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THE RATIONALISATION OF DRINKING WATER SUPPLIES FOR PIG HOUSING

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A thesis submitted in partial fulfilment of the requirements of the Council for National Academic Awards for the degree of Doctor of Philosophy

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Seale-Hayne Faculty of Agriculture, Food and Land Use,
Polytechnic South West.
In Collaboration with South West Water.

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ABSTRACT

THE RATIONALISATION OF DRINKING WATER SUPPLIES FOR PIG HOUSING

JOHN BARBER

This study consisted of a series of experiments which investigated the water use of growing/finishing pigs (25-90 kg), newly weaned pigs (5-12 kg) and gestating sows. Drinker type was found to affect water use in growing pigs. For example significantly more water (28 %) was used from Mono-flo nipple drinkers than Arato bite drinkers ($P<0.01$). For all classes of pigs studied water use was significantly increased by increasing the water delivery rate. The percent increase in water use over the extremes of water delivery rate tested in individual trials were respectively: ration fed growing pigs, 105 % (300-900 cm^3/min $P<0.001$); *ad libitum* fed growing pigs, 52 % (200-1100 cm^3/min $P<0.01$); gestating sows, 25 % (500-2500 cm^3/min $P<0.01$); and newly weaned pigs 109 % (175-700 cm^3/min $P<0.001$).

In newly weaned piglets, increasing the water delivery rate from 175 to 700 cm^3/min resulted in a significant increase in feed intake (44 g/piglet/day, $P<0.001$) and growth rate (37 g/piglet/day, $P<0.01$).

For growing pigs (27-55 kg), a relationship was established between water intake, feed intake and liveweight, from which it could be hypothesised that the pig had a limit to daily volumetric intake. This was found to be 12.0 ±1.2 % of liveweight. When feed intake was restricted, water intake increased to maintain the 12 % volumetric limit. This hypothesis was validated from other published work extending the weight range to 105 kg. Evidence was produced indicating that newly weaned pigs also have a constant volumetric daily limit. It is suggested that in cases where feed intake needs to be restricted, water intake could be manipulated in order to limit feed intake. This would permit the wider use of *ad lib* feeding systems and the welfare benefits these allow.

The water use of a grower/finisher unit was modelled according to a 12 % volumetric limit and the factors affecting water intake and wastage. The water intake of grower/finisher pigs was predicted using this model. This enabled the percentage of water wasted by different drinker types and delivery rates to be estimated.

For wet fed pigs, increasing the water to feed ratio from 1.63:1 to 3.25:1 significantly increased feed digestibility ($P<0.05$). As many experiments conducted to evaluate the digestible energy of feeds may have used low feed to water ratios (generally around 2:1) it is suggested that many of these studies have attributed incorrect nutritional values to raw materials used in diets for pigs.

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List of abbreviations

ARC	Agricultural Research Council
ADH	Antidiuretic hormone
cm^3	centimetres cubed
r	coefficient of correlation
R^2	coefficient of determination
^0C	degrees Celcius
dy/dx	differential of X with respect to Y
DE	digestible energy
DM	dry matter
g	gramme
>	greater than
<	less than
hrs	hours
kg	kilogramme
W	live weight
$W^{0.75}$	metabolic live weight
MJ	megajoules
m^3	metres cubed
m	metres
m^2	metres cubed
mg	milligrammes
ml	millilitres
mm	millimetres
min	minutes
NS	not significant
P	probability level
RH	relative humidity
S.E.	standard error
S.E.D	standard error of difference
S.E.M.	standard error of mean

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CHAPTER 1. THE USE OF WATER ON PIG UNITS

1.11 Economic background

In recent years, the decreasing profitability of the agricultural industry in the United Kingdom, has lead producers to consider carefully the levels of resource input as well as the levels of product output. It seems that reducing production expenditure may be a viable alternative in maintaining a satisfactory farm income. In the pig sector of the industry the relatively expensive items such as feed and directly applied energy (electricity, gas and oil) have already been given attention, as profitability is largely dependent on these costs.

However one resource which has been largely neglected by pig producers is water. Both its supply and the disposal of the results of excessive quantities used have been given little consideration. This has occurred mainly because water has been accepted as a relatively cheap material, representing only a small percentage of the overheads on most agricultural holdings.

Recently producers have also come under pressure from a number of external influences resulting from increasing public awareness of the part which water plays in farming, thus encouraging them to be less profligate in its use. In 1988 farm pollution of rivers rose to a record of 4,141 reported cases in England and Wales (Water Authorities Association,1989).

Excessive use of water in intensive livestock units results in increased costs of storing and therefore disposal of the extra slurry produced. The additional increase in water demand on a national scale which this implies, coupled with the enormous environmental problems caused by its polluting effects, and the capital cost of increased reservoir capacity is leading the water industry to husband its resources. As a consequence, the newly privatised water companies are already increasing water prices substantially. It is thus in the interests of all producers to examine and contain potential sources of misapplied expenditure such as inefficient water systems providing drinking water.

1.12 Water utilisation

The total water which is used on pig units can be divided into two major categories: drinking water and that used for other purposes such as washing buildings. This study is concerned principally with the drinking water supplied to housed pigs.

Water supplied as drinking water satisfies three distinctly different needs (Figure 1.1).

(1) Physiological requirement; This is the water needed to maintain osmoregularity.

(2) Behavioural requirement; This the water which is required in order to allow the animal to display, as far as possible normal behavioural patterns.

(3) Water wasted from drinkers; This results from inadequate

selection, fitting, maintenance and operation of drinkers.

In this work the term 'water use' shall be defined as the sum of the three needs described above. In the past many workers have used the term water intake when discussing the results from experiments which actually measured water use. The term water intake will be used to describe that water which is imbibed and passes down the oesophagus. It mainly consists of the physiological element but may also include an element of behavioural requirement where water is only imbibed for the purpose of satiety.

1.13 Water supply systems and demand factors

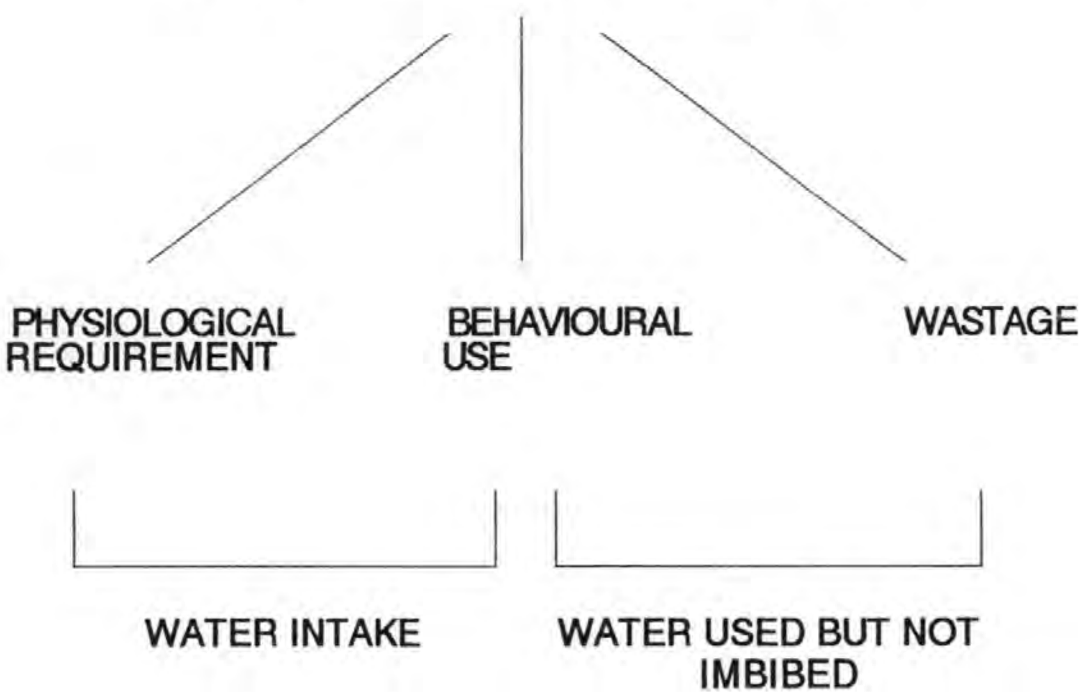
Modern pig units have been erected in rural areas and unbeknown to the Water Supply Authority have been connected to existing water 'mains' networks without prior regard to the character of the existing supply system or the units' likely demands and their consequent effects. Rural water mains networks can be of various ages and consequently in different stages of fracture and dirt ingress. Decayed pipes are more likely to suffer leakage. Soiling and furring up of pipes leads to an increased frictional resistance to the flow of water. Both these factors result in a reduced supply capacity from the original design level of the network due to lower available flows. This problem can be partially overcome by increasing the pressure at the source of supply, but this results in greater leakage and the possibility of further fracture. Therefore when intensive pig units have been linked to already overstretched supply mains they have aggravated an already worsening situation. The general problem has been exacerbated because

