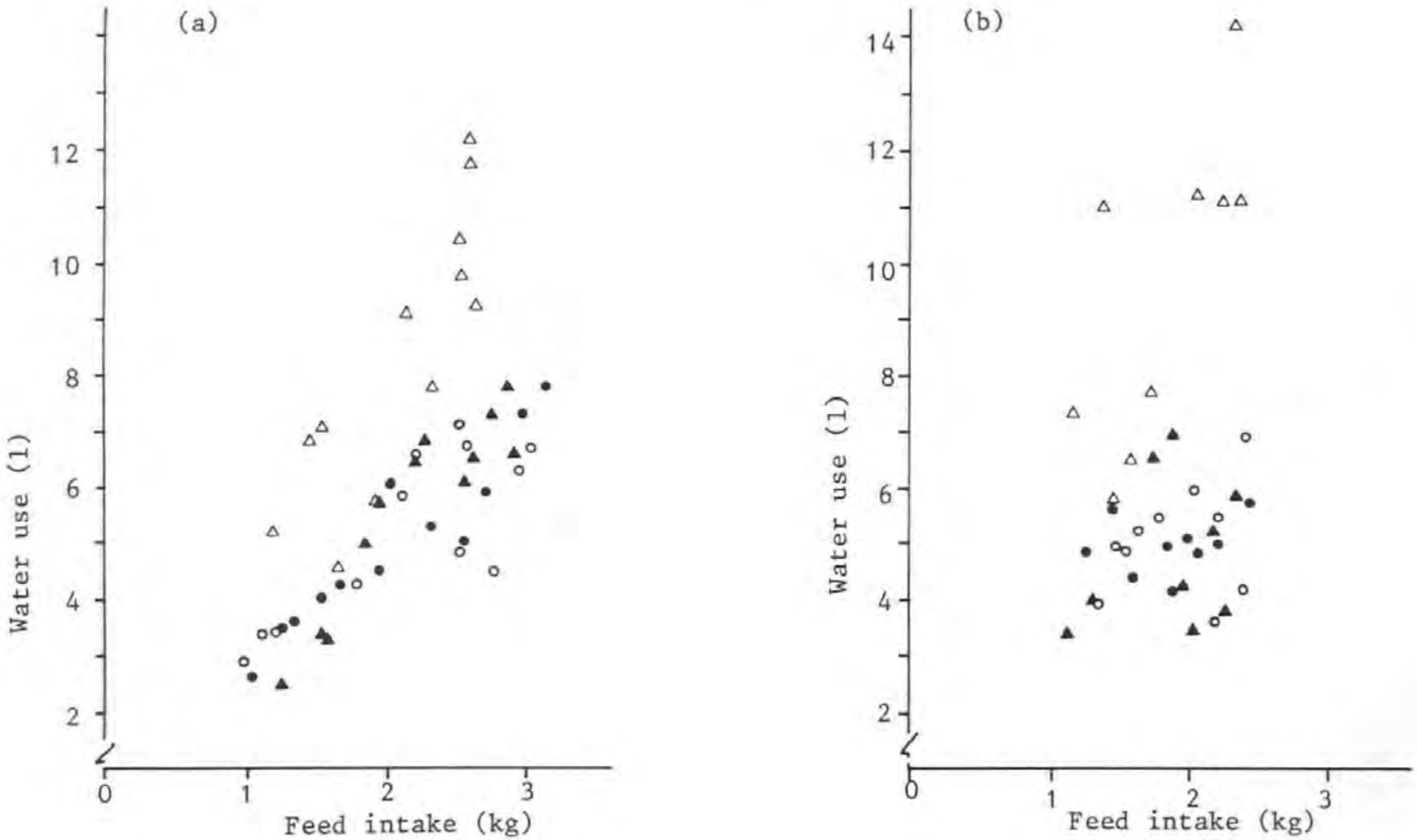
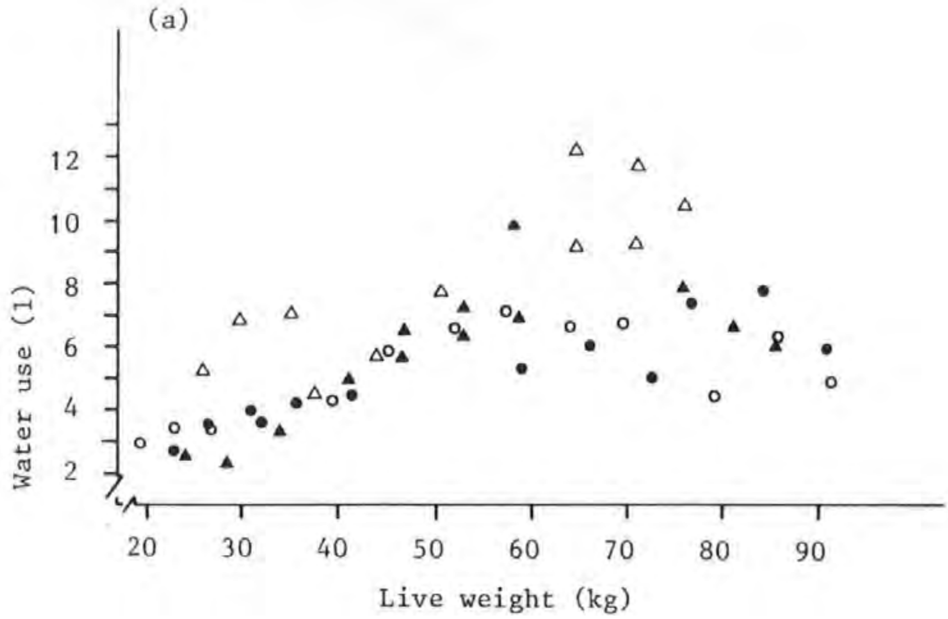
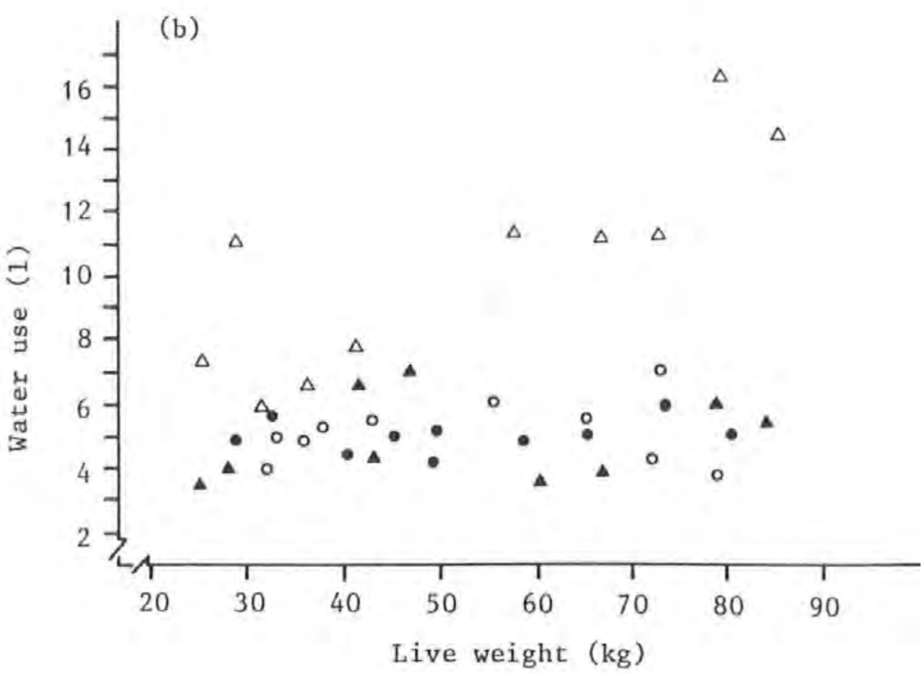


Figure 2.17 Relationship between mean live weight and water use of growing pigs fed either (a) ad libitum or (b) on a scale related to metabolic body weight and offered water from 4 different types of drinker: Δ Mono-flo, ▲ Arato 80, ● Lubing type I, O Lubing type II.





Mono-flo nipple drinker was greater, highly variable and inconsistent compared with that obtained from the bite drinkers.

With *ad libitum* feeding, water use increased curvilinearly with increasing feed intake and live weight and reached a maximum of about 7 l/pig day at 60 kg W. Thereafter water use decreased to about 5 l/pig at the end of the trial period.

With scale fed pigs water use reached 7 l/pig day at about 40 kg W and thereafter plateaued to 5 l/pig day to the end of the trial period.

Experiment 6 A comparison of water use from five different types of drinker by early weaned piglets from 3 to 6 weeks of age.

Materials and methods

Experimental design and treatments

The performance of weaner pigs reared in pens fitted with one of five different types of drinker was investigated. The different drinkers evaluated were:-

A	Arato 76 nipple drinker	(Figure 2.18)
B	Lubing bite drinker, type I	(Figure 2.13)
C	Lubing bite drinker, type II	(Figure 2.14)
D	Mono-flo nipple drinker 3/8 inch BSP	(Figure 2.8)
E	Alvin piglet bowl drinker	(Figure 2.19)

Ten replicate groups of weaned littermates were randomly allocated with time, to the drinker type treatments according to a Randomised Complete Block design.

Animals and housing

Groups of 4 entire male and 4 female littermates of similar weaning weight were selected from suckling litters at 21 $\pm$1 days of age. The piglets were ear tagged for identification, weighed and allocated as littermate groups to pens in a flat-deck weaner house (see Appendix).

The animals were managed as previously described in experiment 3, except that each pen was fitted with two drinking points and the

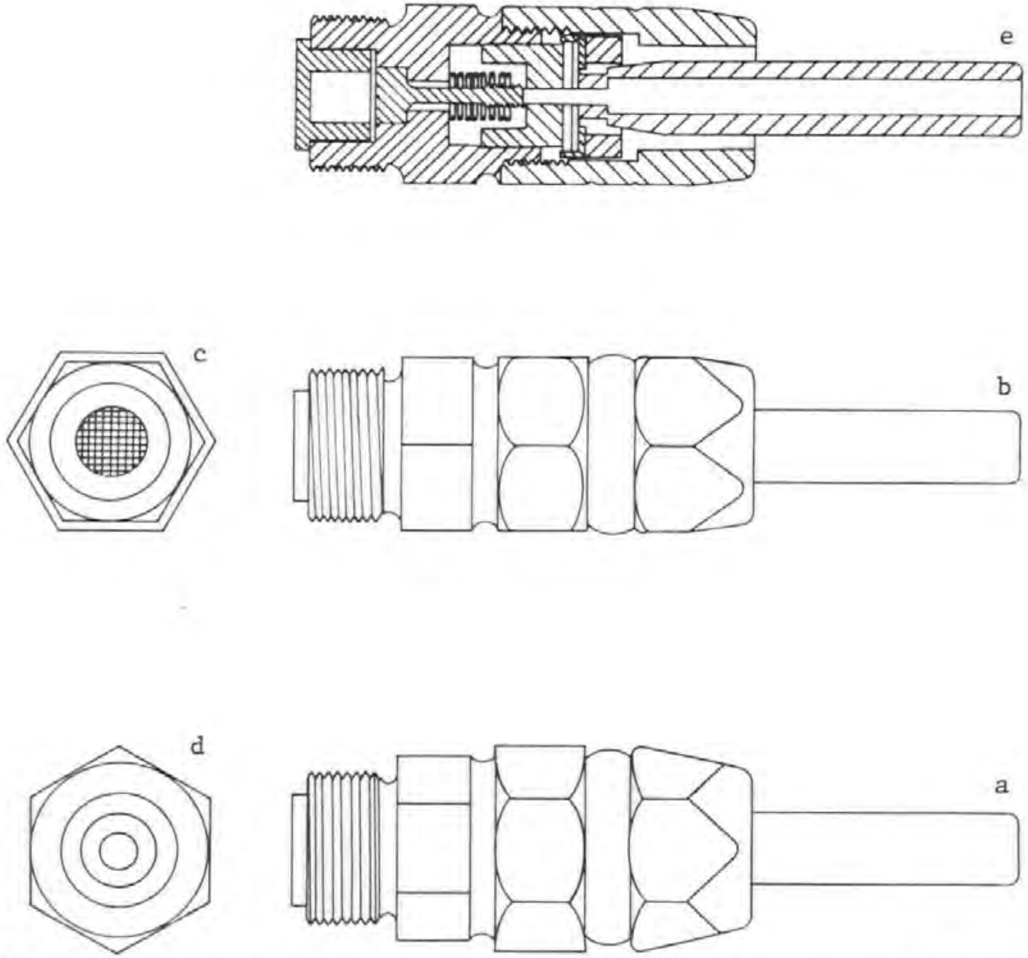
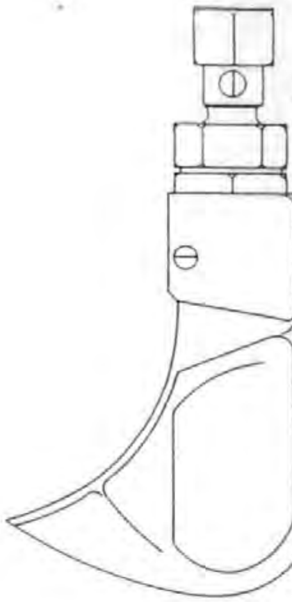


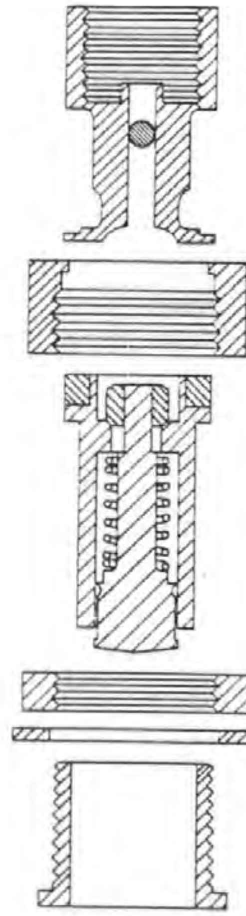
Figure 2.18 Arato[1] 76 nipple drinker. (a) Side elevation; (b) top elevation; (c) end elevation (d) front elevation; (e) cross section (drawn to full scale).

[1]Arato, Weeley Heath, Essex.

Figure 2.19 Alvin[1] piglet bowl drinker. (a) side elevation; (b) front elevation; (d) cross section of valve. (a, b, c 0.5 x full scale; d full scale).



a



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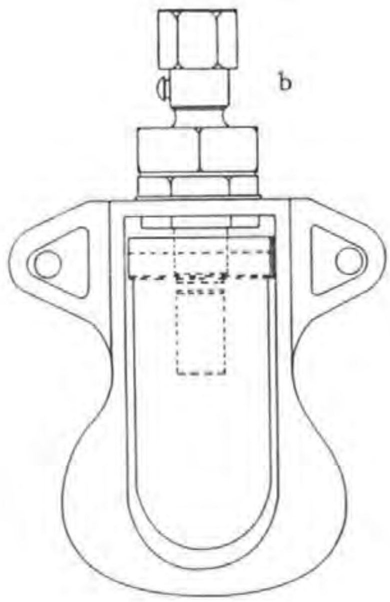
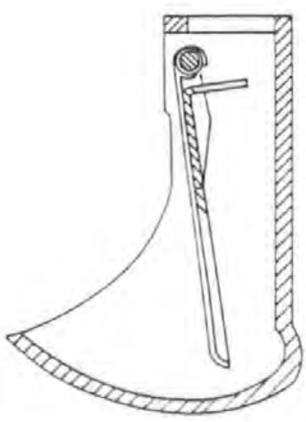


b



c

[1]Fisher Founderies Ltd., Birmingham.

commercial diet (Ultra Wean [R], Dalgety Agriculture Ltd) was pelleted. Proximate and mineral analyses of the diet are presented in Table 2.19. All experimental procedures were similar to those described in experiment 3.

Results

The health of the majority of piglets was satisfactory. However, there were 3 deaths, 1 on treatment B and 2 on treatment E. One replicate group on treatment D developed post-weaning diarrhoea at five weeks of age. They were treated with Scour Formula [R] (Beechams) and recovered in the subsequent week. Seven pen groups showed weight loss during the first week after weaning without any noticeable health problems (1A, 2B, 1C, 2D and 1E). Where necessary, data was adjusted for deaths before statistical analyses.

The piglets averaged 5.6 (s.e. 0.10) kg W at weaning and 10.3 (s.e. 2.06) kg W at six weeks of age. Water use and piglet performance data for the five drinker treatments is summarised in Table 2.20. Water use was significantly higher ($P < 0.001$) from the Mono-flo nipple drinker than from the Arato 76 nipple, Alvin bowl and Lubing type I and II bite drinkers. Drinker treatment had no significant effect on feed intake. Live-weight gain was significantly higher ($P < 0.05$) for replicate groups reared in pens fitted with Arato 76 nipple drinkers. A similar trend was observed for the Alvin bowl drinker. Within pen variation in piglet live weights was significantly lower ($P < 0.001$) in replicate groups supplied with drinking water from the Arato 76 nipple and Lubing type II bite drinkers. (There were no

Table 2.19. Proximate and mineral analyses of the diet used in experiment 6

Dry matter (%)	88.6
Digestible energy (MJ/kg DM)	16.3
Crude protein (g/kg DM)	248.0
Crude fibre (g/kg DM)	62.0
Neutral detergent fibre (g/kg DM)	141.0
Ether extract (g/kg DM)	77.0
Total ash (g/kg DM)	73.0
Calcium (g/kg DM)	10.4
Phosphorous (g/kg DM)	7.6
Magnesium (g/kg DM)	3.5
Sodium (g/kg DM)	1.8
Potassium (g/kg DM)	15.7
Chloride (g/kg DM)	2.6

DE calculated using equation given on page 120.