Figure 1.1 The use of water on pig units

1 WATER FOR CLEANING BUILDINGS (PRESSURE WASHING)

2 WATER WASTED THROUGH DECAYED PIPES AND FITTINGS

3 WATER SUPPLIED FOR DRINKING



economies of scale have resulted in units increasing in size. Small units with only a relatively minor demand on the water system have developed into large intensive units still connected to an unchanged main.

As little information has been available on the water utilisation of pig units, their demands have largely been overlooked by the Water Authorities as well as pig producers. This has resulted in growth of 'connected load' to the point where rural supply networks are being stretched to their limits. Overstretched supply networks result in a reduced flow to all consumers at times of peak demand but particularly to those outlets which are furthest from the original source. Such a reduction of flow to large pig units can produce an under supply of water to the pigs and consequent reduction in performance and welfare.

1.2 Water use, wastage and its cost

In 1985 it was estimated that the U.K. pig industry consumed 19.12 million cubic metres of water at a cost of almost £5 million per year (Carpenter 1985). However under £4 million of that was actually consumed by the pig, the remainder was wasted. The cost of this wasted water together with the associated costs of storing and disposing of the extra effluent it produced represents an avoidable cost to the pig industry of almost £25 million per year, see Table 1.1.

There is little evidence available to enable quantification of total water consumed on pig units or the relative amount used as drinking water. Borzym, (1984) showed that when theoretical parameters were

Table 1.1 Estimated costs of water use and water wastage on U.K. pig units.

Water used (cubic metres)	15 million
Water cost (£)	3.9 million
Water wasted (cubic metres)	4.12 million
Cost of wastage (£)	24.76 million

Assumptions:

1. National Herd = 6.75 x 106 pigs
2. Water Costs = 26p/cubic metre
3. Wastage costs includes cost of water at 26p/m^3 plus storage and disposal of effluent at £5.75/m^3 average (£4.50-7.00 range estimated)

(Carpenter, 1985)

Table 1.2 The calculation of the effluent storage capacity required for a 200 sow unit with followers to bacon weight assuming at any one time a total pig population of 2000 of mixed ages. Storage required for four months.

Calculation:

68 lactating sows at 12 litres/day	0.816 m^3
132 dry sows at 8 litres/day	1.056 m^3
1800 followers at 4 litres/day	7.2 m^3
washing/waste, 2000 pigs at 0.5 litres/day	1.0 m^3
Total slurry per day	10.072 m^3
In four months (122 days)	1229 m^3

Assumptions:

1 sow plus litter to weaning will excrete 12 litres/day.
1 dry sow excretes 8 litres/day.
1 pig from weaning to bacon weight fed dry meal excretes 4 litres/day.

Waste water from drinkers and cleaning pens 0.5 litres/pig/day.

used to calculate demand and compared with the measured values, the measured water delivery was nearly double that of the theoretical demand. The excess water supplied was due to substantial leakages in the external and internal water pipe work, loose fixtures, and the consumption of water for cleaning purposes.

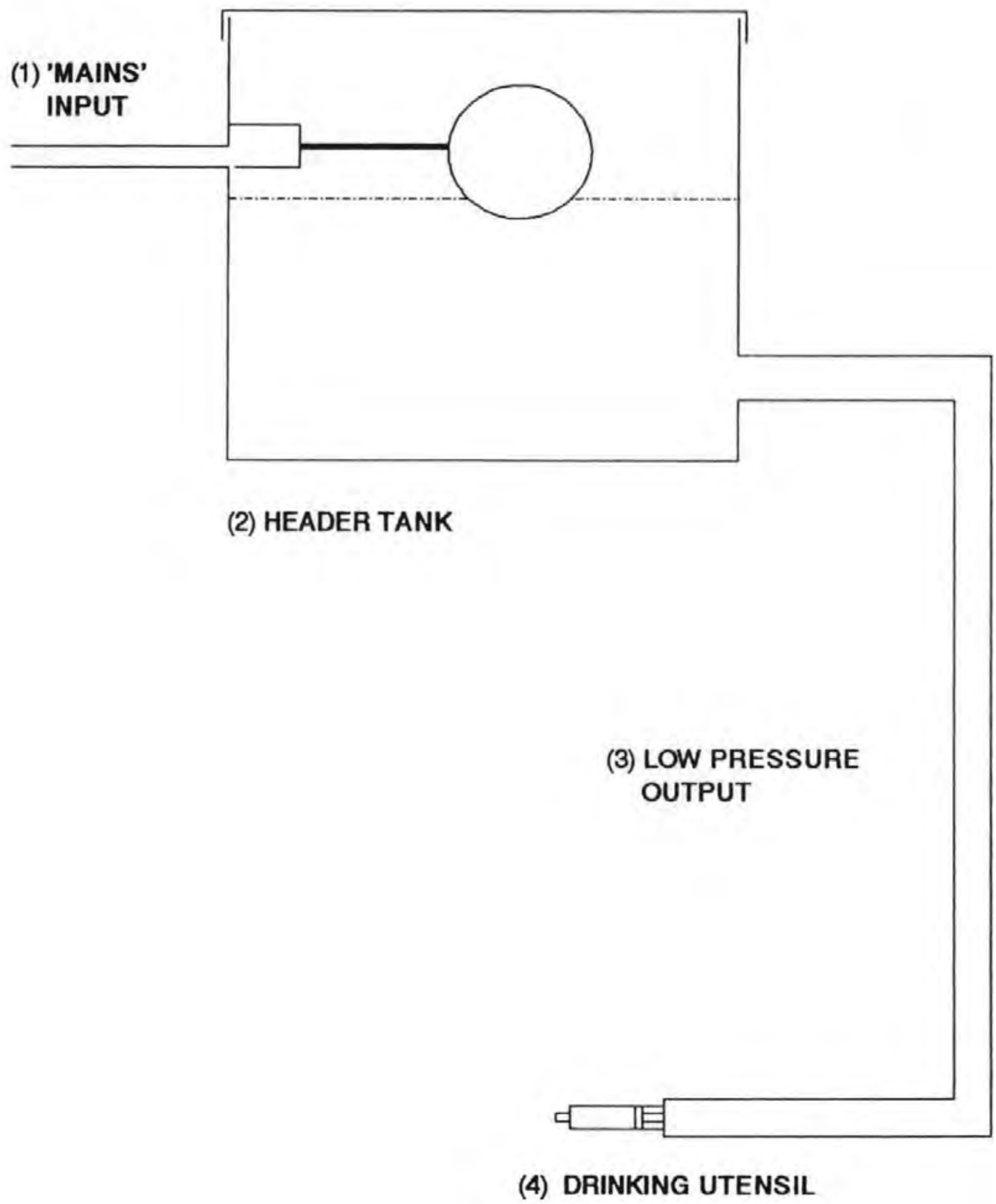
Day and Irgens, (1963), reported that wastage from pressure washers resulted in six times more liquid manure than when washers were installed that did not allow wastage into the pits.