Table 2.20. Water use, feed intake and performance of weaned piglets from 3 to 6 weeks of age provided with water from five different types of drinker

Drinker Treatment	Arato 76 nipple		Lubing bite type I		Lubing bite type II		Mono-flo nipple		Alvin bowl		
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	P
Water flow rate (ml/min) Min	188		390		420		495		390		
Max	195		458		545		598		460		
Water use (l/piglet day)	1.02^{a}	0.079	0.91^{a}	0.070	0.97^{a}	0.069	1.59^{b}	0.123	1.01^{a}	0.078	<0.001
Feed intake (kg/piglet day)	0.36	0.032	0.33	0.032	0.35	0.027	0.34	0.030	0.33	0.032	NS
Live weight (kg)											
Initial	5.94	0.222	5.60	0.163	5.71	0.207	5.44	0.205	5.43	0.283	NS
Final	11.40	0.362	10.02	0.618	10.35	0.388	9.62	0.582	10.07	0.781	
Live-weight gain (kg/piglet day)	0.260^{a}	0.029	0.213^{b}	0.027	0.221^{b}	0.026	0.199^{b}	0.025	0.224^{ab}	0.028	<0.05
Within pen group variation in piglet live weights (σ_{n-1})	0.88^{a}	0.062	1.16^{b}	0.091	0.98^{a}	0.079	1.14^{b}	0.094	1.21^{b}	0.097	<0.001
Feed conversion ratio	1.44	0.147	1.48	0.359	2.26	0.598	2.93	1.034	1.70	0.224	NS
Water use: Feed intake ratio	3.23	0.255	3.68	0.835	2.90	0.109	5.32	0.504	3.49	0.262	
Water use: Live weight ratio	0.13	0.007	0.12	0.007	0.13	0.007	0.23	0.012	0.14	0.010	

^{a,b} Means with the same superscript within the same row did not differ significantly (P > 0.05).

significant differences in within pen group live weight variation at weaning). Feed conversion was not significantly affected by drinker treatment. The ratio of average water use to feed intake varied considerably between pigs using different drinker types. This was due to high coefficients of variation in both water use and feed intake. The mean water use to live weight ratio showed less variation, with water use averaging 13% of body weight (excluding Mono-flo nipple drinker data). No significant age x drinker treatment interactions were found for water use, feed intake and piglet performance.

For each drinker treatment, weekly data was used to examine the relationship between water use and feed intake (Figure 2.20) and live weight (Figure 2.21) using analyses of regression. Daily data was used to examine the relationship between water use and the number of days post weaning (Figure 2.22). The results of the regression analyses are summarised in Table 2.21. All equations were linear and highly significant ($P < 0.001$).

The residual standard deviation, slope and intercept of each equation were compared between drinker treatments according to the procedure given by Snedecor and Cochran (1967). The results of this analysis are summarised in Table 2.22. There were no significant differences in the slopes of the regressions of water use on feed intake, live weight and NDPW between the Arato 76 nipple, Alvin bowl and Lubing type I and type II bite drinkers. However comparison of residual standard deviations and intercepts suggested that the relationship between water use and feed intake, live weight and NDPW was dependent on the type of drinker used.

Figure 2.20 Relationship between average daily feed intake and water use for weaned piglets of between 3 and 6 weeks of age offered water from 5 different types of drinker: ▲ Arato 76, ● Lubing type I, O Lubing type II, Δ Mono-flo, □ Alvin.

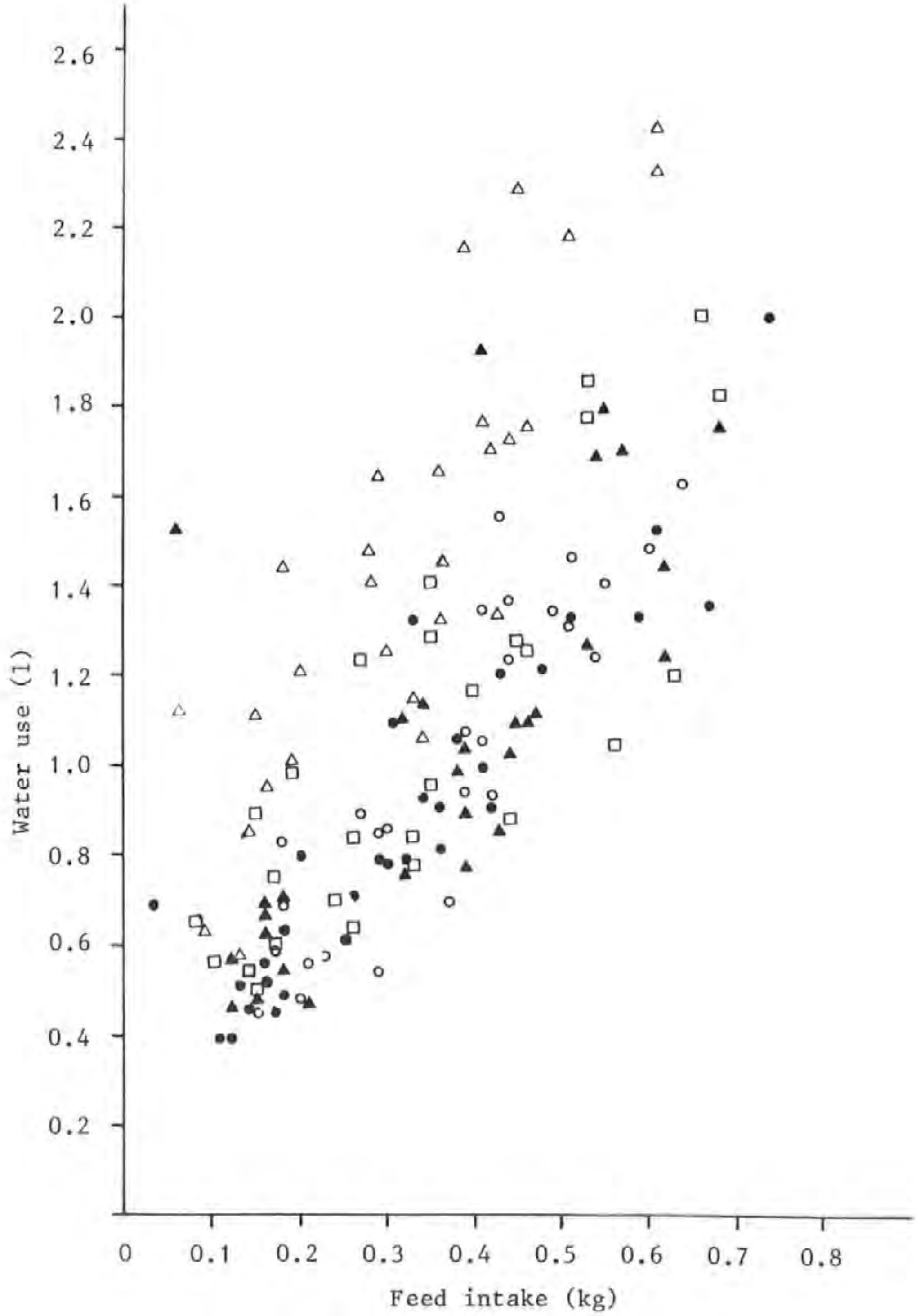


Figure 2.21 Relationship between mean live weight and water use for weaned piglets of between 3 and 6 weeks of age offered water from 5 different types of drinker: ▲ Arato 76, ● Lubing type I, O Lubing type II, Δ Mono-flo, □ Alvin.

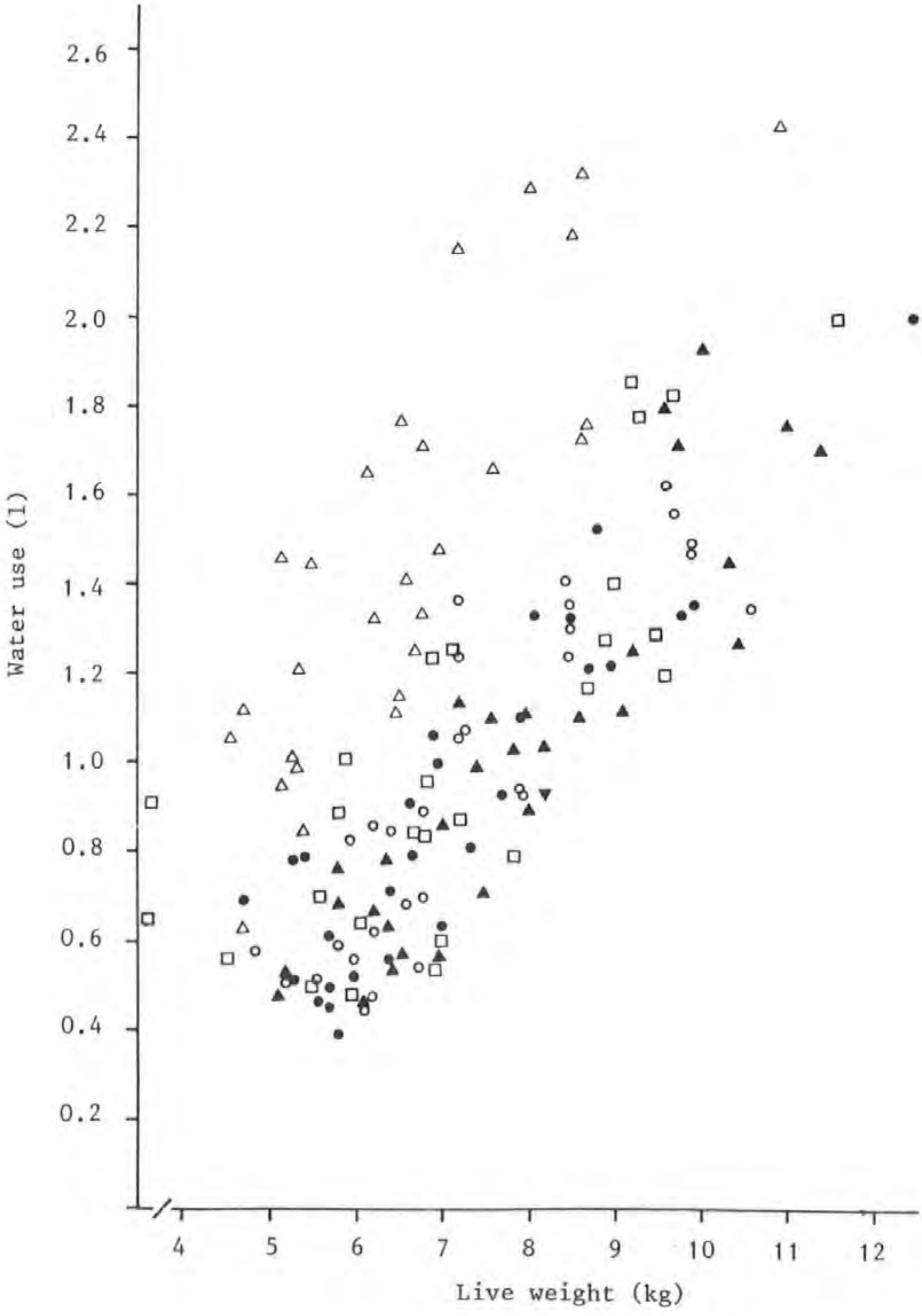


Figure 2.22 Relationship between the number of days post weaning and average daily water use for piglets of between 3 and 6 weeks of age offered water from 5 different types of drinker: ▲ Arato 76, ● Lubing type I, ○ Lubing type II, △ Mono-flo, □ Alvin.

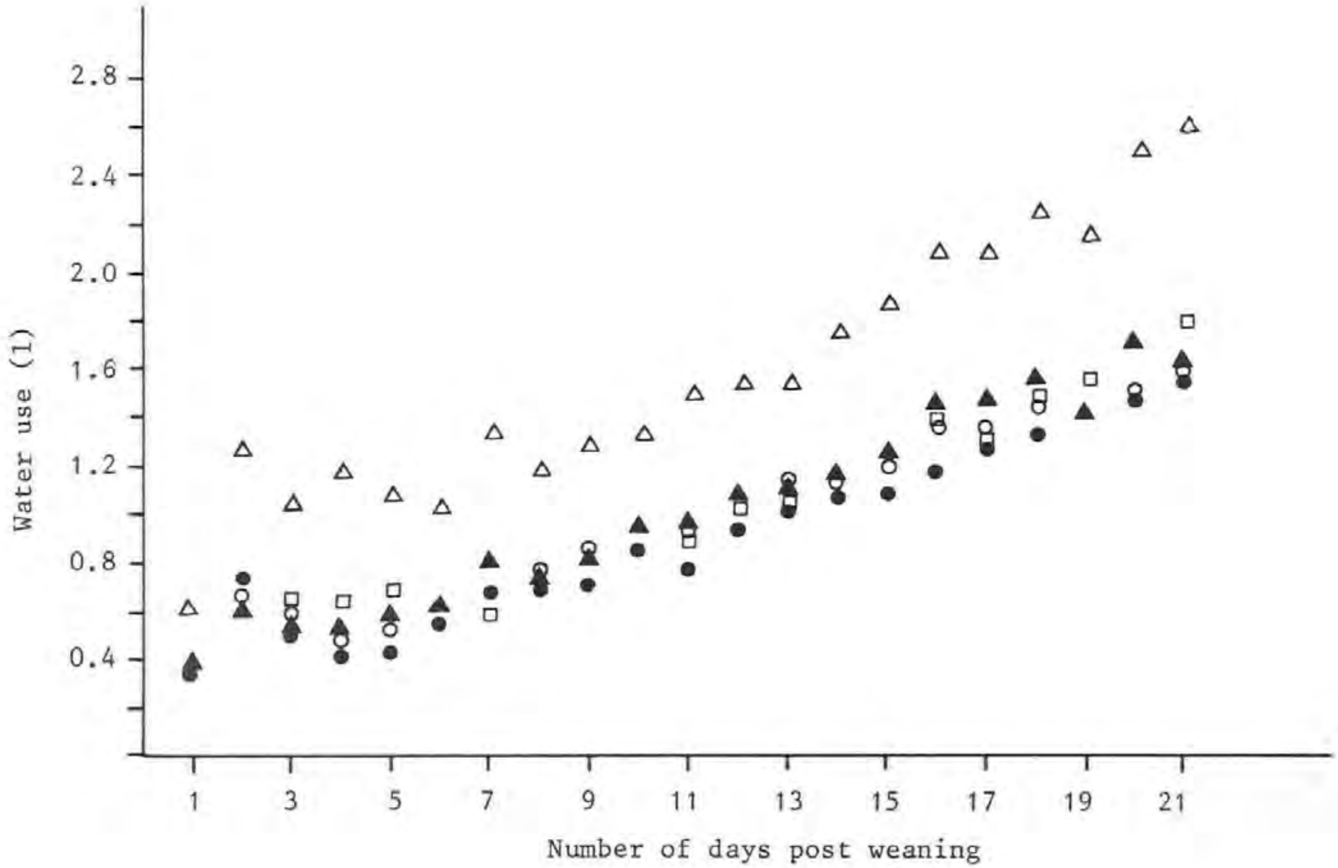


Table 2.21. Regression of water use against feed intake, live weight and number of days post weaning for five different types of drinker used to provide water to weaned piglets from 3 to 6 weeks of age

					Standard error of:	
Treatment	**Regression equation**	**P**	**r.s.d.**	R^2	**intercept**	**slope**
Arato 76	$Y = 0.27 + 2.10\ X_1$	< 0.001	0.235	0.714	0.026	0.251
Lubing I	$Y = 0.26 + 1.99\ X_1$	< 0.001	0.162	0.827	0.019	0.172
Lubing II	$Y = 0.16 + 2.31\ X_1$	< 0.001	0.154	0.839	0.020	0.192
Mono-flo	$Y = 0.31 + 3.60\ X_1$	< 0.001	0.321	0.782	0.039	0.360
Alvin	$Y = 0.33 + 2.06\ X_1$	< 0.001	0.240	0.697	0.025	0.256
Arato 76	$Y = -0.71 + 0.22\ X_2$	< 0.001	0.190	0.813	0.032	0.020
Lubing I	$Y = -0.53 + 0.20\ X_2$	< 0.001	0.163	0.824	0.030	0.018
Lubing II	$Y = -0.62 + 0.22\ X_2$	< 0.001	0.181	0.777	0.033	0.022
Mono-flo	$Y = -0.75 + 0.34\ X_2$	< 0.001	0.345	0.749	0.037	0.037
Alvin	$Y = -0.17 + 0.17\ X_2$	< 0.001	0.268	0.624	0.034	0.025
Arato 76	$Y = 0.31 + 0.06\ X_3$	< 0.001	0.253	0.707	0.036	0.003
Lubing I	$Y = 0.28 + 0.006\ X_3$	< 0.001	0.241	0.679	0.035	0.003
Lubing II	$Y = 0.30 + 0.06\ X_3$	< 0.001	0.182	0.803	0.026	0.002
Mono-flo	$Y = 0.68 + 0.08\ X_3$	< 0.001	0.549	0.455	0.078	0.006
Alvin	$Y = 0.33 + 0.06\ X_3$	< 0.001	0.279	0.655	0.040	0.003

Where: Y = Average daily water use (l/piglet)
X_1 = Average daily feed intake (kg/piglet)
X_2 = Mean live weight (kg)
X_3 = NDPW

Table 2.22. Paired drinker type treatment comparisons of the residual standard deviations, slopes and intercepts of the regression of water use against feed intake, live weight and number of days post weaning presented in Table 2.21

Comparison of:	**r.s.d.**			**Slopes**			**Intercepts**		
Independent variable:	X_1	X_2	X_3	X_1	X_2	X_3	X_1	X_2	X_3
Treatment comparison									
Arato 76 v Lubing I	*	NS	NS	NS	NS	NS	***	***	***
Arato 76 v Lubing II	*	NS	**	NS	NS	NS	***	***	*
Arato 76 v Mono-flo	*	***	***	***	**	*	***	***	***
Arato 76 v Alvin	NS	*	NS	NS	NS	NS	***	***	NS
Lubing I v Lubing II	NS	NS	**	NS	NS	NS	***	***	*
Lubing I v Mono-flo	***	***	**	***	***	***	***	***	***
Lubing I v Alvin	*	**	*	NS	NS	NS	***	***	***
Lubing II v Mono-flo	***	**	***	***	**	***	***	***	***
Lubing II v Alvin	*	*	**	NS	NS	NS	***	***	**
Mono-flo v Alvin	NS	NS	**	***	***	**	***	***	***

Where: X_1 = Average daily feed intake (kg/piglet); X_2 = Mean live weight (kg)
X_3 = NDPW; *$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

The pattern of water use from the Mono-flo nipple drinker was more variable and inconsistent than that observed for the other drinker types. Data was pooled from replicate pen groups allocated to the Arato 76 nipple, Alvin Bowl and Lubing type I and type II bite drinkers for further examination of the relation between water use, feed intake and live weight. The residual plots from the pooled linear regressions of water use against feed intake and against live weight indicated that square-root transformation was necessary to stablise the variance for water use (Sokal and Rohlf, 1981). The completed regression analyses of water use against feed intake, live weight and against NDPW using the pooled data is summarised in Table 2.23. In the multiple regression of water use against feed intake and live weight, only 5.1% of the variation in water use was explained by live weight whereas feed intake explained 75.4% (see Appendix). This suggested that the relationship between water use and live weight was confounded by feed intake.