In estimating the effluent storage capacity required for a 200 sow unit (Table 1.2), A.D.A.S. (1984), assumed that 0.5 litres of water per pig per day was wasted from drinkers and the pen cleaning operations. Table 1.2 gives an indication of the proportion of water used for drinking as opposed to that used for pressure washing. Although the volume of effluent is not equal to the amount of water used it is closely related, (Lightfoot,1984). The effluent produced from the growing pigs accounts for over 70% of the total slurry produced on the whole unit.

1.3 Piped supply systems for pig housing

In the United Kingdom housed pigs are usually provided with water from the public supply. In order to protect the public water supply, the statutory requirements of the Water Authorities require that the distribution of water to commercial livestock must be carried out by the use of self refill header tanks. These are connected to the 'mains' system via an air gap of 300 mm from the supply valve to the

Figure 1.2 The main components of a piped drinking water supply system



top of the retained water surface. The main components of a piped drinking water supply system are shown in Figure 1.2 and are as follows:

(1) A high pressure mains input. Mains water pressure varies from authority to authority, between different regions within an authority and at different times of the day depending on other demands closer to the supply source.

(2) A header tank usually made of metal or plastic. The capacity of the header tank should be such that it can continue to supply water to the pigs for a period of time should there be an interruption in the mains supply.

(3) A low pressure drinker supply line. The pressure in this line depends on the head of fluid which is determined by the height differential between the header tank and the drinker. This supply line is usually made of copper, alkathene, polybutylene galvanised iron or plastic.

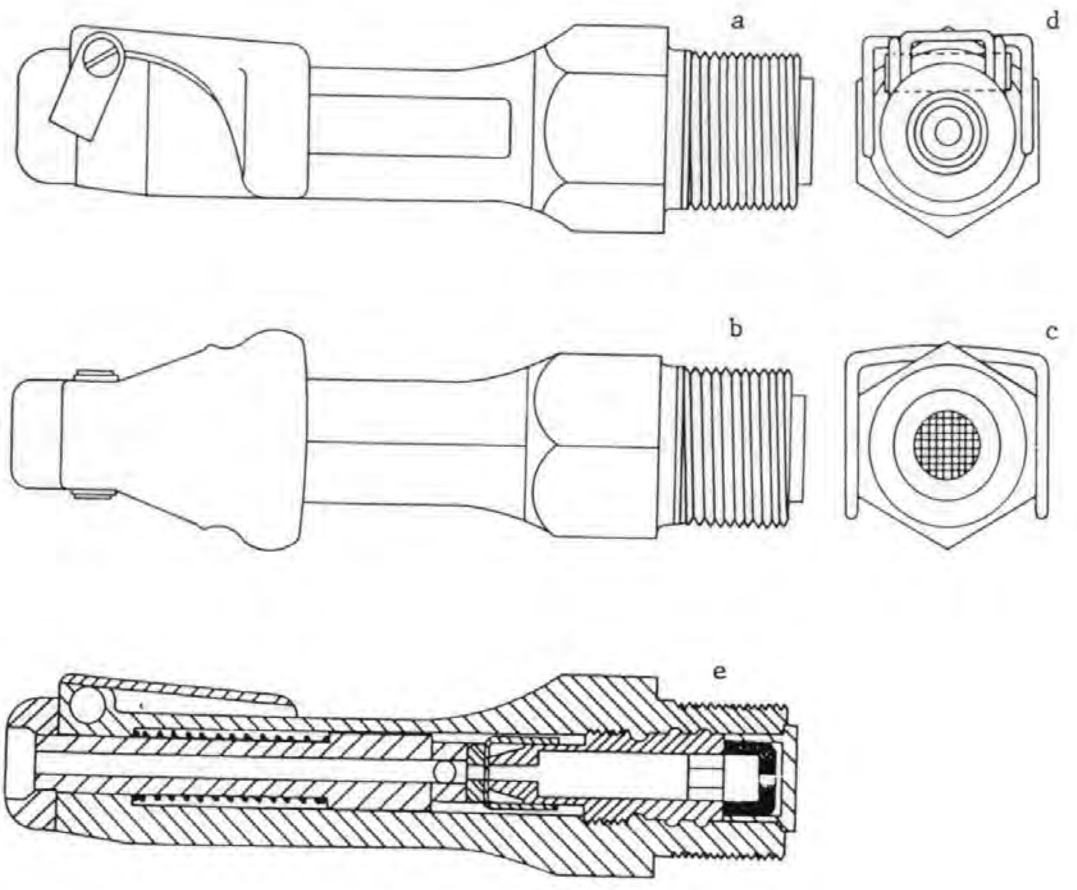
(4) Drinking utensils. There are many different types of pig drinker available to the commercial producer. These broadly fall into three main categories: bowl drinkers, bite drinkers and nose drinkers. These are described in the next section.

1.4 Drinking utensils

(1) Bite drinkers

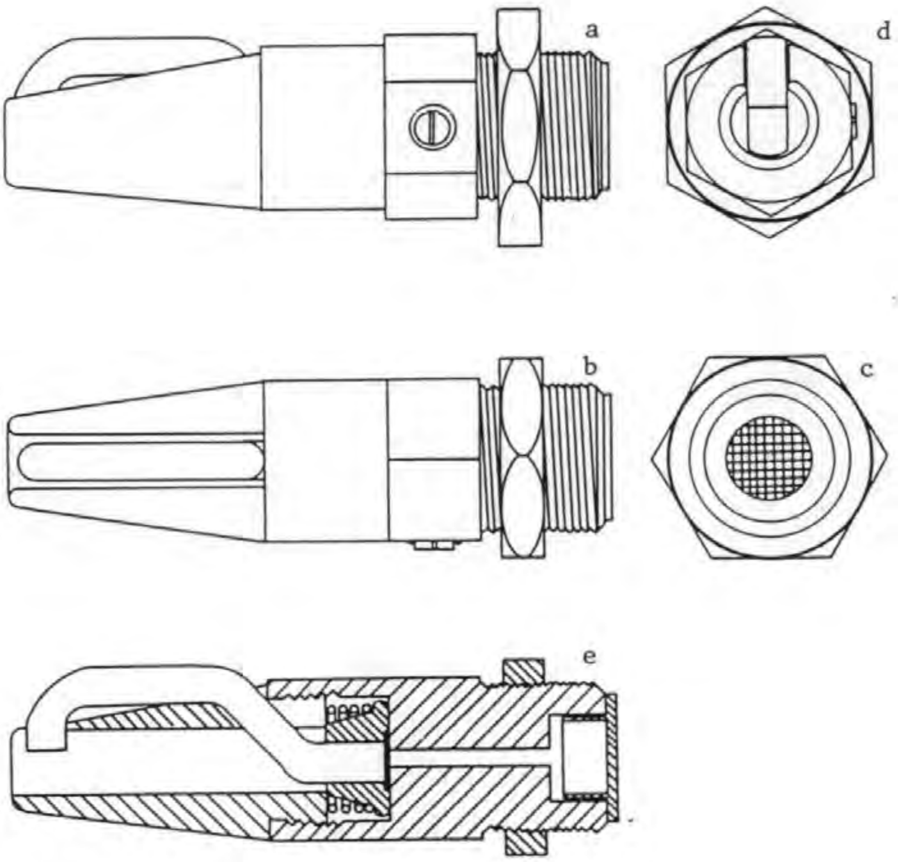
These are so called because the biting action of the pig allows water to flow from the drinker by unseating a spring loaded valve from an 'O' ring washer. The valve assembly is shielded by a strong metal