Discussion

A common feature in the experiments reported here was that water use from the Mono-flo nipple drinker was much greater, more variable and inconsistent than that observed for the other types of drinker. Although water use was recorded accurately, it was not possible to determine the proportion of that water which was wasted or lost through leakage. These losses may account for the difference in water use from the Mono-flo nipple drinker and from the other five types of drinker investigated in this study. A number of observations support this hypothesis.

Table 2.23. Regression of water use against feed intake, live weight and number of days post weaning of the pooled data from replicate groups provided with water from the Arato 76 nipple, Alvin bowl and Lubing type I and II bite drinkers

Regression equation	P	r.s.d.	R^2	Standard error of: Intercept	Standard error of: slope
$Y = [0.61 + 1.06\ X_1]^2$	< 0.001	0.096	0.770	0.020	0.053
$Y = [0.27 + 0.10\ X_2]^2$	< 0.001	0.144	0.711	0.042	0.006
$Y = 0.31 + 0.06\ X_3$	< 0.001	0.245	0.698	0.018	0.001

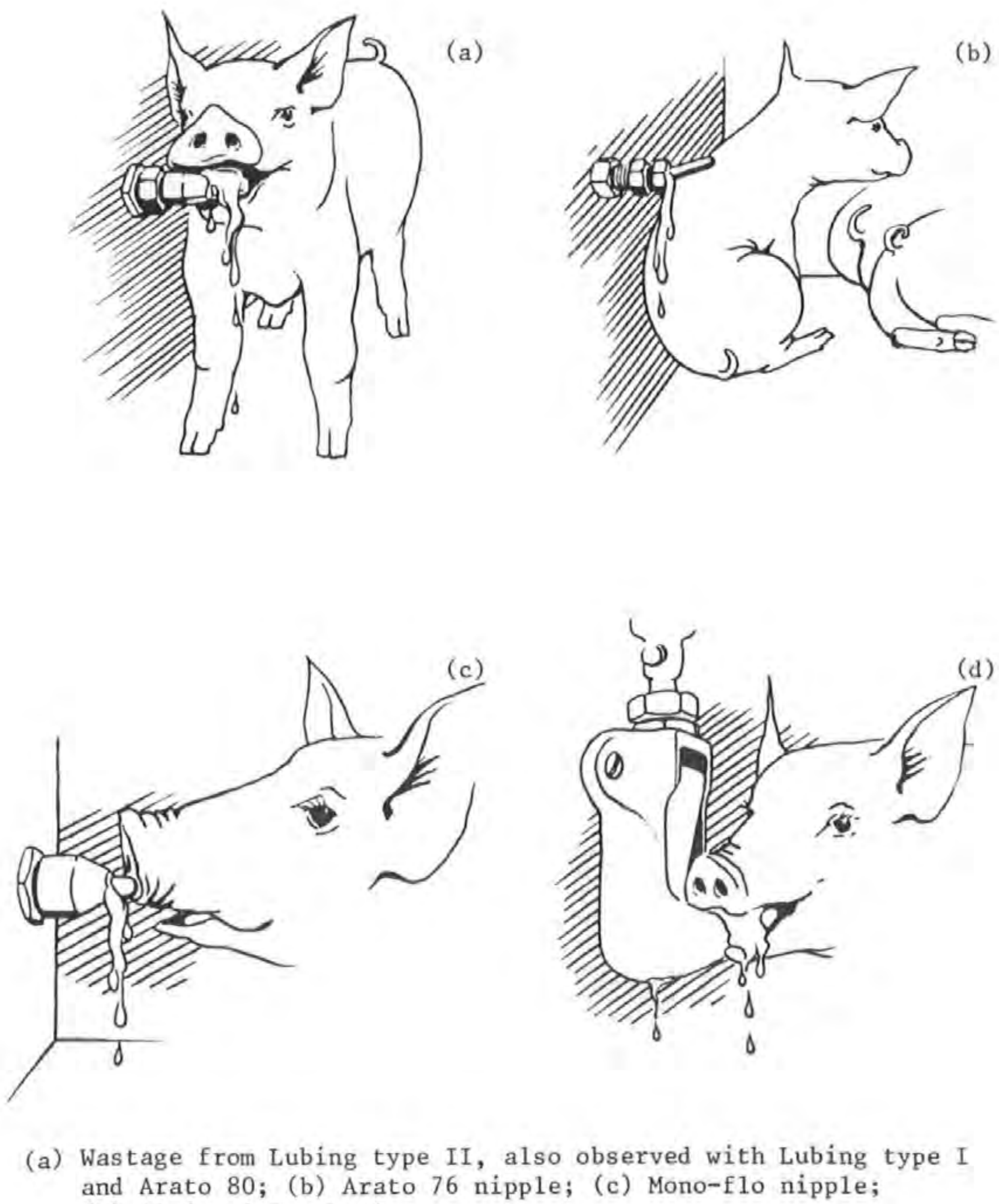
Where: Y = Average daily water use (l/pig day)
X_1 = Average daily feed intake (kg/piglet)
X_2 = Mean live weight (kg)
X_3 = NDPW

Firstly, the valve assemblies in the Arato 80, Lubing type I and II bite drinkers, Arato 76 nipple and Alvin piglet bowl drinker share similarities in design which ensure that the drinker minimises or eliminates leaks when not in use. In comparison the Mono-flo nipple drinker relies on a simple gravity operated ball bearing mechanism which was observed to leak on numerous occasions.

Certain external design features may reduce losses during drinking by ensuring that water is directed straight into the rear of the pig's mouth. Arato have claimed this to be an important consideration in the design of their 80 bite and 76 nipple drinkers. Consequently these drinkers are on average narrower and longer than the other types evaluated within this study. However since water use from the Arato and Lubing drinkers were similar, external design feature may not be of great importance in reducing water wastage. For example Lightfoot (1985) found no significant differences in water use by growing pigs from the Arato 80, Lubing type II and Jalmarson No. 1150 (similar to Lubing type I) bite drinkers.

Irrespective of what manufacturers may claim for their products, pigs were found using these drinkers in many different ways, often in a manner which caused considerable wastage of water (Figure 2.23). This was particularly apparent with the Mono-flo nipple drinker. On many occasions water from this drinker type was released by the pig pressing against the point of the nipple with the flat of its snout. As a result, very little water was seen entering the mouth and the majority dribbled along the jowl of the pig and onto the pen floor.

Figure 2.23 Water wastage by weaned piglets and growing pigs from the different types of drinker studied in experiments 4, 5 and 6.



(a) Wastage from Lubing type II, also observed with Lubing type I and Arato 80; (b) Arato 76 nipple; (c) Mono-flo nipple; (d) Alvin piglet bowl.

Three factors other than drinkers type which were not investigated in the current series of experiments may also play an important role in influencing the amount of water lost or wasted. These are flow rate, location and positioning of drinkers within pens and the number of pigs per pen per drinker.

In a series of experiments conducted with early weaned and growing pigs, Nienaber and Hahn (1984) found that the amount of water used from nipple drinkers was shown to increase with increasing flow rate. Further evidence has come from two similar studies conducted by Stansbury et al. (1981) and Carlson and Peo (1982) who reported a positive correlation between water use and inlet orifice size of nipple drinkers.

Flow rates reported in the current experiments were set according to the manufacturer's recommendations. Considering the studies reviewed above, flow rate could account for the increased level of water use from the Mono-flo nipple drinker. However water use was not positively correlated with flow rate for the other types of drinkers. For example water flow rate was much lower from the Arato 76 nipple than from the Alvin piglet bowl drinker, yet water use from these two drinker types was very similar.

There is very little objective information which provides detailed advice on the location, mode of fixation and presentation of different drinking devices. Recommendations are occasionally provided by manufacturers but these are usually based on background knowledge and subjective information. However there is now some evidence to suggest that the location of drinkers within the pen, their height and angle of presentation can have a significant effect on water use and water wastage. Olsson (1983) reduced water wastage by 0.89 l/pig day by repositioning a bite drinker from the rear of a dunging area to a site on the back of a partition between the dunging area and sleeping area. Wastage was reduced by a further 0.47 l/pig day, when the angle of drinker presentation was changed from 45^{o} downwards to 45^{o} upwards. However this alternative angle of presentation was not successful as the valves became completely plugged by water borne particles within a few months of use under farm conditions. This problem was also encountered (with drinkers positioned 45^{o} upwards) by Carlson and Peo (1984). Fiedler (1981) found that a bite valve located over a partly slatted floor compared with nipples positioned directly above a feeding trough resulted in water usage of 1.6 m^3 and 0.5 m^3/pen per day respectively.

From general study on the installation of drinking equipment, Gotkovsky (cited by Best 1982) observed that drinking bowls fixed too high increased spillage by encouraging pigs to take the rim of the bowl in their mouths during drinking. Similarly McNeil (1977) found that sows in farrowing crates adopted different drinking postures according to the height at which nipple drinkers were fixed over feeding troughs. Nipple drinkers fitted inside the troughs reduced losses by ensuring that sows used the troughs as an receptacle for any water that was released from the nipple drinker with their nose. Conversely nipple drinkers placed high above the troughs (0.47 m above floor level) increased water loss as a result of spillage running down the jowl of the sow and onto the crate floor.

In the current study, the drinkers were installed according to the manufacturers' recommendations. For trials 5a and 5b, adjustable brackets were used to increase the height of the drinkers above floor level as the pigs grew. No objective method was used, but it was ensured that pigs had to raise their heads in order to operate the drinker. In experiments 4 and 6 all drinkers were permanently fixed at a constant height above floor level. Details of the location of drinkers within pens for each of the experiments are provided in the Appendix.

The number of drinkers per pen or the number of pigs per drinker may also influence water use. For example Simonsson et al. (1977) and Olsson (1983) reported an 8% saving in water use as a result of increasing the number of bite drinkers from 1 to 2 in pens holding groups of 10 growing pigs each. This is not in agreement with the findings of experiment 6 using early weaned piglets. The regression of average daily water use (Y) on the number of piglets per pen (X) showed that water use decreased as pen group size increased:-

$$Y = 1.33 - 0.0394X \ (R^2 = 0.13; \ rsd = 0.19; \ P < 0.05)$$

This discrepancy is probably a reflection of the differences in drinking activity between unsettled groups of weaned piglets and established groups of growing pigs.

Playing with drinkers is usually a common complaint against excessive water use and wastage under intensive systems of pig production. In the current study, it would be difficult to establish how differences in design may encourage pigs to play with one drinker more than another. However, wastage did occur from the Mono-flo and Arato 76 nipple drinkers due to pigs unwittingly releasing water when scratching and lying against them. This was noticed several times during casual observations of piglet activity in experiments 3 and 6. Occasionally piglets were found using the Mono-flo nipple drinker as a shower possibly to alleviate heat stress. This behaviour has also been reported by Nienaber and Hahn (1984) with young pigs using nipple drinkers and reared under high ambient temperatures (35^{o}C).

There have been very few comparative investigations of the effects of different drinker types on pig performance. Although the results obtained from current experiments with growing pigs were not conclusive, there was evidence to indicate that the animal's biological performance can be affected by the type of drinker used, particularly in the period immediately after weaning.

In a recent study, Lightfoot (1985) reported no significant differences in the performance of scale fed growing pigs offered unrestricted access to water from three types of bite drinker .

Performance was found to be marginally superior with the Arato 80 bite drinker. It is not possible to identify a consistent improvement in performance which can be related to a specific type of drinker in the current experiments on the growing pig. For example when pigs were scale-fed, weight gain and feed intake were significantly higher with both Lubing type I and II bite drinkers, whereas with *ad libitum* feeding pig performance was similar on all four types of drinker tested.

Contrary to the results obtained with growing pigs, the evidence on the effects of drinker type on performance was more conclusive with early weaned piglets. Satisfactory performance after weaning depends on how quickly the early weaned piglet can adapt to its new environment and establish a "normal" pattern of feed and water intake. The latter in turn may depend on the length of the learning period required before the piglet can adequately release water and drink from the delivery device used. Therefore differences in piglet performance found in this study may be attributable to differences in the lengths of the learning period required to operate and use each drinker type. However there were no significant age x drinker type interactions on water use, feed intake, growth rate and feed conversion of weaned piglets in experiment 6. In other studies the length of the learning period has been found to be an important factor in the ability of young pigs to use various nose-operated valve drinkers and consequently to maintain satisfactory levels of performance on transfer to finishing units (Olsson, 1983).

In the current study, overall performance was superior in replicate groups reared in pens fitted with the Arato 76 nipple drinker. Manufacturers of this drinker claim that it is easily operated and that piglets very quickly become accustomed to using it. However no experimental evidence has been provided to support this claim. According to Brooks *et al*. (1964), the absence of visible water in enclosed delivery systems such as bite and nipple drinkers may delay the commencement of drinking. This may provide some explanation why piglets offered water from the Alvin bowl drinker had marginally increased growth rates compared with those provided with water from the Mono-flo nipple, Lubing type I and II bite drinkers.

The quantity of water used from each drinker type provides no reliable information on the amount of that water which is actually consumed. Observations of piglet behaviour immediately following weaning revealed that piglets effectively learnt to release water from the Mono-flo nipple drinker by using their snouts. However a large proportion of this water was lost and little if any actually entered the mouth. Therefore poor design features may result in excessive water loss and could unwittingly restrict water intake thereby adversely affecting pig performance. Poor performance may also result from unsatisfactory pen hygiene due to excessive water spillage from faulty and badly designed drinkers (Olsson, 1983).

In the present study, the effects of flow rate on water use and on pig performance were not investigated. Nienaber and Hahn (1984) found no significant differences in the performance of weaned piglets offered water from nipple drinkers at different flow rates. Similarly Stansbury et al. (1981) found no significant effects of flow rate from nipple drinkers on the performance of growing pigs. Conversely Carlson and Peo (1982) reported improvements in the weight gains of growing pigs when the diameter of inlet orifice of nipple drinkers was increased from 1 to 3 mm. In all these investigations, there was a positive correlation between flow rate and water use.

The regression analyses conducted on the results obtained from experiments 4 and 6 provide a description of the quantitative relationship between water use and feed intake, live weight and NDPW for each of the drinker types studied. From the analyses it can be seen that not only is the relationship drinker type dependent, but that the shape of the sample regression lines differed vastly between drinker types. For example in experiment 4, the regression of water use against feed intake was linear for the Mono-flo but curvilinear for the Arato 80 drinker. This difference was most likely attributable to the high variation in the data for water use obtained from the Mono-flo nipple drinker. The curvilinear regression equation of water use against feed intake obtained with the Arato 80 bite drinker probably gives a more accurate description of the underlying physiological relationship between water demand and feed intake in growing pigs.

Similarly in experiment 6, the regression analyses produced independent linear equations which described the quantitative relationship between water use and feed intake, live weight and NDPW specific to each of the five different types of drinker.

The residual variance, slope and intercept of the regression equations were not significantly different in only 1 out of 10 paired drinker treatment comparisons (within each independent variable). This suggests that the coefficients of sample regression lines fitted to data relating water use to an independent variable were influenced by the type of drinker used.

The regression analyses of pooled data from the Arato 76 nipple, Alvin bowl, Lubing type I and II bite drinkers showed that the underlying physiological relationship between water demand and feed intake and live weight is probably curvilinear, where water intake increases exponentially with increases in feed intake and live weight. This is in close agreement with the equations established from experiment 3.

Summary

The results obtained from this series of experiments show that drinker type had a significant influence on the amount of water used by early weaned and growing pigs. Furthermore there were indications that the animal's biological performance may also be affected by the type of drinker used, particularly following weaning. Consequently, the quantitative relationships between water use and other variables established from regression analyses were found to be drinker type dependent.

Part III THE EFFECTS OF DIETARY MINERAL CONCENTRATION ON THE WATER DEMANDS OF EARLY WEANED AND GROWING PIGS

Introduction

Commercial diets usually contain levels of potassium which are considerably higher than the value of 2.5g K/kgDM suggested as adequate to meet the potassium requirements of growing pigs (ARC, 1981). Available potassium in pig diets originates mainly from ingredients such as vegetable proteins, fish meal and molasses. Cereals which make up the bulk of commercial diets have potassium concentrations which generally exceed 5g/kgDM. As a consequence the potassium content of pig diets formulated from the normal range of dietary ingredients cannot be reduced below 7 g/kgDM without the use of purified materials and a significant increase in cost. Therefore potassium deficiency is very rare but over supply is common. On the other hand vegetable feedstuffs such as cereals and soya-bean meal do not contain sufficient quantities of sodium to meet the recommended requirement of 1.3g Na/kgDM (ARC, 1981). This inadequacy is overcome by including sodium in the form of common salt (NaCl) in the diet. However, when no allowances are made for either the high levels and wide variations in the levels of Na and Cl found in animal protein feedstuffs, the addition of common salt can lead to either an imbalance or an excess of these minerals in the diet. In addition the increasing use of least-cost diet formulations using computer matrix values tend to further increase the variation of K, Na and Cl concentrations. This is because matrix values do not allow for the wide ranges in the concentrations of the minerals which have been reported in individual samples of raw materials (Bain, Mitchell and Dewar, 1983).

Although the physiological response of pigs to wide variations in the intake of NaCl and to the intra-venous infusions of NaCl and KCl salts have been extensively documented (Sinclair, 1939; Holmes and Gregersen, 1950; Mason and Scott, 1972 and 1974; Hagsten and Perry 1976; Ingram and Stephens, 1979; Alcantra, Hanson and Smith, 1980) the extent to which dietary Na, K and Cl play independent roles in regulating water balance and influencing water demand and thirst are poorly understood. The quantitative relationship between dietary potassium and chloride intake and water demand has also received little attention. Furthermore the physiological importance of considering the overall mineral cation (K^+ and Na^+) and anion (Cl^-) balance in relation to water requirements, growth and performance in the pig have not been extensively researched.

The aim of the studies reported here was to investigate whether variations in dietary potassium concentrations within the ranges reported in commercial diets have any significant effect on the water demand and performance of weaned and growing pigs. The significance of dietary chloride, the anion accompanying the potassium and sodium cations, and its effect on water demand, growth and performance was studied in the weaned piglet.

Experiment 7 The effects of dietary potassium concentration on the water use and performance of growing pigs fed *ad libitum* (trial 7a) and to a scale based on metabolic body weight (trial 7b).

Materials and Methods

Experimental design and treatments

In two 12 week feeding trials growing pigs were fed a basal diet supplemented with K_2CO_3 to provide four dietary treatment levels of potassium (8, 11, 14 and 17 g K/kg air-dry feed). The treatments were randomly allocated to four pen groups of growing pigs within each trial, according to a 4 x 4 Balanced Latin Square design, in which each pen group received each treatment once only for a period of three weeks.

Diet formulation

The basal diet was formulated from commonly used feedstuffs to provide 8 g K/kg air-dry feed and to meet ARC (1981) recommended nutrient allowances for growing pigs. Composition of the basal diet is presented in Table 2.24. Potassium carbonate (K_2CO_3) was added to the basal diet to provide the desired levels of K concentration in the experimental diets. The amount of barley used within diets was reduced by a quantity equal to the weight of K_2CO_3 added. Proximate and mineral analyses of the experimental diets are given in Table 2.25.

Table 2.24. Composition of the basal diet used in trials 7a and 7b

Ingredient	% inclusion
Wheat	48.2
Barley	20.0
Wheat feed	7.6
Soya bean meal	17.1
Meat and blood meal	4.7
Fat	1.6
Limestone flour	0.2
Lysine HCl	0.2

Table 2.25. Proximate and mineral analyses of the diets used in trials 7a and 7b

Diet	A	B	C	D
K_2CO_3 (g/kg air-dry)	0	5.3	10.6	15.9
Dry matter (%)	89.0	88.3	88.4	88.9
Gross energy (MJ/kgDM)	18.6	18.6	18.6	18.5
Digestible energy (MJ/kgDM)	16.1	16.0	16.0	15.7
Crude protein (g/kgDM)	255.1	262.2	261.3	240.2
Crude fibre (g/kgDM)	34.8	36.4	32.2	33.2
NDF (g/kgDM)	141.6	138.7	138.0	132.7
Ether extract (g/kgDM)	40.9	37.8	39.7	36.4
Free fatty acids (g/kgDM)	11.2	11.8	6.4	6.4
Total ash (g/kgDM)	63.3	66.8	70.6	73.6
Calcium (g/kgDM)	12.9	12.6	12.8	11.6
Phosphorous (g/kgDM)	7.5	7.4	7.4	6.7
Sodium (g/kgDM)	1.2	1.2	1.2	1.3
Chloride (g/kgDM)	2.8	2.9	2.8	2.6
Potassium (g/kgDM)	8.3	11.8	15.0	17.1
(g/kg air-dry)	7.4	10.4	13.3	15.2

DE calculated using eqation given on page 120 .

Animals, housing and experimental procedures

Twelve entire males and 12 females with a mean initial weight of 14.3 (s.e. 0.48) kg W were selected for trial 7a. Sixteen entire males and 16 females with a mean initial weight of 20.0 (s.e. 0.34) kg W were selected for trial 7b.

The experimental procedures, housing and management of animals in trials 7a and 7b were the same as those described for trials 5a and 5b respectively.

Blood samples and carcass measurements

Samples of blood draining from the carcass of each pig from trials 7a and 7b were taken during exsanguination at slaughter. Six samples were taken from each pig using four heparinised and two oxalate/fluoride 10 ml tubes. Two of the heparin tubes were centifuged (2500 rev/min for 20 minutes) immediately on collection and the plasma separated into a clean bottle. Blood samples were analysed by the Ministry of Agriculture Veterinary Investigation Centre, Starcross. Potassium, Na and packed cell volume (PCV) were determined on whole blood and K, Na, Mg, Cl and P on blood plasma. Measurements of loin, shoulder and backfat thickness, the weight and length of the chilled split carcass were taken the day following slaughter.

Results

Twelve pigs developed diarrhoea in week 1 of trial 7a (Table 2.26). Six pigs were badly affected and showed poor weight gains

Table 2.26. Pigs affected by diarrhoea between week 1 and 5 of trial 7a

Pen Number	Pig Number	Sex**	Treatment
4	19	F	A → C
4	20	M	A → C
4	22	M	A → C
4	24*	M	A → C
1	5*	F	B → D
3	13	F	C → B
3	16*	F	C → B
3	17	F	C → B
3	18*	M	C → B
2	8*	F	D → A
2	10	F	D → A
2	12*	M	D → A

* Pigs that were badly affected
** F Female, M Male
→ Change of treatment after first 3 weeks on trial

during weeks 1 to 5 of trial 7a. One pig (No. 7) developed diarrhoea in week 1 and another (No. 26) started to produce diarrhoeic faeces in week 6 of trial 7b. Both pigs were badly affected for about four weeks and showed poor weight gain. Anal swabs were taken from all badly affected animals in week 1 of both experiments and sent to The Ministry of Agriculture Veterinary Investigation Centre, Starcross for bacteriological examination. The tests revealed non-haemolytic E. coli with faecal streptococci and proved negative for salmonella and swine dysentery. However, subsequent laboratory cultures confirmed the presence of Treponema hyodysenterae. All pigs were immediately treated with lincomycin (Lincocin ^{R}, Upjohn Ltd) added to the drinking water according to veterinary recommendations. Medication was withdrawn at the end of week 6. Pig No. 26 of trial 7b was thereafter individially treated with intramuscular injections of lincomycin (Lincocin Sterile Solution ^{R}, Upjohn Ltd).

Final live weights averaged 78.2 (s.e. 1.75) and 84.9 (s.e. 1.21) kg W for trial 7a and 7b. The effects of dietary potassium treatment on water use, feed intake and pig performance are compared between the two feeding regimes in Table 2.27.

Dietary potassium content significantly increased ($P < 0.05$) water use. With ad libitum feeding water use increased linearly with dietary potassium concentration. With feeding based on a scale related to metabolic body weight, water use showed a maximum dose response at the intermediate dietary potassium concentration of 14 g K/kg air-dry feed. Dietary potassium content had no significant effect on feed intake, live-weight gain and feed conversion ($P > 0.05$).

Table 2.27. Water use, feed intake and performance of growing pigs fed _ad libitum_ or according to a scale related to metabolic body weight, diets containing four different levels of potassium

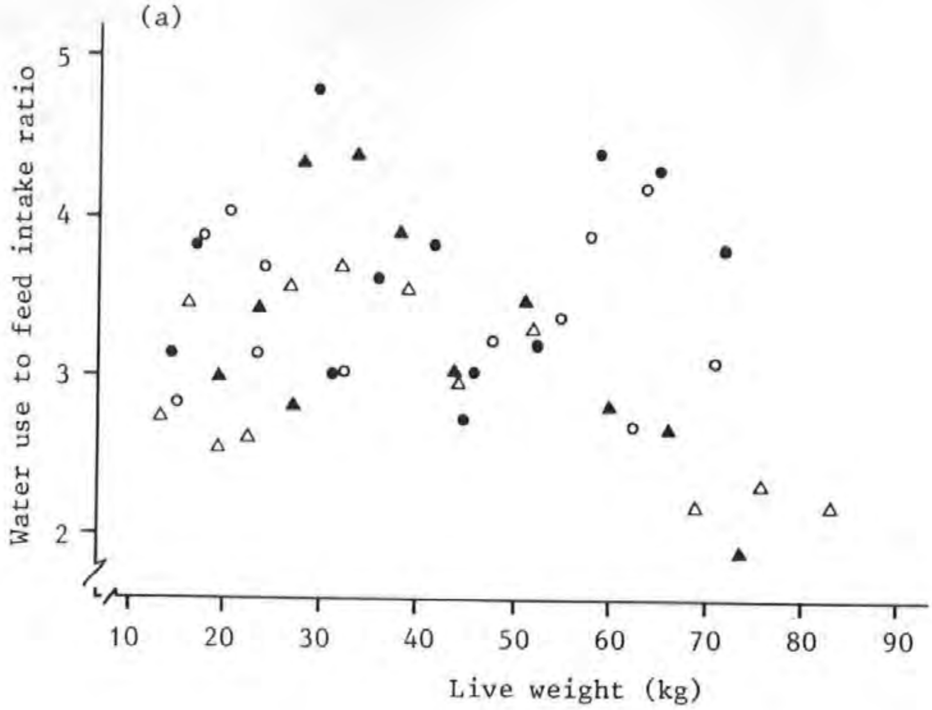
Potassium (g/kg air-dry feed)	Feeding regime	8 Mean	8 s.e.	11 Mean	11 s.e.	14 Mean	14 s.e.	17 Mean	17 s.e.	P
Water use (l/pig day)	Ad libitum	4.07^{a}	0.440	4.42^{ab}	0.370	4.81^{bc}	0.565	5.04^{c}	0.562	< 0.05
	Scale	4.98^{a}	0.461	5.41^{ab}	0.435	5.91^{b}	0.544	5.51^{ab}	0.304	< 0.05
Feed intake (kg/pig day)	Ad libitum	1.45	0.185	1.40	0.127	1.40	0.162	1.39	0.138	NS
	Scale	1.58	0.057	1.60	0.048	1.63	0.059	1.58	0.051	NS
Live-weight gain (kg/pig day)	Ad libitum	0.73	0.036	0.80	0.043	0.77	0.039	0.75	0.041	NS
	Scale	0.79	0.032	0.78	0.034	0.77	0.034	0.75	0.033	NS
Feed conversion ratio	Ad libitum	2.00	0.154	1.78	0.092	1.84	0.077	1.94	0.097	NS
	Scale	2.21	0.105	2.30	0.074	2.25	0.062	2.45	0.142	NS
Water use: Feed intake ratio	Ad libitum	2.91	0.165	3.26	0.207	3.46	0.142	3.64	0.182	
	Scale	3.21	0.104	3.42	0.140	3.68	0.132	3.67	0.214	
Water use: Live weight ratio	Ad libitum	0.112	0.009	0.120	0.010	0.124	0.006	0.130	0.007	
	Scale	0.117	0.006	0.124	0.007	0.137	0.008	0.135	0.011	

^{a,b,c}Means with the same superscript within the same row did not differ significantly (P > 0.05).

Water use and feed intake were consistently higher with metabolic weight based scale feeding, however feed conversion was superior under *ad libitum* feeding. Live-weight gain was similar under both feeding regimes. The ratios of water use to feed intake and to live weight were narrower with *ad libitum* feeding. There was a tendency for the ratio of water use to feed intake to decrease with increasing live weight under both feeding regimes (Figure 2.24).

Within each feeding regime, weekly data was used in the regression of water use against dietary potassium content, feed intake and against live weight. The results of the regression analyses are summarised in Table 2.28. The regression of water use against dietary potassium content did not reach significance ($P > 0.05$) within either feeding regime. The regression of water use against feed intake was found to be quadratic with *ad libitum* feeding ($P < 0.001$) but linear with scale feeding ($P < 0.001$). The regressions against live weight were quadratic ($P < 0.001$) for both feeding regimes (see Appendix). According to the sample regression equations, water use reached a maximum (where $dY/dx_2=0$) at 57.9 and 64.6 kg W with *ad libitum* and scale feeding respectively. In the multiple regression of water use against feed intake and live weight, only 5.4 and 3% of variation in water use was explained by live weight where as 64.1 and 73.5% was explained by the intake of feed in trials 7a and 7b respectively (see Appendix). This suggested that relationship between live weight and water use was confounded by feed intake. The sample regression equations with their respective 95% confidence limits for

Figure 2.24 Relationship between mean live weight and water use to feed intake ratio of growing pigs fed either (a) ad libitum or (b) to a scale related to metabolic body weight, diets formulated to 4 different concentrations of potassium: Δ 8, ▲ 11, ○ 14, ● 18 gK/kg air-dry feed.



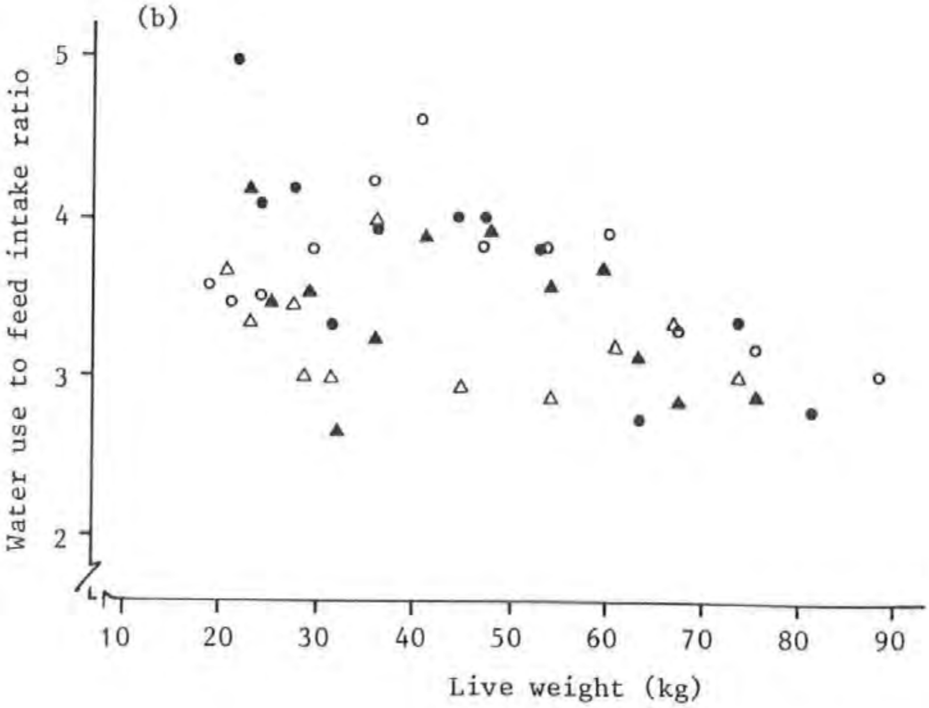


Table 2.28. Regression of water use against dietary potassium content, feed intake and live weight of growing fed ad libitum or according to a scale related to metabolic body weight diets containing four different levels of potassium

Feeding regime	Independent variable (X_n)	Regression equation	P	r.s.d.	R^2	Standard error of: intercept	b_1	b_2
Ad libitum	Feed intake	$Y = 2.5 + 8.18X_1 - 1.978{X^2}_1$	< 0.001	0.898	0.730	0.966	0.211	0.0105
Scale		$Y = 1.35 + 2.57X_1$	< 0.001	0.795	0.735	0.381	0.227	
Ad libitum	Live weight	$Y = -1.42 + 0.25X_2 - 0.0021{X^2}_2$	< 0.001	0.787	0.792	0.593	0.031	0.0003
Scale		$Y = -1.64 + 0.27X_2 - 0.0021{X^2}_2$	< 0.001	0.855	0.809	0.684	0.031	0.0003
Ad libitum	% K in air-dry feed	$Y = 3.21 + 1.10X_k$	NS	1.665	0.049	0.927	0.717	
Scale		$Y = 4.59 + 0.69X_k$	NS	1.525	0.024	0.849	0.656	

Where: Y = Average daily water use (l/pig)
X_1 = Average daily feed intake (kg/pig)
X_2 = Mean live weight (kg)
X_k = Dietary potassium content (% K in air-dry feed)

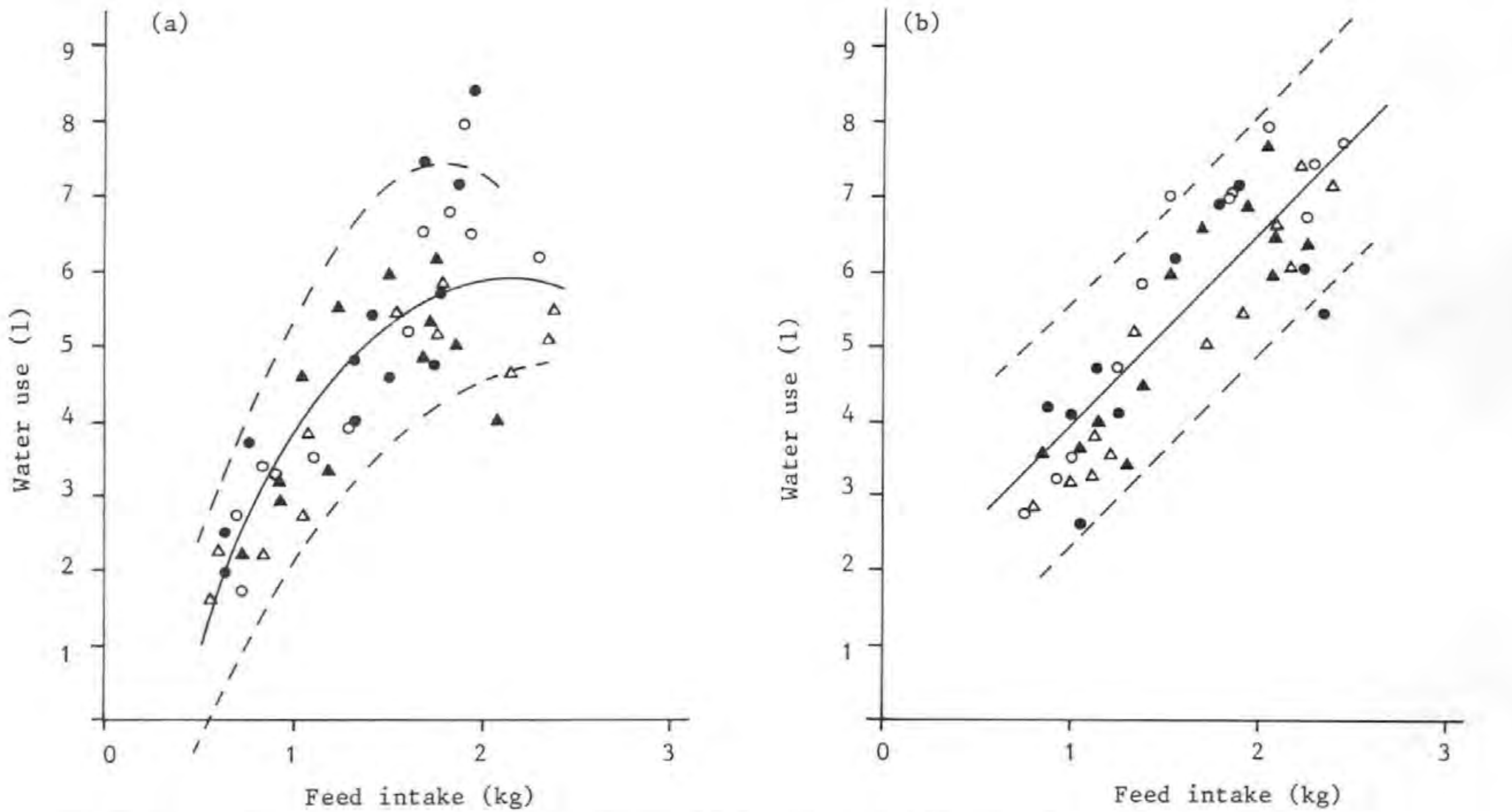
predicted individual values of water use according to feed intake and live weight have been illustrated with scatter plots in Figures 2.25 and 2.26.