Figure 1.3 Aratol 80 bite drinker (a) side elevation; (b) top elevation; (c) end elevation; (d) front elevation; (e) cross section (drawn to scale). (Gill, 1989).



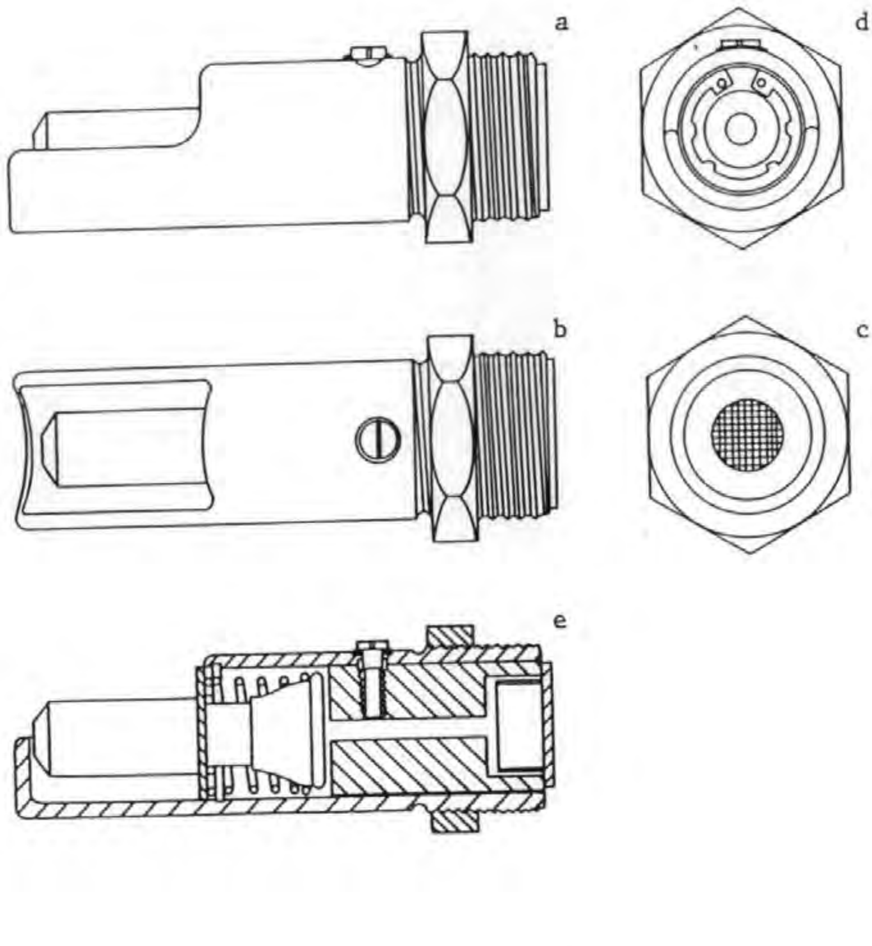
[1]Arato; Weeley Heath, Essex.

Figure 1.4 Lubing[1] type II bite drinker (a) side elevation; (b) top elevation; (c) end elevation; (d) front elevation; (e) cross section (drawn to scale). (Gill, 1989).



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

Figure 1.5 Jalmarson bite drinker (a) side elevation; (b) top elevation; (c) end elevation; (d) front elevation; (e) cross section (drawn to scale). (Gill, 1989).



surround and the whole apparatus is small enough to be completely taken into the mouth. Most bite type drinkers have a filter to protect the valve from abrasive materials such as grit. Many designs have some means of adjusting the water delivery rate, whether this be a screw adjustment or different sized flow restricters. Figures 1.3, 1.4 and 1.5 show detailed diagrams of bite drinkers.

(2) Nose operated drinkers

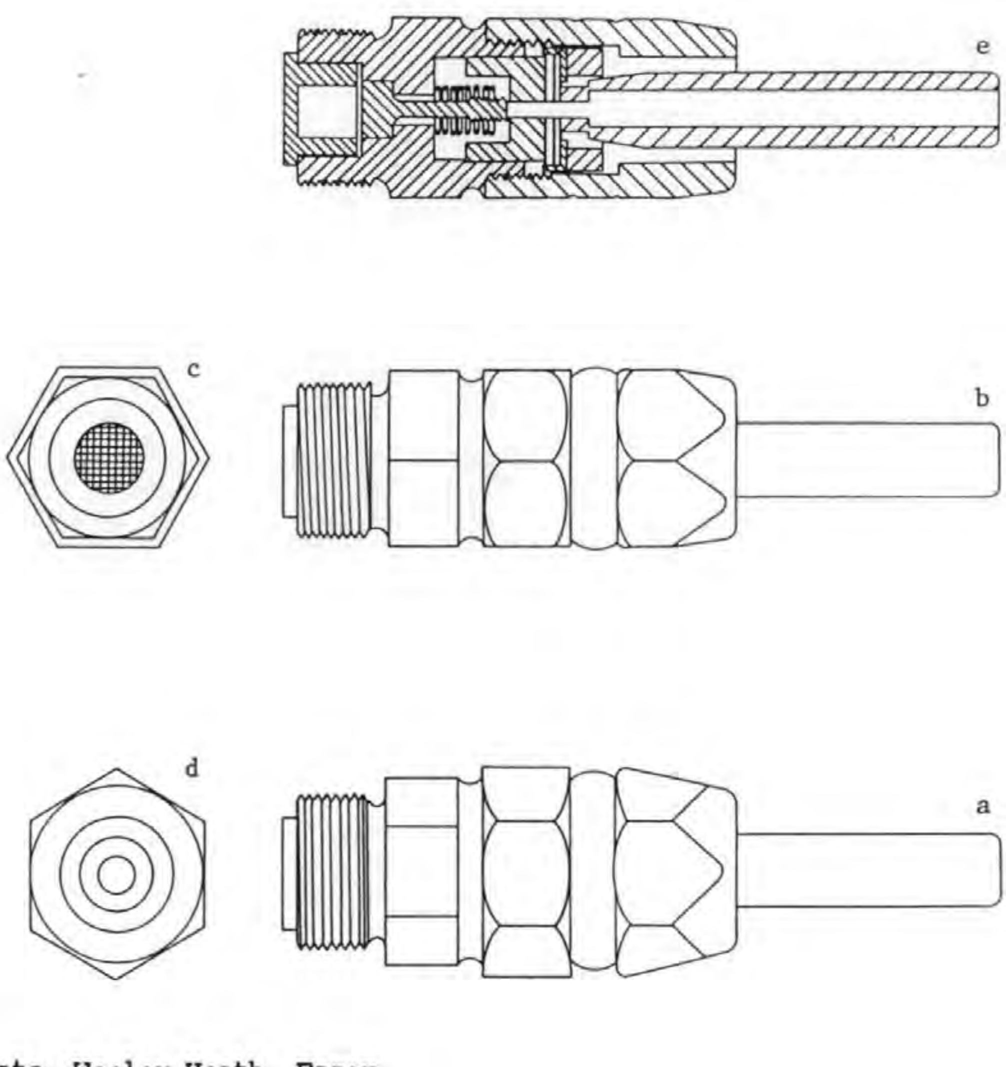
Nose operated drinkers are similar to bite drinkers but do not require a biting action to operate them. Instead these drinkers have a small teat, nipple or tube which requires only a small force to displace a valve and allow water to flow into the pigs mouth. The valve can be of two different types, either a spring loaded valve (similar to that found in bite drinkers) or a stainless steel ball, which is kept closed by the combined forces of gravity and water pressure. These drinkers are only suitable for low pressure systems. Most nose operated drinkers do not have the facility for adjustment of delivery rate. Figures 1.6 and 1.7 detailed diagrams of two types of nose operated drinker.