Results from the mineral analyses of whole blood and plasma according to dietary potassium treatment and feeding regime are presented in Table 2.29. These indicate that the levels of potassium and other minerals in the circulatory system were not influenced by dietary potassium content. Measurements on the carcasses of pigs from trials 7a and 7b are presented in the Appendix.

Discussion

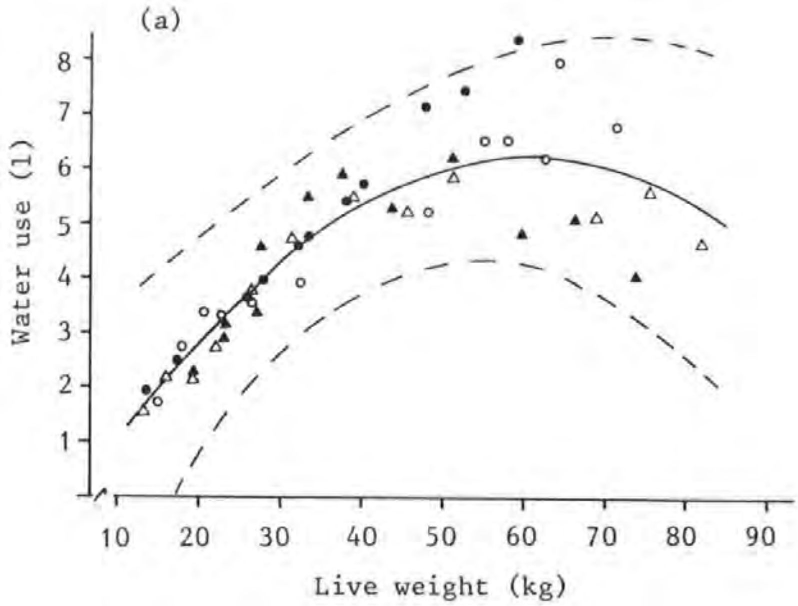
The results found with growing pigs in the current study suggest that potassium has an osmotic potential which can initiate an increased water demand for the excretion of excess dietary intake. It is difficult to find similar studies supporting this evidence because the relationship between water demand and dietary potassium content in the growing pig has not been extensively investigated. Farries (cited by ARC, 1981) found that in growing and pregnant pigs water demand was positively correlated with potassium intake. A study on rats by Gamble, Putnam and McKhann (1929) suggests that potassium has an osmotic potential equal to that of sodium. Young rats fed diets supplemented with either NaCl or KCl increased their water intake by an amount proportional to the weight of each salt consumed. Furthermore it was found that additions of both NaCl and KCl to the diet had an additive effect on water demand. However these results may have been confounded by chloride in the sodium and potassium salts.

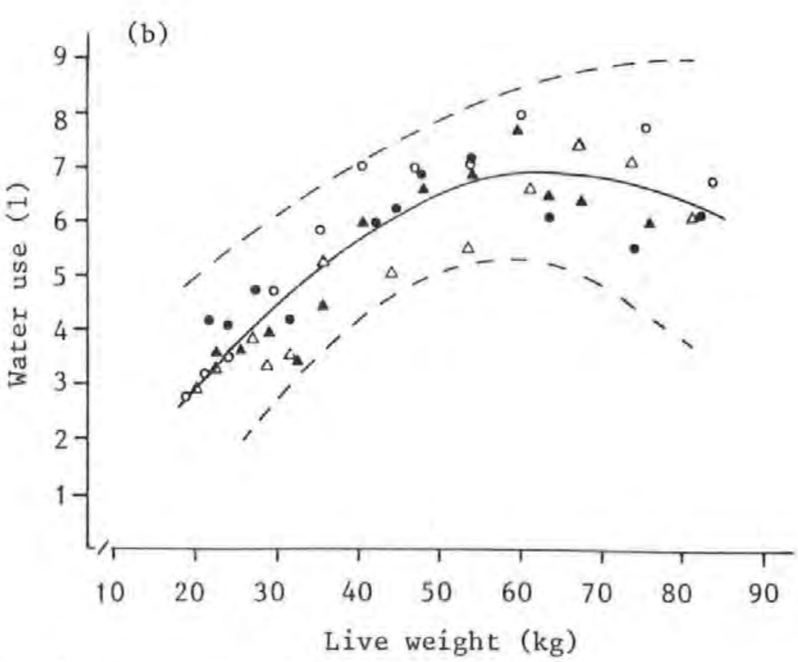
Figure 2.25 Regression of average daily water use against average daily feed intake for growing pigs fed either (a) *ad libitum* or (b) to a scale related to metabolic body weight, diets formulated to 4 different concentrations of potassium: △8, ▲11, ○14, ●18 g K/kg air-dry feed.



(-) Sample regression lines (---) 95% confidence limits for individual values of water use.

Figure 2.26 Regression of average daily water use against mean live weight of growing pigs fed either (a) ad libitum or (b) to a scale related to metabolic body weight, diets formulated to 4 different concentrations of potassium: △ 8, ▲ 11, ○ 14, ● 18 g K/kg air-dry feed.





(-) Sample regression lines.
(---) 95% confidence limits for individual values of water use

Table 2.29. Mineral analyses of whole blood and plasma of growing pigs fed ad libitum or according to a scale related to metabolic body weight diets containing four different levels of potassium

Feeding regime	Dietary potassium (g/kg air-dry feed)	Potassium Whole blood	Potassium Plasma	Sodium Whole blood	Sodium Plasma	Chloride Plasma	Phosphorous Plasma	Calcium Plasma	Magnesium Plasma
		← mmol/l			→	meq/l	← mmol/l		→
Ad-libitum									
	8	12.77	8.28	117.8	141.5	94.0	2.32	2.85	0.78
	11	12.73	8.47	111.5	139.8	95.8	2.87	2.99	0.83
	14	12.78	8.63	110.2	140.3	93.8	2.58	2.90	0.74
	17	12.45	9.02	124.2	142.3	93.8	2.52	2.96	0.76
	s.e.	0.08	0.19	2.6	0.5	0.4	0.07	0.05	0.02
Scale									
	8	12.80	7.01	111.2	140.1	96.4	2.48	2.68	0.68
	11	12.48	6.57	108.1	139.5	94.9	2.50	2.55	0.69
	14	12.67	7.39	110.2	138.9	94.8	2.59	2.62	0.71
	17	13.39	7.07	109.2	141.9	93.9	2.68	2.67	0.70
	s.e.	0.07	0.15	0.55	0.44	0.52	0.04	0.03	0.01

It has been suggested that for every 10 g increase in NaCl intake above requirement the demand for water is increased by one litre (ARC, 1981). Similarly in the current study, with both feeding regimes, every 10 g increase in potassium intake above 7 g K/kg on average was associated with one litre increase in water use.

The literature suggests that the increased water intake by pigs fed diets containing high levels of potassium is due to an increased demand for renal clearance.

In pigs the main excretory route of excess dietary potassium is through the urine (Mason and Scott, 1972; Georgievskii, Annenkov and Samokhin, 1979), whereas excess sodium is excreted both in the urine and faeces (Hagsten and Perry, 1976). Furthermore Mason and Scott (1972) found that excess dietary potassium clearance was accomplished by increasing the volume but not the osmotic pressure of the urine.

Since the availability of dietary potassium from various sources is greater than 90% (Combs and Miller, 1985) a rise in plasma potassium clearance is minimised by a rapid increase in the rate of renal clearance. The rate of urinary potassium excretion being directly proportional to the rate of increase in dietary potassium intake (Mason and Scott, 1972). This would explain the lack of effect of dietary potassium content on whole blood and plasma potassium concentration found in the present study.

Therefore physiological maintenance of isotonicity under conditions of excess dietary potassium supply will depend on the provision of unrestricted water to meet the demand for renal clearance. This is supported by the results of the current study.

The significance of providing a satisfactory water supply to pigs fed diets containing high levels of potassium has been demonstrated by studies on the use of potassium rich plant protein supplements for growing pigs (Braude et al., 1977; Barber, Braude, Mitchell, Partridge and Pittman, 1979 and 1980). The complete or partial replacement of between 3.5 and 7% white fish meal in the diets of growing pigs by lucerne or grass juice on an isoprotein basis was associated with signs of salt toxicity, mortality and poor performance when animals were restricted to 2.5 parts of water (including water content of plant juices) per part of meal. Barber, Braude, Mitchell and Partridge (1981) concluded that the poor performance of pigs receiving lucerne juice was due to sub-clinical effects of excessive mineral loading particularly K, Na, Ca and Mg. The provision of an ad libitum water supply alleviated problems associated with mineral toxicity and significantly improved growth rate and performance.

The higher levels of water use found with the feeding regime based on metabolic body weight is associated with increased feed intake compared with ad libitum feeding. Lower feed intake levels found with ad libitum feeding were due to the lighter average starting and finishing live weights of pigs on this trial.

It is difficult to explain why feed conversion was poorer in the scale-fed pigs, particularly since the incidence of diarrhoea was markedly higher with ad libitum feeding which would have expected to adversely affect the conversion of feed to gain of pigs on trial 7a. Furthermore, mean daily minimum and maximum ambient temperatures in the house accommodating pigs on trial 7b were marginally higher than for trial 7a (14.7 v 14.6^{o}C; 19.1 v 17.7^{o}C). However as these temperatures were recorded above pig level and away from the pens, they do not provide a good indication of the thermal environment of these animals. The lower temperature range reported for trial 7a would not have had an adverse effect on performance as the pigs were provided with bedding or supplementary heating using infra-red lamps over the lying areas and were bedded with fresh straw. Pigs fed to scale were not provided with bedding or supplementary heating in the kennel areas.

Experiment 8 The effects of dietary potassium and chloride concentration on the water use and performance of weaned piglets from 3 to 6 weeks of age.

Materials and methods

Experimental design and treatments

Ten dietary treatments consisting of five levels of potassium (7, 9, 11, 13 and 15 g K/kg air-dry feed) and two levels of chloride (2 and 4 g Cl/kg air-dry feed) were arranged factorially. Four replicate groups of weaned litter mates were randomly allocated over time to treatments according to a Randomised Incomplete Block design.

Diet formulation

A basal diet was formulated from commonly used raw materials to provide 7 g K and 2 g Cl/kg air-dry feed. The composition of the basal diet is presented in Table 2.30. Potassium carbonate and sodium chloride were added to the basal diet to provide the required levels of K and Cl concentrations in the experimental diets (Table 2.31). Dietary Na concentration was held constant by substituting Na_2CO_3 for NaCl. To minimise the dilution of basal nutrients, the amount of barley used within each diet was reduced by a quantity equal to the combined weights of Na and K salts added. Details of the proximate and mineral analyses of the experimental diets are presented in Table 2.32.

Table 2.30. Composition of the basal diet used in experiment 8

Ingredient	**% inclusion**
Barley	30.0
Wheat	25.5
Fine maize	16.3
Soya bean meal	15.8
Fish meal	10.0
Fat	1.8
Limestone flour	0.2
Salt	0.2
Lysine HCl	0.2

Table 2.31. Amounts of potassium carbonate, sodium chloride and sodium carbonate added to the basal diet to achieve the required levels of K and Cl concentrations in the diets used in experiment 8

Diet	% K (air-dry)	% Cl (air-dry)	g K_2CO_3/ kg air-dry	g NaCl/ kg air-dry	g Na_2CO_3/ kg air-dry	Total Na & K salts g/kg air-dry
A	0.7	0.20	0	0	0.69	0.69
B	0.9	0.20	3.53	0	0.69	4.22
C	1.1	0.20	7.07	0	0.69	7.76
D	1.3	0.20	10.60	0	0.69	11.29
E	1.5	0.20	14.14	0	0.69	14.83
F	0.7	0.40	0	0.76	0	0.76
G	0.9	0.40	3.53	0.76	0	4.29
H	1.1	0.40	7.07	0.76	0	7.83
I	1.3	0.40	10.60	0.76	0	11.36
J	1.5	0.40	14.14	0.76	0	14.90

Table 2.32 Proximate and mineral analyses of the diets used in experiment 8

Diet	A	B	C	D	E	F	G	H	I	J
Dry matter (%)	90.7	89.2	89.4	89.5	90.8	89.4	90.6	90.7	89.7	90.4
Gross energy (MJ/kgDM)	18.9	19.1	18.9	19.0	18.9	19.0	18.8	18.8	18.9	18.8
Digestible energy (MJ/kgDM)	16.9	16.8	16.7	16.5	16.6	16.9	16.9	16.9	16.7	16.7
Crude protein (g/kgDM)	262.4	252.2	249.4	253.7	232.4	255.0	248.3	243.7	252.0	251.1
Crude fibre (g/kgDM)	30.0	28.5	28.4	31.1	32.7	27.6	26.9	24.4	33.3	29.3
Neutral detergent fibre (g/kgDM)	124.6	122.2	117.4	124.0	128.9	118.6	114.8	113.6	111.5	109.5
Ether extract (g/kgDM)	48.7	50.6	46.5	47.6	48.8	53.6	48.6	53.8	46.0	45.6
Free fatty acids (g/kgDM)	11.5	12.7	11.7	5.8	5.7	11.6	12.5	12.5	7.7	7.6
Total ash (g/kgDM)	52.0	54.1	56.7	61.6	52.1	54.0	53.5	55.3	58.3	60.3
Calcium (g/kgDM)	7.4	6.6	7.0	6.8	5.8	7.0	6.7	7.6	7.7	7.4
Phosphorous (g/kgDM)	6.8	6.7	6.8	6.7	6.4	6.9	6.7	7.2	7.6	7.3
Sodium (g/kgDM)	1.2	1.2	1.8	1.9	1.1	1.9	1.1	1.2	1.2	1.2
Chloride (g/kgDM)	2.3	2.5	3.0	3.4	1.5	2.8	2.1	1.8	2.1	2.0
(g/kg air-dry)	2.1	2.2	2.7	3.0	1.4	2.5	1.9	1.6	1.9	1.8
Potassium (g/kgDM)	7.9	8.9	11.4	12.2	12.8	7.5	9.3	11.8	15.1	17.3
(g/kg air-dry)	7.2	7.9	10.2	10.9	11.6	6.7	8.4	10.7	13.5	15.6

DE based on equation given on page 120 .

Animals and housing

Three hundred and twenty piglets in 40 groups of 8 littermates of similar weaning weight were selected from suckling litters at 21 ±1 days of age. The pigs were housed in flat-deck accommodation and managed according to the procedures described in experiment 3. The watering system was identical to that described in experiment 3, except that all pens were fitted with 2 Arato 76 nipple drinkers (Figure 2.18, page 188).

Experimental procedures

The experimental procedures were similar to those described in experiment 3, except that a record of daily feed intake by each pen group was maintained for the first week after weaning and each pen group remained on trial for only two weeks after weaning.

Results

Despite routine water medication with lincomycin (lincocin^R, Upjohn Ltd.) against scour and swine dysentery, most replicate groups produced watery diarrhoeic faeces after weaning.