(3) Bowls

These can be further subdivided into constant level bowls and lever operated bowls.

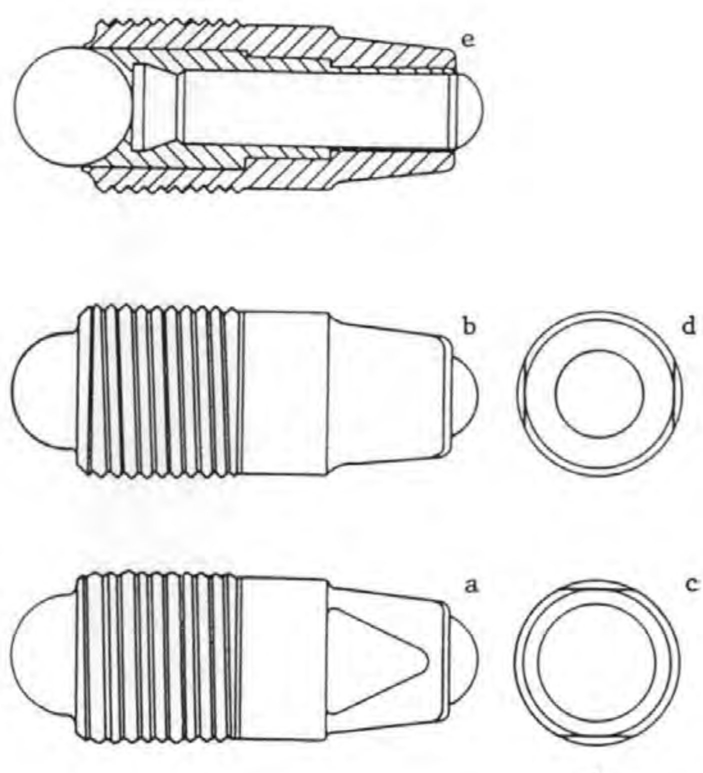
In constant level bowls, the water level is held constant by a float controlled valve to which the animal does not have direct access. They are generally constructed in two parts; a bowl accessible to the animal, and a protected zone in which the delivery nozzle and control valve is situated. The height of the water in the bowl can be altered by simple adjustment of the float position. The refill time will be

Figure 1.6 Aratol 76 nose operated drinker (a) side elevation; (b) top elevation; (c) end elevation; (d) front elevation; (e) cross section (drawn to full scale). (Gill, 1989).



1Arato, Weeley Heath, Essex.

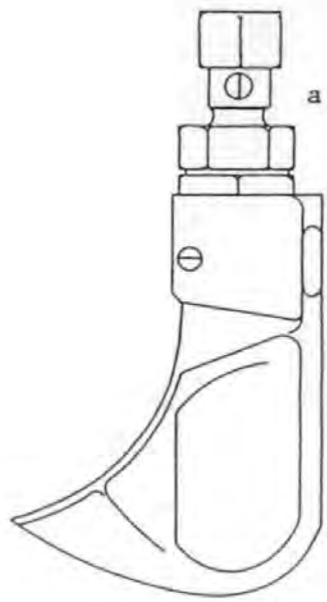
Figure 1.7 Mono-flo1 nose operated drinker (a) side elevation; (b) top elevation; (c) end elevation; (d) front elevation; (e) cross section (drawn to full scale). (Gill, 1989).



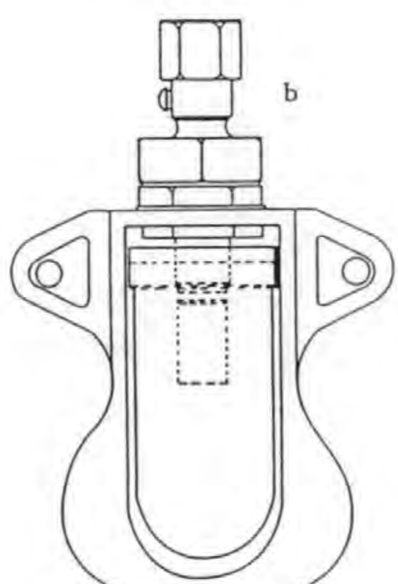
1Mono-flo Lister; Halifax, Yorkshire.

Figure 1.8 Alvinl piglet bowl drinker.
(a) side elevation;
(b) front elevation;
(c) cross section of bowl
(d) cross section of valve
(a,b,c 0.5 x full scale;
d full scale)

(Gill, 1989)



a



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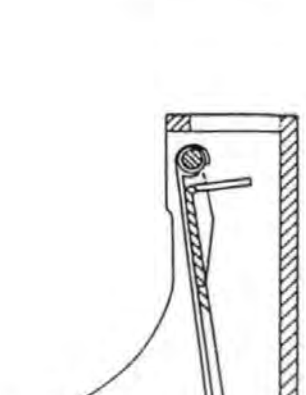

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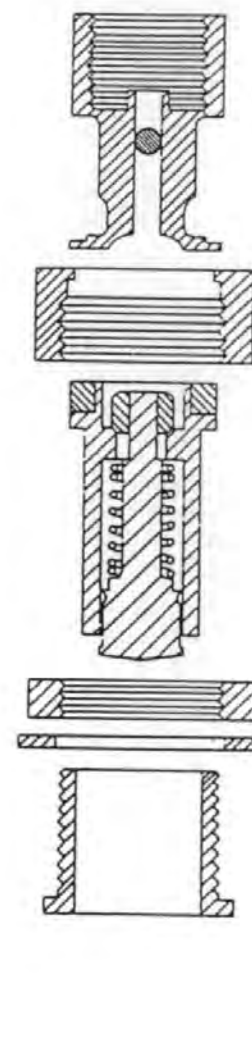


d

[1]Fisher Foundries Ltd.; Birmingham.

dependent upon delivery rate through the valve which may or may not be adjustable.

With lever operated bowls the valve allowing water to flow into the bowl is actuated by the pig's nose. The water can only flow when the lever is being pressed. The aim is to ensure a continuous replenishment of water in the basin during each drinking action. Figure 1.8 shows in detail a lever operated bowl drinker.