Live weight at weaning and five weeks of age averaged 6.53 (s.e. 0.12) and 7.80 (s.e. 0.18) kg/piglet respectively. Water use, feed intake and piglet performance on each treatment is summarised in Table 2.33. No significant treatment effects were found. Main factorial effects of dietary K and Cl content on water use, feed intake and piglet performance are presented in

Table 2.33. Water use, feed intake and performance of weaned piglets from 3 to 5 weeks of age and fed 10 diets containing 5 and 2 different levels of K and Cl arranged factorially

		Water use (l/piglet day)		Feed intake (kg/piglet day)		Live weight gain (kg/piglet day)		Feed conversion ratio		Water use: feed intake ratio		Water use: live wt ratio	
Potassium (g/kg air-dry feed)	Chloride	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
7	2	0.66	0.071	0.21	0.043	0.12	0.041	1.75	0.105	3.73	0.520	0.09	0.006
9	2	0.60	0.052	0.20	0.033	0.10	0.035	2.00	0.094	3.25	0.313	0.08	0.005
11	2	0.63	0.098	0.21	0.046	0.14	0.043	1.50	0.107	3.49	0.463	0.09	0.010
13	2	0.56	0.061	0.17	0.039	0.09	0.042	1.89	0.093	4.45	0.785	0.08	0.008
15	2	0.61	0.050	0.20	0.030	0.10	0.033	2.00	0.091	3.24	0.249	0.09	0.005
7	4	0.63	0.066	0.17	0.033	0.09	0.042	1.89	0.079	4.66	0.928	0.09	0.006
9	4	0.55	0.046	0.17	0.033	0.06	0.026	2.83	0.127	3.79	0.452	0.08	0.006
11	4	0.52	0.061	0.22	0.044	0.07	0.034	3.14	0.129	2.75	0.336	0.08	0.008
13	4	0.63	0.062	0.21	0.036	0.11	0.032	1.91	0.113	3.43	0.378	0.09	0.008
15	4	0.58	0.056	0.16	0.029	0.05	0.030	3.2	0.097	4.20	0.459	0.09	0.075
		NS		NS		NS		NS					

Table 2.34. Main factorial effects of dietary K and Cl content on water use, feed intake and performance of weaned piglets from 3 to 5 weeks of age

	Water use (l/piglet day)		Feed intake (kg/piglet day)		Live weight gain (kg/piglet day)		Feed conversion ratio		Water use: feed intake ratio		Water use: live wt ratio	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
Dietary K (g/kg air-dry feed)												
7	0.64	0.074	0.19	0.027	0.10	0.029	1.90	0.093	4.20	0.528	0.09	0.004
9	0.57	0.034	0.19	0.023	0.08	0.022	2.38	0.105	3.52	0.274	0.08	0.004
11	0.57	0.058	0.22	0.031	0.10	0.028	2.20	0.111	3.12	0.292	0.08	0.006
13	0.59	0.043	0.19	0.026	0.10	0.026	1.90	0.100	3.94	0.441	0.08	0.005
15	0.59	0.037	0.18	0.021	0.08	0.023	2.25	0.091	3.72	0.281	0.09	0.005
	NS		NS		NS		NS					
Dietary Cl (g/kg air-dry feed)												
2	0.61	0.030	0.20	0.017	0.11	0.017	1.82	0.100	3.63	0.224	0.09	0.003
4	0.58	0.026	0.18	0.015	0.08	0.014	2.25	0.107	3.77	0.257	0.09	0.003
	NS		NS		*		NS					

Figure 2.27 Average daily water use (Δ ± s.e.) from weaning to 5 weeks of age and feed intake (O ± s.e.) during the first week after weaning by piglets used in experiment 8.

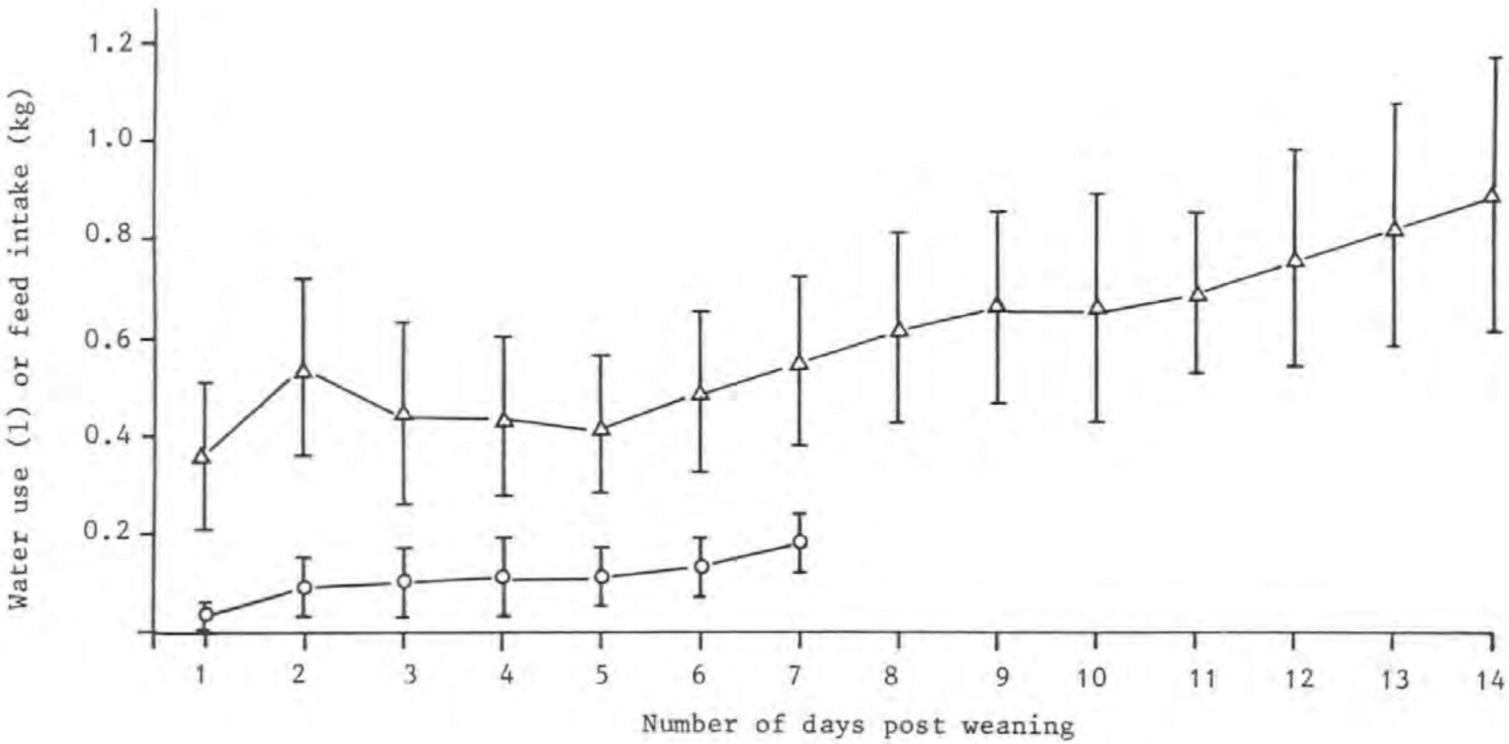


Table 2.34. The weight gain of replicate groups offered diets formulated to 2 g Cl/kg air-dry feed was significantly higher ($P < 0.05$) than those given 4 g Cl/kg air-dry feed. There were no other significant dietary K and Cl effects. No significant dietary K x Cl interactions were found.

Average daily water use from weaning to five weeks of age and feed intake in the first week after weaning is illustrated in Figure 2.27.

Discussion

Results from the mineral analyses of the experimental diets indicated that levels of K and Cl did not correspond with those expected from the calculated composition. This was particularly apparent for Cl levels. However there was a tendency for potassium to increase in the different diets in the anticipated direction. Due to this discrepancy, it would be inappropriate to attach unnecessary significance to the results obtained from this feeding trial. However the effects of dietary K and Cl on water demand was studied using the regression of water use on the values of K and Cl concentrations determined from mineral analyses. No significant effects were found (Table 2.35).

In contrast to the results obtained with growing pigs, dietary K intake had no effect on the water demand of early weaned piglets. Similarly dietary Cl intake did not influence water use. Figure 2.27 shows that a pattern of "normal" water use was not established until the end of the first week after weaning.

Table 2.35. Regression of average daily water use by weaned piglets of between 3 and 5 weeks of age against dietary K and Cl concentrations as determined from mineral analyses

Regression equation	**P**	**r.s.d.**	R^2	**Standard error of:** intercept	**Standard error of:** slope
$Y = 0.63 - 0.004\ X_K$	NS	0.176	0.003	0.078	0.007
$Y = 0.57 + 0.012\ X_{Cl}$	NS	0.176	0.001	0.086	0.036

Where: Y = Average daily water use (l/piglet)
X_K = Dietary potassium (g/kg air-dry feed)
X_{Cl} = Dietary chloride (g/kg air-dry feed)

Furthermore feed intake did not start to increase until there was an appreciable increase in water use. The trauma of weaning could therefore have had an adverse effect on the regulation of body water and mineral balance. As a consequence, normal physiological sensitivity to dietary mineral concentrations may be disturbed by the stresses of weaning in the young piglet. This may explain the lack of relationship between dietary mineral content and water demand in early weaned piglets.

In the current study, there were no consistent differences in feed intake, growth and performance between piglet groups subjected to various dietary potassium treatments. Jensen, Terrill and Becker (1961) found that piglets of between 2 and 3 weeks of age fed purified diets containing between 0.02 and 0.47% potassium had an optimum growth rate at a dietary potassium level of 0.26%. Deficiency symptoms were observed in piglets fed diets containing less than 0.17% potassium. On the basis of this and other published evidence, a potassium requirement of 2.5 g K/kgDM for pigs weighing between 2 and 45 kg W has been suggested (ARC, 1981). These recommendations are only of academic interest and deficiency is unlikely to occur as commercial diets are formulated from ingredients which are naturally rich in potassium. Potassium levels investigated in the present study resemble those found in commercial diets.

In poultry, research indicates that the ratio of dietary mineral cations to anions have a more significant effect on biological performance than the absolute levels of individual minerals in the feed (Talbot, 1978; Harms, 1981). In commercial poultry diets the ratios of Na^+, K^+ and Cl^- are taken to be of practical importance and these are used to calculate the electrolyte balance of the feed (see Appendix). The theory is that disproportionate changes in the ratio of Cl^- to Na^+ and K^+ in the diet create a physiological acid-base imbalance by altering the rate of obligatory endogeneous production of acid or free base in order to achieve electrolyte homeostasis (Mongin, 1980).

In the chick, diets which are deficient or contain excessive Cl^- concentrations have been shown to create alkalosis and acidosis respectively, resulting in reduced growth and performance (Melliere and Forbes, 1966). Studies with laying hens have shown that for egg production and feed conversion, the optimum $Na^+ + K^+ - Cl^-$ electrolyte balance is 200 meq/kg feed (Sauveur and Mongin, 1978).

The principle of mineral electrolyte balance has not been extensively studied in the pig. Fletcher (1980) suggested that the concentrations of Na, Cl and K in pig feeds are expected to be reasonably constant at 0.13 to 0.20%, 0.25 to 0.35% and 0.65 to 1.0% respectively. This represents an $Na^+ + K^+ - Cl^-$ electrolyte balance of between 146 and 238 meq/kg feed. The range of Na, Cl and K reported in individual feed ingredients by Bain et al. (1983) suggest that the resulting electrolyte balance in the diets formulated for weaned and growing pigs could vary between 143 and 215; 151 and 244 meq/kg feed respectively. However in practise the use of novel ingredients containing very high levels of Na or K and inaccuracies in weighing could result in diets with wider ranges of electrolyte balance.

Nevertheless various studies have shown that diets having electrolyte balances which fall outside these expected ranges appear to have little or no adverse effects on the performance of pigs. Combs (1981) used a factorial experiment to study the effects of 3 levels of dietary K (0.3, 0.6 and 0.9%) and 3 of Cl (0.07, 0.13 and 0.18%) on the performance of piglets weaned at 3 weeks of age. Although weight gains of piglets fed 0.9% potassium were lower than those fed 0.3 or 0.6% potassium (0.22 v 0.24 kg/day; $P < 0.05$), there were no significant effects on feed intake or conversion. Moughan and Smith (1984) found no difference in the energy and nitrogen metabolism of young pigs fed diets containing either 45, 72 or 218 meq/kg feed of the $Na^+ + K^+ - Cl^-$ electrolyte balance. Austic, Madubuike, Boyd, Klasing and Riley (1982) observed no effect on the growth rate and feed conversion of pigs offered diets ranging in $Na^+ + K^+ - Cl^-$ electrolyte balance between - 100 and + 500 meq/kg feed.

Assuming that experimental diets used in the current study contained levels of Na, K and Cl anticipated from the calculated composition, the $Na^+ + K^+ - Cl^-$ electrolyte balance would have ranged from 119 to 375 meq/kg air-dry feed. However results from the mineral analyses suggest that the actual values ranged from 168 to 387 meq/kg air-dry feed.

This, and other studies suggests that pigs can tolerate wide electrolyte imbalances resulting from excess levels of Na and K in the feed by increasing the rate of renal excretion and urine volume provided they have access to an unrestricted supply of water. In fact Sinclair (1939) found that the large volumes of urine output resulting from increased water consumption by growing pigs fed diets containing high concentrations of NaCl, made it difficult to maintain satisfactory pen hygiene.

In poultry water intake is also positively correlated with dietary salt intake (Paver, Robertson and Wilson, 1953). The additional water intake is excreted through the kidneys and because both urine and faeces are voided from a single orifice, the cloaca, the moisture of the droppings increased causing the problems of 'wet litter'. James and Wheeler (1949) found that the consumption of water and the incidence of wet droppings increased linearly as the intake of dietary potassium by growing chickens was increased from 10 to 20 mEq/bird day.

In the present study piglets offered diets formulated to 4 gCl/kg air-dry feed had a significantly reduced growth rate compared to those offered 2 g Cl/kg air-dry feed. This may be due to the higher incidence of post-weaning diarrhoea within pen groups fed diets formulated to 4 g Cl/kg air-dry feed (Table 2.36). Although high levels of faecal Cl have been associated with the occurance of diarrohea (Etheridge, Seerley and Huber, 1984), it is unlikely that high levels of dietary Cl or ingested Cl induce scours in the early weaned piglets. For example Anderson and Stothers (1978) reported no differences in the incidence of scours in groups of weaned pigs offered drinking water containing either 5882 ppm chloride salts or 125 ppm of total solids.

Post-weaning diarrhoea caused by pathogenic bacteria is known to create electrolyte and acid-base imbalances and dehydration

Table 2.36. Main factorial effects of dietary K and Cl content on the total mean pen scour score+ for weaned piglets from 3 to 5 weeks of age

	Age (weeks)		
Dietary K (g/kg air-dry feed)	**3**	**4**	**5**
7	0	2.5	4.1
9	0.6	0.9	1.0
11	0	2	6.8
13	0	0.9	1.9
15	0	2.4	3.1
Dietary Cl (g/kg air-dry feed)			
2	0	0.2	1.4
4	0.3	3.3	5.4

+ Each piglet within each pen was scour scored between 0 to 5.

0 Not scouring
5 Severely scouring

Total pen scour score = sum of scour scores for each animal within each pen group.

resulting from increased losses of minerals and water from the intestinal tract. As a consequence the effects of dietary potassium and chloride treatments on growth and performance may have been obscured by the high incidence of post-weaning scours reported in the current study.

PART IV WATER DEMAND BY GROWING PIGS ON A LIQUID FEEDING REGIME

Page

Introduction

Many producers consider liquid feeding as a viable alternative to dry feeding, because it is generally recognised that the mixing of meal with water prior to feeding results in superior growth rate and feed conversion (Smith and Lucas, 1957; Roller et al., 1965; Braude and Rowell, 1967; Kneale, 1972; Smith, 1976). Further evidence has come from a review of 86 published articles by Kracht, Ohle and Otto (1979) concerning the effects of the dry matter content of the diet on the performance of growing pigs, which suggested that in the majority of cases moistening of the feed had a positive or at least no detrimental effect on weight gain and feed intake. In addition liquid feeding systems offer greater flexibility over dry feeding as they allow novel and cheap ingredients to be incorporated into the wet mix. However the use of liquid feeding systems has often led to the assumption that the entire water needs of wet fed pigs are satisfied by water consumed in the liquid diet. It is therefore common for liquid fed pigs to have no separate source of drinking water. Although the Codes of Recommendations for the Welfare of Livestock : Pigs (1983) recognises the importance of a free water supply, it makes this recommendation optional if at least 2.5 litres of water are added to each kg of meal. This experiment was conducted to investigate whether these recommendations satisfy the water needs and safeguard the welfare of liquid fed pigs and to evaluate the effects of water to feed ratio of the liquid diet on growth and performance.

Experiment 9 Water use by growing pigs offered a liquid diet containing differing water to meal ratios.

Materials and methods

Experimental design and treatments

A commercial meal was mixed with water to produce liquid feed of four different water to meal ratios namely 2 : 1, 2.5 : 1, 3 : 1 and 3.5 : 1, volume for weight respectively. Four pen groups of eight pigs were randomly allocated to the treatments according to a 4 x 4 Blanced Latin Square design, in which each pen group received each treatment once only for a period of three weeks.

Animals and housing

Sixteen entire males and 16 females were selected with a mean initial weight of 14.6 (s.e. 0.25) kg W, housed and managed according to the procedure described in trial 2b.

Experimental procedures

Pigs were weighed and individually fed the commercial meal based liquid diets to a scale which provided 700 g meal/kg $W^{0.75}$ per pig per week. Proximate and mineral analyses of the meal are presented in Table 2.37. The calculated weekly meal allowance for each pig was divided into 13 equal feeds such that pigs were fed twice daily at 0900 and 1600 h except on Sundays when only the afternoon feed was given. The dry meal for each pen group was manually mixed with water in four plastic bins before feeding to produce the required water to meal treatment ratios. The mixture was agitated before each withdrawal to ensure that the

Table 2.37. Proximate and mineral analysis of the diet used in experiment 9

Dry matter (%)	87.5
Digestible energy (MJ/kgDM)	15.4
Crude protein (g/kgDM)	206.0
Crude fibre (g/kgDM)	56.0
Neutral detergent fibre (g/kgDM)	160.0
Ether extract (g/kgDM)	40.0
Total ash (g/kgDM)	64.0
Calcium (g/kgDM)	13.0
Phosphorus (g/kgDM)	8.0
Magnesium (g/kgDM)	2.0
Sodium (g/kgDM)	2.4
Potassium (g/kgDM)	10.4
Chloride (g/kgDM)	2.7

DE calculated using equation given on page 120.

dry-matter content of each pig's ration was the same. Pigs were allowed 30 minutes within which to clear the feeding troughs. Rejected liquid feed was removed from troughs after each feeding time, weighed and oven dried at 100°C for 24 h to determine the unconsumed fractions of meal and water. Pigs were individually weighed weekly and their meal allowance was increased accordingly. Live weight records were adjusted for increases in weight attributable to the water content of the liquid diet. Water use was recorded daily at 0900 h.

Results

The health of the pigs was good. Water use, feed intake and performance data is summarised in Table 2.38. Voluntary water was utilised on all water to meal treatment ratios. The amount of voluntary water used decreased significantly ($P < 0.001$) as the water content of the liquid feed was increased. As the decrease in voluntary water use was not proportional to the water content of the liquid feed, total water use increased significantly ($P < 0.001$) with increasing water content of the liquid feed. The ratio of total water use to meal intake and to live weight increased as the water content of the liquid feed was increased.

The water to meal ratio of the liquid feed had no significant effect on meal intake. Live-weight gain and feed conversion significantly improved ($P < 0.05$) as the water content of the liquid feed was increased.

Table 2.38. Water use, feed intake and performance of growing pigs fed a liquid diet containing four different water to meal ratios.

Treatment (Water: Meal)	Voluntary Water use (l/pig day)		Total water use (l/pig day)		Meal intake (kg/pig day)		Live-weight gain (kg/pig day)		Feed conversion ratio		Total water use: meal intake ratio		Total water use: live wt ratio	
	Mean	**s.e.**	**Mean**	**s.e.**	**Mean**	**s.e.**	**Mean**	**s.e.**	**Mean**	**s.e.**	**Mean**	**s.e.**	**Mean**	**s.e.**
2 : 1	1.26^{a}	0.100	4.23^{a}	0.396	1.48	0.056	0.73^{a}	0.023	2.1^{a}	0.034	2.97	0.102	0.10	0.067
2.5 : 1	0.78^{b}	0.081	4.51^{a}	0.461	1.49	0.057	0.74^{a}	0.026	2.00^{a}	0.038	3.12	0.092	0.11	0.076
3 : 1	0.44^{c}	0.036	4.85^{b}	0.421	1.46	0.048	0.75^{ab}	0.021	1.95^{ab}	0.036	3.36	0.052	0.12	0.085
3.5 : 1	0.24^{d}	0.037	5.40^{c}	0.514	1.47	0.049	0.77^{b}	0.023	1.90^{b}	0.038	3.69	0.029	0.13	0.098
P	< 0.01		< 0.001		NS		< 0.05		< 0.05					

[a, b, c] Means with the same superscript within the same column did not differ significantly ($P > 0.05$).

Discussion

This study demonstrated that liquid fed pigs will readily utilise a separate water supply even when the water to meal ratio of the liquid feed exceeded 2.5 : 1, which is the current recommendation in The Codes of Welfare (1983). The additional water taken with liquid feed consumed at a water to meal ratio of 2.5 : 1 resulted in a final ratio which was greater than 3 : 1. Therefore the ARC (1981) recommendation which states that the water requirement of growing pigs can be met with a water to feed ratio of 2 : 1 do not adequately satisfy the pig's needs for water.

A common feature which has emerged from this study and supported by other published work is that pigs offered free access to water show considerable variations in daily water demand. When both feed and water are freely available, pigs can adjust their water and feed intake which allows them the opportunity to express their individual needs for both dry matter and fluid. Computer assisted liquid feeding systems which deny access to a supplementary water supply, limit the water intake of pigs to discrete feeding times with fixed water to meal ratios and will therefore restrict the expression of normal drinking and feeding behaviour.

The conditions of this experiment did not make it possible to determine whether the provision of a supplementary water supply to liquid fed pigs has any effects on growth and performance. In a recent trial Smith (1983) found that pigs fed a liquid diet mixed to a water to meal ratio of 3 : 1 and offered a supplementary water source on average used an extra 1.32

litres/day and showed marginal but non-significant improvements in growth rate compared with control groups offered no additional water (805 vs 790 g/day). Olsson (1983) found that growing pigs offered liquid feed supplemented with a frequent watering regime showed between 1.5 and 2.0% improvements in growth and feed conversion. Conversely Braude and Rowell (1967) found that pigs given a liquid diet containing 2.5 parts of water per part of meal and offered no supplementary water had significantly increased growth rates compared with those offered 1.5 parts of water mixed with each part of meal and given an unrestricted water supply (0.62 vs 0.61 kg/day).

Improvements in pig performance resulting from increasing the water content of the liquid feed found in the current study have not been reported in earlier investigations (Barber et al., 1963; Braude and Rowell, 1967). Unfortunately direct comparisons cannot be made with this experiment as the performance of pigs given liquid diets differing in water to meal ratios was not assessed under the provision of a supplementary water supply in these previous investigations. Further research is required on the effects of differing water to meal ratios on the performance of liquid fed pigs before the results presented here can be substantiated.

CONCLUDING DISCUSSION

A programme of research was conducted to obtain quantitative information on the water use by pigs managed under various conditions of housing, feeding and nutrition. Conclusions from the experiments reported in this study have been discussed according to the specific objectives of this research programme.

1. To assess the effects of age, live weight, feed intake and physiological status on the water demand of the pig.

Experiments were conducted to assess the effects of different variates on the water demand of lactating sows, early weaned piglets and growing pigs. Within each of these classes of pig, where appropriate, analysis of regression was used to study the relationship between water use and feed intake, live weight, stage of lactation, litter size suckled, litter weight gain from birth to weaning and days post weaning (Table 3.1).

The demand for water was positively correlated with the intake of feed. Feed intake explained between 53 and 83 per cent of the variation in water use ($P < 0.001$). In the weaned and the growing pig, the high correlations of determination (R^2) between water use and other independent variables (eg live weight and number of days post weaning) were explained by the fact that these variables were themselves highly correlated with feed intake. For example, in experiments 3 and 7a it was found that only feed intake was the significant ($P < 0.001$; $P < 0.05$; see Appendix) variable in the multiple regression of water use against feed intake and live

Table 3.1 Summary of the regressions of water use against various independent variables reported in experiments 1, 3, 6 and 7 of this study

Independent variable (X_n)	Class of pig	Expt. No.	Regression equation	% R^2	r.s.d.	P
Feed intake X_1 (kg/day)	Lactating sow	1	$Y = 4.22 + 2.52X_1$	53.2	4.80	< 0.001
	Weaned Piglet	3	$Y = [0.48 + 1.13X_1]^2$	83.0	0.097	< 0.001
		6	$Y = [0.61 + 1.06X_1]^2$	77.0	0.096	< 0.001
	Growing Pig	7a	$Y = 2.5 + 8.18X_1 - 1.978X_1^2$	73.0	0.898	< 0.001
		7b	$Y = 1.35 + 2.57X_1$	73.5	0.795	< 0.001
Live weight X_2 (kg)	Lactating sow	1	$Y = 16.1 + 0.01X_2$	1.0	7.12	< 0.05
	Weaned piglet	3	$Y = [0.13 + 0.11X_2]^2$	66.5	0.135	< 0.001
		6	$Y = [0.27 + 0.10X_2]^2$	71.1	0.144	< 0.001
	Growing pig	7a	$Y = -1.42 + 0.25X_2 - 0.0021X_2^2$	79.2	0.787	< 0.001
		7b	$Y = -1.64 + 0.27X_2 - 0.0021X_2^2$	80.9	0.684	< 0.001

Table 3.1 (Continued)

Number of days post weaning X_3	Weaned piglet	3	$Y = 0.19 + 0.07X_3$	67.4	0.286	< 0.001
		6	$Y = 0.31 + 0.06X_3$	69.8	0.245	< 0.001
Number of days post farrowing X_4	Lactating sow	1	$Y = 7.63 + 1.81X_4 -0.05X_4{}^2$	51.5	4.91	< 0.001
Litter size suckled X_5		1	$Y = 16.7 + 0.22X_5$	4.0	7.02	< 0.05
Litter weight gain (kg/d) X_6		1	$Y = 18.1 + 4.89X_6$	23.4	2.31	< 0.01

weight. In the lactating sow, the relationship between water use and the stage of lactation was confounded by the feeding scale which provided 2 kg/sow at farrowing which was then incremented by 0.5 kg/day post partum. For example, in the multiple regression of water use against feed intake and number of days post farrowing only feed intake was the significant variate ($P < 0.001$; see Appendix). As a consequence the demand for water after farrowing paralleled feed intake and did not follow the characteristic shape of the laction curve described in the sow by Elsley (1970) and White and Cambell (1984). Similarly the relationship between litter-weight gain from birth to weaning and water use may be a function of the auto-correlation between feed intake and milk yield rather than the direct influence of piglet growth rate on the water demands of the nursing dam.

Comparison of the residual standard deviations of the regressions of water use against the different independent variables, from experiments 1, 3 and 6, further indicates that feed intake was the single most important factor which influenced the demand for water (Table 3.1). The close interdependence between feed intake and water use found in this study is in agreement with previous studies on other farm animal species including the pig (Fonnesbeck (1968) in horses; Forbes (1968) in sheep; Mount et al. (1971) in pigs; Castle and Thomas (1975) in cattle).

Although it was found that both feed intake and the demand for water were on average positively correlated, a number of differences specifically relating to suckling and weaned piglets, lactating sows and growing pigs need further discussion.

Results from experiments 2, 3 and 8 have been used in Table 3.2 to compare the water and dry matter intake and performance of a 21 day old piglet on the day before and after weaning and during the first, second and third week after weaning. Also presented for comparison at each of these stages are values for the minimum daily amount of water required to maintain physiological homeostasis, which have been calculated using the factorial method described in Chapter 1 of this study.

It can be seen that sow milk supplies water in excess to the suckling piglet's total daily requirement for obligatory losses and growth at 21 days. A daily gain of 220 g/day at this age was almost entirely supported by the intake of sow milk since the consumption of creep feed was only 8 g/day. Furthermore the provision of water and/or creep feed did not significantly ($P > 0.05$) influence the performance of suckling piglets weaned at 21 days of age (experiment 2). This indicates that the piglet's requirement for water and nutrients from birth to 3 weeks of age were satisfied by the intake of sow milk.

Hunger or the need to satisfy stomach fill may also be served by the water content of sow milk which was estimated to be between 34 and 86% surplus to the requirements for growth and obligatory losses. On the other hand gut capacity may limit the intake of water and dry matter from other sources when the supply of sow milk satisfies both the requirement for nutrients and stomach

Table 3.2 Water and feed intakes, performance and factorial+ estimates of the amount of water required to maintain body water balance of piglets before and after weaning at 21 days of age

	Suckling piglet 21 days of age	Weaned piglet			
		First day post weaning[c]	Week post weaning[b]		
			1	2	3
Water use (l/piglet day)	0.037[a]	0.36	0.49	0.89	1.46
Milk intake (l/piglet day)	0.800[d]	-	-	-	-
Milk-water intake (l/piglet day)	0.648	-	-	-	-
Feed intake (kg/piglet day)	0.008[a]	0.026	0.20	0.41	0.63
Moisture from feed (l/piglet day)	0.001	0.003	0.03	0.06	0.09
Total water intake[e] (l/piglet day)	0.679	0.291	0.422	0.772	1.258
Total dry matter intake (kg/piglet day)	0.159	0.023	0.18	0.35	0.54
DE intake (MJ/piglet day)	4.078	0.385	2.72	5.29	8.15
Live weight (kg)	5.60[a]	6.50	6.00	7.10	9.34
Live-weight gain (kg)	0.22[a]	-	0.09	0.22	0.41
Feed (DM) conversion	0.72	-	3.17	1.64	1.35
Water: Dry matter intake ratio	4.27	12.65	2.34	2.21	2.33

Table 3.2 continued

	Suckling piglet 21 days of age	Weaned piglet			
		First day post weaning[c]	Week post weaning[b]		
			1	2	3
Water loss (l/piglet day)					
Urine	0.027 to 0.160	0.031 to 0.185	0.029 to 0.171	0.034 to 0.202	0.044 to 0.266
Faeces	0.030	0.012	0.098	0.191	0.294
Skin	0.095	0.105	0.099	0.111	0.132
Respiratory	0.081	0.094	0.087	0.103	0.135
Water in growth (l/piglet day)	0.158	(0.158)	0.065	0.158	0.295
Metabolic water (l/piglet day)	0.042	0.055	0.045	0.053	0.069
WATER REQUIREMENTS (l/piglet day)	0.349 to 0.482	0.345 to 0.499	0.333 to 0.475	0.573 to 0.741	0.781 to 1.091

(a, b, c) data from experiments 2, 3 and 8; (d) assuming sow milk intake is 800 g/piglet day, sow milk contains 810 g water/kg and 5.2 MJ GE/kg (ARC, 1981) with a GE digestibility of 0.95; (e) assuming water intake is 80% of water use.

+ Details of factorial calculations given in Chapter 1 and in the Appendix.

fill. For example, in experiment 2 it was found that the provision of creep feed significantly reduced ($P < 0.001$) daily water use between 8 and 21 days of age. This suggests that gut capacity may limit the total daily volumetric intake of water and dry matter. This volumetric intake was estimated as 28% of body weight at 8 days which decreased to about 16% at weaning.

Gastric volume and fill have been shown to regulate the ingestive behaviour of suckling animals in other studies. Satinoff and Stanley (1963); Stephens (1975); Houpt, Houpt and Pond (1977) found that piglets and puppies reduced their intake of milk from the mother following stomach loading by gavage with milk or kaolin, thus indicating that intake was primarily controlled by fullness of the upper gastrointestinal tract.

The suckling piglet up to 3 weeks of age satisfies its requirement for both water and nutrients in a single package from the sow. Weaning at this age represents an abrupt change where the piglet's source of water is removed from its source of nutrients which are usually presented in the form of dry feed.

Comparison of the water and dry matter intakes and performance before and after weaning shows that piglets were unable to quickly adapt to this system of early weaning (Table 3.2).

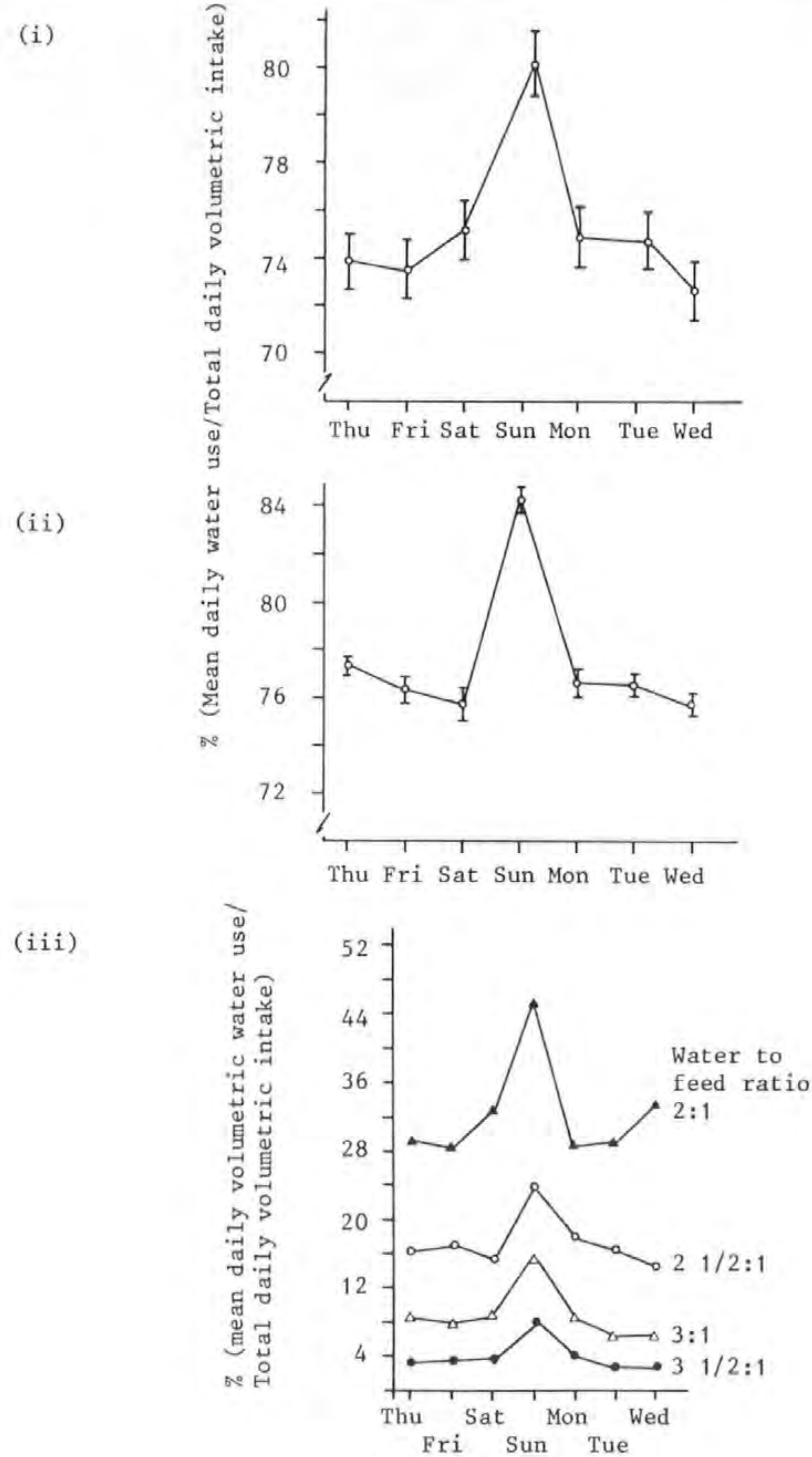
Assuming that wastage from nipple drinkers was about 20% of the amount used (Olsson, 1983) then an intake of 291 g on the day following weaning was barely sufficient to cover a total obligatory water loss of between 345 and 499 g/day. As a consequence the piglet cannot sustain a growth rate of 220 g/day, as that achieved before weaning, without a serious deficit in its body water balance. In addition to dehydration the newly weaned piglet is almost certainly experiencing hunger from a severe reduction in food and water intake since total daily volumetric intake as a percentage of body weight decreased from 16% before to 5% after weaning. Stress, low water and feed intake must be the main factors which contribute to the poor performance found in the first week after weaning under this system of housing, watering and feeding. Only in the second week was performance comparable with that achieved by the suckling piglet at 21 days of age.