In many bowls of this type the flow of water into the bowl can be regulated by a flow adjustment screw. Bowl characteristics such as shape, volume and correct adjustment of delivery rate are important, in order to minimise wastage and to keep the water as clean as possible.

1.5 The pattern of water demand

The periodicity of water use is an important design parameter for any pipe network supply. It is necessary to predict times of peak demand in order to be able to supply the required amount of water. It is also important to examine the effects of the periods of peak demand on the water supply system as a whole. Albar et al.,(1985), showed that for ration fed bacon pigs, fattening pigs and lactating sows, the peak water demand occurred immediately after feeds. For sows the peaks in demand were 20 % of the total of the total daily water consumption, that is 40 % being consumed in the two hours after the two feeding events. For bacon pigs and fattening pigs, the peaks in demand were 13 % and 15 % respectively.

Similarly, Hepherd, Hanley, Armsby and Hartley, (1983) in an experiment measuring the water use of two herds of bacon pigs showed that water demand rose sharply after the first feed and increased to a maximum just after the second feed. Little water was consumed between midnight and 0700 hours.

Houpt, Weixler and Troy, (1985) showed that pigs consume a large proportion of their requirement periprandially. Rushen, (1984) showed that the frequency of drinking was highest after feeding for tethered sows.

There is a paucity of literature concerning the pattern of water use of pigs, however that reviewed here suggests that large peaks in demand for water do occur during the day.

CHAPTER 2. THE REQUIREMENT FOR WATER

2.1 Introduction

Water is one of the most important of all nutrients and is often neglected when the nutrition of pigs is being considered. The reasons for this seem to be two-fold. Firstly, until recently water has not been considered an economically significant input into pig units. Secondly, nutritionists have proceeded on the assumption that the provision of water was not limited and as a result would not be limiting to pig performance.

Animals can survive without feed for longer periods than they can survive without water. A starving animal may lose nearly all of its fat, half of its body protein and forty percent of its body weight and still live. However if it loses ten percent of its water serious disorders will occur and if it loses twenty percent of its body water it will die, (Maynard, Loosli, Hutz and Warner, 1979).

When faced with the problem of supplying water to pig housing it is imperative to know the drinking water requirements of pigs. This chapter considers the importance and function of water as a major constituent of the animal's body. Water metabolism is briefly discussed and two models describing the theoretical drinking water requirement of pigs are compared. The physiology of thirst and the motivational mechanism of drinking are then discussed. Finally the chapter is concluded by listing the causes and practical problems normally associated with water deprivation.

2.2 The importance of water for bodily function

Water fulfils the following important functions in all animals:

1. It affords a medium for the transportation of various substances such as cell nutrients and cell waste products. For example potassium which is an essential dietary component is carried to the cell dissolved in water, crosses the cell wall and is again within a fluid medium.
2. It is necessary to the life and shape of every cell and is a constituent of every body fluid.
3. It is necessary for many of the chemical reactions of digestion and metabolism.
4. It plays a major role in temperature regulation in the body cooling the animal by evaporation from the skin and upper respiratory tract (insensible heat loss).
5. It aids gaseous exchange in respiration by keeping the lung alveoli moist.
6. As a constituent of the synovial fluid, it lubricates the joints; in the cerebrospinal fluid, it acts as a water cushion for the nervous system; in the perilymph in the ear, it transports sound; and in the eye it is concerned with sight and provides a lubricant for the eye.
7. Due to the high specific heat capacity of water, large changes in heat production can take place within the animal with very little alteration in body temperature.
8. It acts as a solvent for a number of chemicals which can be detected by taste buds.

The above functional requirements may be additive and also additional to the requirements of production. The functions listed above may have a higher priority than production, and therefore when the animal is in a situation in which water supply is inadequate, production functions will suffer in favour of the above life functions. Consequently there will be a reduction in animal performance.

2.3 The water content of the body

This topic has been extensively reviewed by Gill, (1989). His major conclusions are summarised below.

The empty body weight of pigs is fifty percent water, (Maynard et al., 1979) and the proportion of water decreases with increasing weight and age, Shields, Mahan and Graham, (1983). The variation of water body content is largely attributable to the variation in body fat content, Whittemore, Tullis and Emmans, (1988). Gill,(1989) explains that there is a negative relationship between body fat and water content described by an equation produced by Whittemore et al., (1988):-

Percent body fat = 84- 1.29 Percent body water ($p < 0.001$).

This can be explained by the fact that lean and lipid tissue on average contains 75-80 % and 9-12 % water by weight respectively (Whittemore and Elsley, 1979).
An increase in absolute body fat content is related to a decrease in absolute body water content, (Shields et al., 1983). Thus as an animal matures, it requires proportionately less water on a weight basis because it consumes less feed per kg liveweight and the water content of the body is being replaced by fat. This accounts for the fact that

gains in older animals are more costly than those in younger animals. The 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.

The stomach and digestive tract may contain a considerable volume of water. An adult pig of 190 kg liveweight can have a total digestive capacity of about 27 litres (Maynard, Loosli, Hintz and Warner, 1979). The amount of water in the digesta can be variable and may be included in measurements of total body water content.

2.4 Compartmentalisation of body fluid

The water content of the body is organized into two main compartments: that inside the cells, referred to as intracellular fluid and that outside the cells described as extracellular fluid. The extracellular fluid is further divided into the vasculature (blood plasma) and that between the cells (interstitial). Two thirds of the body fluid is intracellular. Most of the extracellular water is outside the vascular compartment in the interstitial compartment. Blood capillaries do not make direct contact with the cells however the interstitial fluid forms the link between them, (Toates, 1979).

Ultimately the amount of water which needs to be imbibed to maintain the homeostatic balance depends on the movement of water between the various compartments. The fluid in the two main compartments differs in that most of the sodium and chloride ions are in the extracellular compartment while most of the potassium ions are intracellular. These differences are due to the properties of the cell membrane and capillary walls. The capillary walls are the barrier between the plasma and the interstitial fluid and allow movement of all components of the plasma except the proteins. The cell membrane dividing the intercellular and extracellular components is impermeable to proteins and actively functions to maintain the differences in concentration of sodium and potassium ions across the membrane. The movement of water between the fluid compartments and the consequential development of thirst is controlled by osmosis. A full account of the process of osmosis is given by Vander, Sherman and Luciano, (1975).

2.5 Water metabolism: Obligatory losses and gains.

Originally life started in the saline environment of the sea where the simplest progression for animals was to evolve with an internal composition of similar composition to the salt water in which they lived. When early animals moved from the sea to the land they retained a sea like internal composition and therefore were faced with the problems of conserving and obtaining water, (Toates, 1979). This section is concerned with the mechanisms by which water is lost and gained from a relatively advanced creature- the pig.

Total body water content is a function of water intake, water metabolism and water loss. There are two primary sources of water available to pigs kept under normal systems of housing, feeding and management. These are drinking water and water contained in feed, (A.R.C. 1981). There is a third source of water gain, metabolic water. This is water formed as a by product of the oxidative catabolism of dietary carbohydrate, fat, protein, and the metabolism of body tissues, (A.R.C. 1981). The four main avenues of water loss are: in the faeces and urine, and by evaporation from the skin and the upper respiratory tract during exhalation. Additionally the pig uses water for growth and in the case of reproducing animals for the products of conception and for milk production, (Brooks and Carpenter, 1990).

In order to maintain a homeostatic balance water lost must be equal to water gained. When there is an imbalance in body water, (water loss exceeds water intake), drinking normally occurs to rectify the situation. Chew (1965), states that when water is present *ad libitum*, considerable water is probably used only to bring about moment-to-moment optimum balances in the body. On a restricted water intake, water balance is still maintained on a long-term basis, but probably not adequately from moment to moment'. The physiology of thirst and the motivational mechanism of drinking are described later in sections 2.6 and 2.7.

2.5.1 The theoretical requirement for drinking water

Gill,(1989) and Brooks *et al.*,(1990) have both extensively reviewed various published values and their derivations for the obligatory water inputs and losses in pigs. Both authors have produced factorial models quantifying the amounts of each of the water losses and gains for a 60 kg liveweight pig, allowing the amount of daily drinking water required to maintain body water balance to be calculated theoretically. The models of Gill, (1989) and Brooks *et al.*,(1990) are presented in Tables 2.1 and 2.2 respectively.

Table 2.1 Example of the water balance of a 60 kg liveweight pig fed a compounded diet and gaining 700g/day in a thermoneutral environment.

(from Gill, 1989).

Water used /lost	(ml)	Water consumed /formed	(ml)
Growth[1]	480	Food water[5]	380
Respiration[2]	580	Food oxidation[6]	450
Skin[3]	420		
Faeces[4]	970		
Urine[8]	290-1710	Water consumed[7]	1910-3330
Total	2740-4160	Total	2740-4160

Assumptions:

(1) Growth (700g/d) assumed to be 50% water, estimated from sequential slaughter data (Shields *et al.*,1983).

(2) Respiration loss assumed to be 0.58 l/day (Holmes & Mount, 1967).

(3) Insensible moisture loss from skin assumes 13.4 g/m2 per hour at thermoneutral temperature and 70% RH as obtained by Morison et al., (1967). Surface area = 0.10W0.63, (Brody, 1964).

(4) *Ad Libitum* fed pig of 60 kg liveweight assumed to eat 2.72 kg food (1.85 kg DM), (A.R.C., 1981). DM digestibility assumed to be 82% and faecal DM 30%, (Whittemore and Elsley, 1979).

(5) Compound diet assumed to be 14% moisture.

(6) Metabolic water produced is 7.43 ml/kg W per day, (Gill, 1989).

(7) Water intake derived by difference.

(8) Assuming that urine is 95% water, (Cushny, 1926), a pig is expected to have a renal water loss of between 4.75 and 28.5 ml/Kg W per day, (Dukes, 1984).

Table 2.2 Example of the water balance of a 60 kg liveweight pig fed a compounded diet and gaining 700g/day in a thermoneutral environment.

(from Brooks and Carpenter, 1990).

Water used /lost	(ml)	(%)	Water consumed /formed	(ml)	(%)
Growth[1]	469	(8.2)	Food water[5]	380	(6.6)
Respiration[2]	580	(10.1)	Food oxidation[6]	1015	(17.7)
Skin[3]	420	(7.3)			
Faeces[4]	908	(12.9)			
Urine[8]	3370	(61.5)	Water consumed[7]	4352	(75.7)
Total	5747		Total	5747	

Assumptions:

(1) Growth (700g/d) assumed to be 67% water. (Whittemore and Elsley, 1979).

(2) Respiration loss assumed to be 0.58 l/day (Holmes & Mount, 1967).

(3) Insensible moisture loss from skin assumes 13.4 g/m2 per hour at thermoneutral temperature and 70% RH as obtained by Morison et al., (1967). Surface area = 0.10W0.63, (Brody, 1964).

(4) Ad Libitum fed pig of 60 kg liveweight assumed to eat 2.72 kg food (2.23 kg DM), (A.R.C., 1981). DM digestibility assumed to be 82% and faecal DM 35%, (Kornegay and Vander Noot, 1968).

(5) Compound diet assumed to be 14% moisture.

(6) The diet is assumed to contain per 1000 g fresh weight, fat 70 g, carbohydrate 590 g and protein 180 g. The protein is assumed to have a biological value of 70 therefore 54 g of the protein would not be used in protein growth and would be deaminated. Therefore the yield of metabolic water per kg feed would be:

	g/kg	water yield/g	Total
Fat	70	1.10	77
Carbohydrate	590	0.60	354
Protein	54	0.44	24
			455

(7) Water intake assumed to be 1.6 kg per kg feed which was the lowest ratio recorded by Yang et al.,(1981) for pigs fed ad *libitum*.

(8) Urine volume derived by difference.

From Gill's model, (1989), it can be seen that the theoretical water intake of a 60 kg liveweight pig under the conditions described lies between 1.91 and 3.33 litres per day. In contrast, the theoretical value of water intake from the model of Brooks et al.,(1990) is 4.35 litres per day.

The single value from Brooks et al.,(1990), is 30 % greater than the range offered by Gill, (1989). The main differences between the two models which account for the differences in theoretical water requirement are:

(1) The amount of water produced from the oxidation of food.

(2) The method used to calculate water lost through the voiding of urine and water gained through drinking.

Gill calculated that 0.45 litres water was formed from the oxidation of 2.72 kg of air dried food, whereas Brooks et al., calculate 1.01 litres to be produced. A.R.C., (1981) state that 400 g of water are formed per kg of feed which would yield 1.08 litres of water. According to Yang, Price and Aherne (1984), every kg of air dried feed eaten will contribute between 0.28 and 0,48 litres of metabolic water. Therefore 2.72 kg will yield between 1.03 and 1.3 litres of water. It appears that Gill's value disagrees with the values from the other three sources. However Brooks et al., indicates, simple calculations based on the apparent composition of a diet may considerably over estimate the yield of metabolic water due to the following three reasons:

(1) The digestibility of individual diet components needs to be taken into account.

(2) All fat digested is unlikely to be oxidised for energy.

(3) A large proportion of the protein absorbed will be utilised in protein metabolism and not oxidised.

Lloyd, McDonald and Crampton, (1978), pointed out that although oxidation yields metabolic water, this process actually results in a net demand for water as the water required for dissipation of the heat produced and the water required to excrete the end products of the process may exceed that yielded by the reaction.

The greatest discrepancy between the two models in the calculation of the theoretical requirement of water occurs in the method used to calculate water lost through urine and gained by drinking. Brooks et al.,(1990) calculate water intake from a minimum water to feed ratio measured by Yang *et al.*,(1981), enabling urine production to be calculated by difference. Gill (1989) however, assuming that water intake is unknown uses the range of urine production of the pig, cited by Dukes, (1984) and calculates the additional water to balance the model by difference. The water intake value from the model of Brooks et al., (1990) is based on a water to feed ratio of 1.6 to 1. The water to feed ratio calculated from Gill's model lies between 0.79 and 1.50 to 1. These values are in agreement with the findings of Barber, Braude and Mitchell, (1963), Holmes and Robinson, (1965), Bowland (1965) and Cunningham and Friend, (1966), who showed that restricting the water to feed intake ratio of growing pigs as low as 1.5 : 1 had little adverse affect on growth and performance.

The water to feed ratio of 1.6 to 1 used by Brooks *et al.*,(1990) to calculate water intake was a minimum measured by Yang, Howard and McFarland, (1981) for pigs of no more than 30 kg.

Estimates of water requirement using factorial methods such as these represents the minimum daily intake required to maintain homeostasis. Brooks *et al.*,(1990) state 'that the relative contribution of the different inputs and losses is extremely variable. The interactions between them produced by differences in health status, nutrition and environment are considerable and complex. Consequently factorial estimation of water requirement is neither a reliable nor practical proposition.'