Therefore it would not be unreasonable to conclude that early weaning under conditions commonly found in commercial practice constitutes a serious insult to the welfare of the piglet.

Water use by growing pigs fed either ad libitum (experiments 5a and 8a) or on a scale related to metabolic body weight (experiments 4, 5b, 8b and 9) was on average positively correlated with the intake of feed. However pigs which were rationed according to a scale related to metabolic body weight, showed a dramatic increase in water use when they were fed only once daily (Sundays) on a regime which otherwise provided 2 feeds per day at discrete feeding times (Figure 3.1).

Similar responses with young pigs have been reported by Yang et al. (1981). They found that a restriction in daily feed allowance from 1.5 to 0.8 kg/day increased water consumption from

Figure 3.1 Mean daily water use as a percentage of total daily volumetric intake of growing pigs in experiments 2b (i), 8b (ii) and 9 (iii).



2.6 to 3.6 l/day. Rehabilitation or an increase in feed allowance was found to decrease the amount of water consumed by an equal weight. More recently Yang et al. (1984) reported a sustained increase in water consumption by young pigs maintained on daily feed allowances of less than 30g DM/kg W. Rushen (1984 and 1985) has also observed increased levels of post-prandial water intake and drinking activity with pregnant sows on restricted feed allowances.

In short, it seems that in the pig, a restriction in feed allowance does not bring about a proportional decrease in water use although on average the two variables are positively correlated. Therefore water may serve as a substitute for food when feed allowance is insuffucient to satisfy the needs for gutfill.

In conclusion the need to satisfy gutfill may be an important component of the normal ingestive and drinking behaviour of the suckling and growing pig but is a need which the early-weaned piglet is incapable of satisfying.

In experiment 1, sows showed a linear increase in daily water use ($P < 0.001$) during the week before farrowing. It was suggested that this could be associated with the hormonal changes and behavioural activities which occur during the so called preparatory stage. These include an increase in plasma oestrogen, restlessness, signs of discomfort, nervousness and frustration, increased frequency of drinking and urination anad defaecation and increased levels of vocalisation (Hughes and Varley, 1980; English et al., 1982). Recently Baxter (1982) suggested that these activities could be stereotypic responses to confinement in farrowing crates which deny sows the opportunity to perform nest-building behaviour before parturition. For example it was found that sows restrained in crates were found to perform a number of novel behaviours around the time of farrowing which were not seen in unrestrained sows. One of these included water throwing. This involved filling the trough from the drinker and then throwing the water out using vigorous rooting movements. Effects of psychological or emotional disturbance on drinking have been demonstrated in the rat. Siegel and Siegel (1949) found that rats confined in an electrified box for 45 seconds drank about five times more than control rats within a period of 2 hours.

Drinking or drinker manipulation stereotypes may thus replace behavioural norms that cannot be performed under conditions of housing which impose a high degree of stress resulting from confinement, such as in farrowing crates and individual stalls for pregnant sows. Playing with drinkers and excessive water ingestion and urination have been reported as components of stereotypic behaviour in pregnant sows confined in individual stalls (Cronin, 1985). However not all sows incorporated excessive drinking activities into their pattern of stereotypic behaviour. Therefore it is possible that differences in individual behavioural characteristics may be a factor contributing to the high variation in water use between individual sows reported in the current study and by other workers (see page 77).

Similarly some of the large differences in water intake by growing pigs reported between independent studies (see page 71) could be due to the effects of different housing and feeding systems on behaviour related to water use such as stereotypic drinker manipulation and excessive water ingestion.

2. To evaluate the effects of different types of drinker on the water use and performance of early weaned and growing pigs.

Commercial pig producers can choose from many different types of drinkers for all classes of stock. A number of them have been described by MacCormack (1972) and Olsson (1983) but there have been very few published reports which have systematically compared water use or the performance of pigs offered water from the more common types of drinker found in commercial units.

In this study 4 experiments were conducted to investigate whether the type of drinker used had any significant effects on the water use and performance of early weaned (experiment 6) and growing pigs (experiments 4, 5a and 5b).

Water use from the different types of drinker reported in these experiments is summarised in Table 3.3. With both classes of stock water use from the Mono-flo nipple drinker was between 58 and 105% higher than from the other types of drinker ($P < 0.001$).

Table 3.3 Water use by weaned and growing pigs from different types of drinker evaluated in experiments 4, 5 and 6 of this study

	Expt. No.	Mono-flo nipple	Arato 80 bite	Lubing bite type I	Lubing bite type II	Arato 76 nipple	Alvin piglet bowl
				(l/pig day)			
Growing pigs							
Fed to scale	4	4.30	2.47	-	-	-	-
	5b	10.25	5.00	4.94	5.06	-	-
Fed *ad libitum*	5a	8.32	5.63	4.98	5.21	-	-
Weaned piglet	6	1.59	-	0.91	0.97	1.02	1.01

Although it was not possible to measure net intake, it is highly likely that wastage was the main factor which explained the high rates of water usage from the Mono-flo nipple drinker.

Wastage from drinkers, leaks from the delivery system and excessive use of water for cleaning contributes directly to effluent production and to the associated costs of its storage and spreading. With increasing pressure to reduce pollution and the public nuisance created by effluent spreading, a high rate of effluent production is becoming a liability rather than an asset for many intensive pig producers (Nielsen, 1987).

A number of countries are facing more serious environmental problems due to limited availability of cropping area for effluent application from large scale pig units. For example in some regions of the Netherlands, nitrate concentrates in the public water supply have exceeded official Government Health Standards (Lenis, 1988). In order to protect the environment and public health, recent legislations in the Netherlands have aimed to control the rate of effluent discharge from pig units by enforcing effluent quotas (Looker, 1987).

This type of legislative control is at variance with codes of practice which intend to safeguard the welfare of pigs. Commercial pig producers faced with effluent quotas are in the first instance likely to exploit all possible means of reducing water usage rather than to decrease their herd size. This could include drastic measures such as turning off the water supply during the hours of night, restricting water provision to feeding periods, reducing flow rate from nipple drinkers, decreasing the number of drinkers per pen and not providing a supplementary water supply to wet fed pigs.

These restrictive methods of control may compromise pig welfare under conditions where unrestricted access to a supply of water serves needs in addition to meeting the requirements for physiological homeostasis.

Better water and excreta management and research on improved water delivery systems which eliminate water wastage are more constructive methods of reducing effluent production rather than the use of ill-conceived legislative control.

For example effluent production from pig units fitted with the popular Mono-flo type of nipple drinker could be reduced by up to 60% by use of a water delivery system that completely avoids wastage from leaks or spillage. Where more sophisticated types of bite and nipple drinker are used a potential saving of up to 20% is possible (Olsson, 1983) and a more conservative estimate of between 10 and 20% from bowl drinkers (Yang et al., 1981).

Use of a waste free water delivery system could assist in the separate management of urine and faeces. However, this would involve a radicle change in the design of buildings below slat level and considerable amount of further research on parameters of drinker design, which would eliminate losses without compromising continuous access to a satisfactory delivery rate.

A high level of water use from a specific type of delivery vessel is not necessarily a good indicator of satisfactory water provision. For example, in experiment 6 early weaned piglets offered water from the Mono-flo nipple drinker had the lowest growth rates ($P < 0.05$) but water use from this type of drinker was the highest ($P < 0.001$).

Prior to this study and the more recent work of Barber, Brooks and Carpenter (1988a and 1988b), research on water delivery systems and their effects on water use and biological performance would have attracted little interest. The results of experiment 6 indicate that biological performance, particularly in the period after early weaning, was influenced by type of drinker used, although the evidence for the growing pigs was less conclusive.

The notion that growth and performance after weaning could be influenced by method of water delivery is now very plausible considering the finding that the water balances of the early weaned piglet are placed under a high level of stress. Any negative component of the delivery system (eg, unsatisfactory delivery rate, poor design features that unwittingly restrict access to water) which marginally augment this level of stress are likely to have a more adverse effect on performance than at first assumed. For example Barber et al. (1988b) found a positive correlation between voluntary feed intake after weaning and delivery rate from nipple drinkers. The results of such studies emphasise the need for research workers to standardise or report their system(s) of water provision under conditions of experimentation used to evaluate the effects of various parameters on biological performance.

In conclusion future research on water delivery systems and management of water in intensive livestock enterprises should make positive contributions to the welfare of animals and to the commercial interests of the producer.

3. To investigate the effects of dietary mineral concentrations on water demand.

A number of studies have reported the effects of dietary NaCl on water intake (Sinclair, 1939; Hagsten and Perry, 1976; Alcantra et al., 1980) but very few similar studies can be found in the literature on the effects of potassium intake on water demand. This is surprising since commercial diets usually contain levels of potassium between 4 and 8 fold higher than the ARC (1981) recommended allowance of 2.5 g K/kg DM for growing pigs. Furthermore it is not clear whether variations in the ratio of K^+ and Na^+ to Cl^- in the diets of young and growing pigs influence water demand or have similar effects on biological performance as reported in poultry, (Melliere and Forbes, 1966; Talbot, 1978; Harms, 1981).

The experiments reported in this study investigated the effects of variations in dietary potassium concentrations, within the ranges found in commercial diets, on the water demand and performance of weaned and growing pigs. Interactions between chloride and potassium on water demand and performance was studied with the early weaned piglet.

In experiment 7 (a and b) on the growing pig it was found that for every 1 g increase in the concentration of potassium in the diet above 7 g K/kg, water use increased by 100 g/day ($P < 0.05$), without significant effects on feed intake, weight gain and feed conversion ($P > 0.05$). Assuming wastage was about 20% of water usage (Olsson, 1983) then clearly marginal increases in dietary potassium intake appeared to have little effect on water intake. This is probably due to the fact that daily water intake, predicted from regression equations of water use against feed intake for each class of pig given in Table 3.1, was much higher than the amount calculated to maintain physiological homeostasis (Table 3.4). Therefore under conditions of unrestricted access to water marginal increases in the intake of osmotic minerals can be tolerated without a marked increase in water demand.

There is a need to consider why pigs, when given the opportunity, drink more than the amount required to maintain body water balance. Chew (1965) stated 'the water requirements and exchanges of each species of mammals have evolved into a "fit" with its environment which precludes it from expanding its range to environments that are more rigorous'. In this respect ecology of the wild pig could lend some tentative hypotheses to studies on the drinking and feeding behaviour of domesticated pigs.

Pine and Gerdes (1973) noted that surface water and areas that remained moist throughout the year were essential for good wild

Table 3.4 Comparison of water use predicted from regression equations against feed intake for various class of pig reported in this study, with the amount calculated to maintain body water balance

	Expt. no.	**Predicted daily water use (l)**	**95% Cl (l)**	**Daily feed intake (kg)**	**Factorial[a] estimate (l)**
Piglet (10 kgW)	3	1.50	1.05 - 2.01	0.66	0.71 - 0.95
	6	1.61	1.14 - 2.14	0.62	
Growing pig (60 kgW)					
Fed <u>ad libitum</u>	7a	5.95	4.50 - 7.25	2.00	1.91 - 3.33
Fed to scale	7b	7.00	5.30 - 8.60	2.20	
Lactating sow (14 d post partum)	1	21.10	13.80 - 32.6	7.50	8.05 - 11.75

[a] Calculations of factorial estimates provided in the Appendix and Chapter 1.

hog habitat. Graves (1984) found that the preferred habitat of the wild pig was either riverine forests, scrub bush areas surrounding water holes, swamps or marsh lands.

In temperate climates, the diet of wild pigs varies according to the seasonal availability of different foodstuffs. Stomach contents of feral and wild pigs have revealed that succulent foliage, roots, tubers, water weeds and grasses comprised the major portion of the diet in the spring and summer. Acorns, hickory nuts, berries and fruits were selected in autumn and winter (Hanson and Karstad, 1959; Wood and Roark, 1980; Graves, 1984).

These detailed studies indicate that the bulk of the diet of the wild pig consists of vegetation containing a high water to dry matter ratio. Since the pig eats to satisfy its requirement for nutrients, the moisture content of its diet would provide water which is surplus to its needs for homeostasis. Yang et al. (1981) suggested that ingestion of large quantities of low density matter by wild pigs could be the origin of the predigious appetites of domesticated pigs and of their indiscriminatory behaviour towards water and food when hungry. This may also explain why in experiment 9, pigs continued to utilise a supplementary water supply even though the moisture content of the liquid feed was sufficient to meet their requirements for physiological homeostasis.

Additional clues to the pigs evolution in a mesic habitat include its limited ability to conserve water through urine concentration

(McFarlane, 1976), its reliance on wallowing or similar behaviour to increase evaporative heat loss (Ingram, 1965a; Close et al., 1971; Nienaber and Hahn, 1984) which is otherwise restricted by a lack of apocrine activity (Ingram, 1967).

Therefore, water is an integral and major component of the environment and diet of wild pigs. In commercial production, the pig's need for water may be a characteristic derived from its evolution in an environment which is abundant in water and the succulent foodstuffs favoured by the species.

Furthermore the pig's susceptibility to salt poisoning under conditions of water deprivation could be a peculiarity related to its ingestive behaviour which has evolved in an environment where water is an unlimited resource. For example when water supply is temporarily withdrawn, unlike other mammals, the pig does not immediately reduce its voluntary intake of feed (Bing and Mendel (1931), Lepkovsky, Lyman, Fleming, Nagumo and Dimick (1957), Toates (1978) in mice, rats and gerbils; Cizek (1961) in rabbits; McFarlane, Morris, Howard, McDonald and Budtz-Olsen (1961) in Merino sheep). In pigs, voluntary intake of dry feed in the absence of a water supply has been found to increase plasma sodium levels and by a process of impeded diffusion an accumulation of sodium in the brain (Gyrd-Hansen, 1972). A copious intake of water following complete rehabilitation of the supply produces a rapid surge of water into the brain causing ataxia, blindness, convulsions and death (Wells, Lewis, Hawkins and Don, 1984).

Cases of acute salt poisoning are not uncommon in commercial practise. O'Brien (1968) reported an incident with 70% mortality rate following rehabilitation of the water supply after only 24 to 36 hours of complete water deprivation with growing pigs fed ad libitum a diet containing as little as 0.8% NaCl. In most field cases, dry feeding, use of whey, obstructed nipple drinkers, frozen water supplies and insufficient access to water for stocking rate have been considered as the main contributing factors (Wells et al., 1984).

Chronic salt poisoning resulting from extended periods of insufficient access to water can have similar effects on health and performance as acute salt intoxication. For example, reduced daily weight gains, poor feed conversions and increased mortality rates have been reported in several studies involving long term feeding of plant juices contain high levels of potassium to growing pigs on restricted water allowances. (Braude et al., 1977; Barber et al., 1979 and 1980). It is interesting to note that the watering regime used in these studies satisfied the ARC (1981) recommended water allowances for this class of stock.

In experiment 8, piglets weaned at 3 weeks of age were fed one of 10 diets formulated to 5 and 2 different levels of potassium arranged factorially (7, 9, 11, 13 and 15 g K/kg air-dry feed; 2 and 4 g Cl/kg air-dry feed). There were no significant treatment effects on water use and performance ($P > 0.05$). Dietary potassium did not influence water use, feed intake, growth rate or feed conversion ($P > 0.05$). The weight gains of piglets offered diets formulated to 2 g Cl/kg were significantly higher than those fed diets containing 4 g Cl/kg ($P < 0.05$). No significant K x Cl interactions were found ($P > 0.05$).

Unfortunately analyses of the diets showed that K and Cl concentrations did not correspond with those expected from the formulations, particularly for Cl. This is an example of how human error or inaccuracies of measurement can produce diets with mineral concentrations which are considerably different from expected values. However, there was a tendency for K to increase in the different diets in the anticipated direction.

Nevertheless the regressions of water use against actual dietary K and Cl concentrations showed no significant effects of these minerals on water demand ($P > 0.05$). This was in contrast to the results obtained with potassium using growing pigs. This apparent insensitivity to potassium intake by the weaned piglet may be due to the adverse effects of early weaning on the normal physiological response to dietary salts. Alternatively the higher incidence of diarrhoea reported in this experiment may have confounded any possible dietary effects on water use and performance.

Studies with poultry have shown that deviations from an optimum dietary electrolyte balance resulting from disproportionate changes in the ratios of K^+: Na^+: Cl^- can have an adverse effect on biological performance (see page 241). Although this concept has not been widely researched in the pig, this study found no significant responses with either growing or weaned pigs to variations in electrolyte balance ranging between 161 and 387 meq/kg air-dry feed. This is in agreement with other studies on electrolyte balance in the growing pig (Austic et al., 1982; Moughan and Smith, 1984).

In conclusion, pigs should be provided with an unrestricted supply of water in order to safeguard their welfare in the event of any unforseen changes in feed supply, mineral content of the diet or the use of feedstuffs containing high levels of potassium or sodium salts.

Provided that they have access to fresh water at all times, pigs can tolerate a wide range of dietary potassium and sodium concentrations and variations in dietary electrolyte balance resulting from disproportionate changes in either K^+, Na^+ or Cl^-.

SUMMARY

From the various reports considered and from the results of this programme of research the following conclusion almost reflect the visionary words of Professor R M Chew quoted at the outset of this study.

There is no single water requirement for each class of pig or individual; the need for water and the amount used depends upon factors such as management, system of feeding, feed intake, diet, physiological status, method of water provision, conditions of housing and stresses of the environment, climate and behaviour.

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