2.6 The physiology of thirst and the internal control of body water balance

The kidney:

The kidney is responsible for the formation of urine from the blood and therefore maintains the blood volume and composition. In addition the kidney is an endocrine gland producing the hormone renin which plays an important role in the maintenance of body fluid, (Cook 1971). A complete description of the anatomy and functioning of the kidney is give by Frandson (1986).

The control of blood volume and composition is hormonal. Cellular dehydration and decrease in plasma volume result in the releases into the blood stream of antidiuretic hormone (ADH) from the posterior lobe of the hypothalamus. ADH increases the permeability of the kidney collecting ducts, which increases the absorption of water and thereby forming a more concentrated urine (hypertonic). The absence of ADH results in the production of a hypotonic urine and the net loss of water from the body. ADH forms a feedback loop controlling fluid balance (see Figure 2.1), but has no direct affect on fluid intake,

Figure 2.1 The release of antidiuretic hormone, (Rolls and Rolls, 1982).

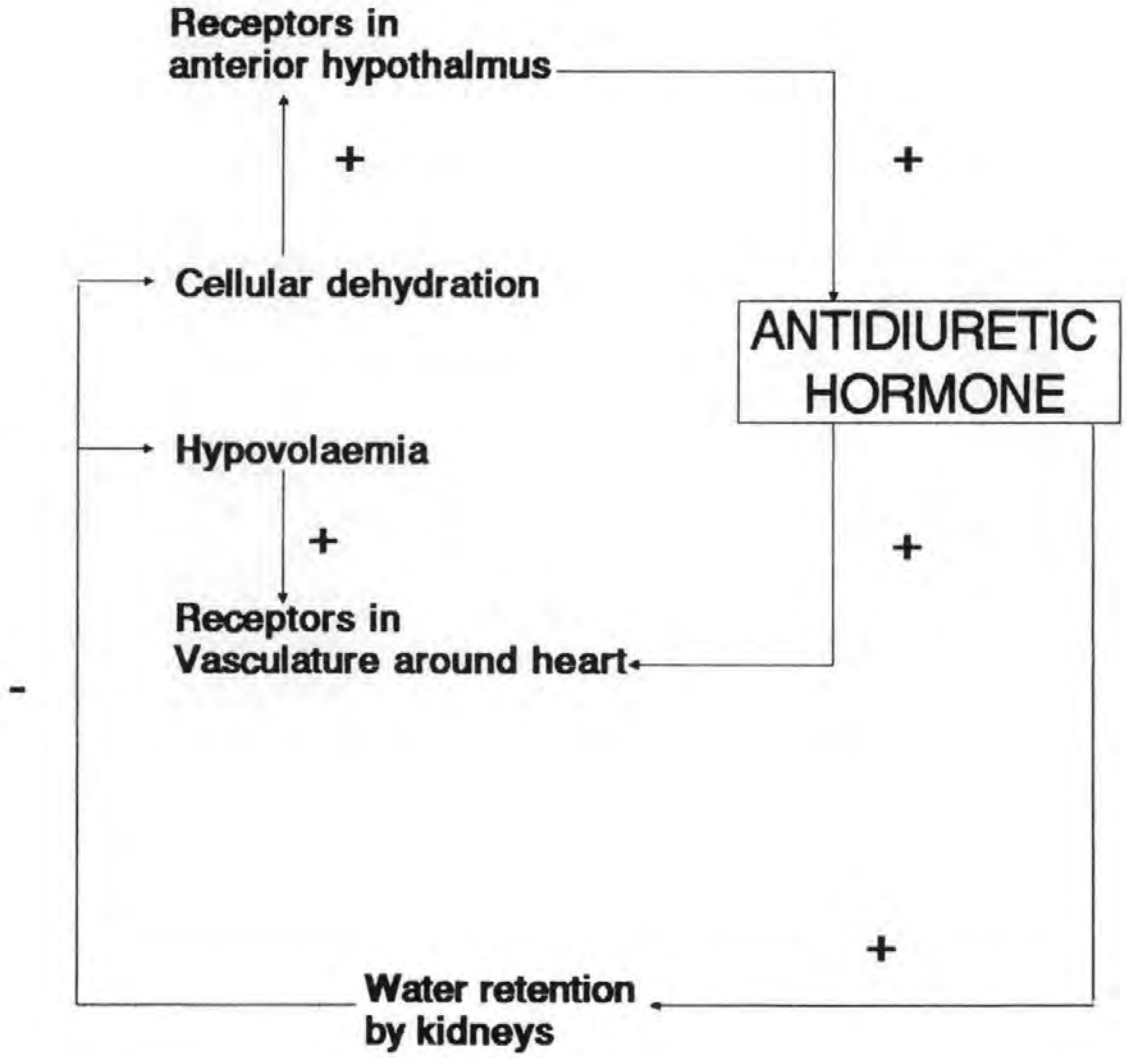
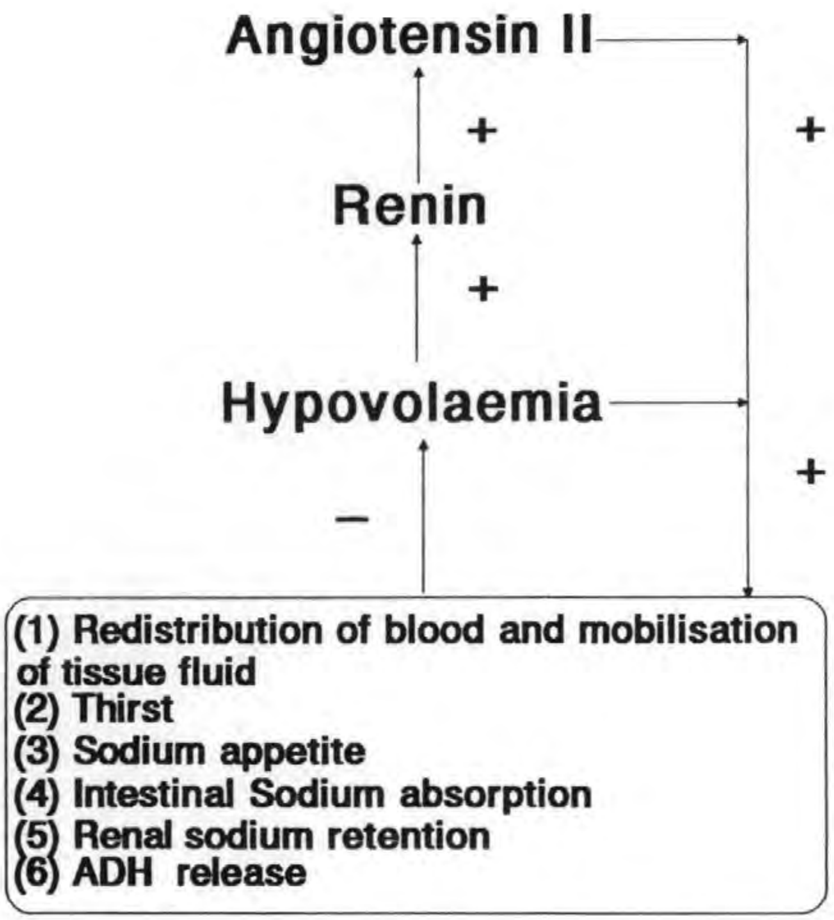


Figure 2.2 Blood volume regulation by angiotensin II, (Fitzsimons, 1976).



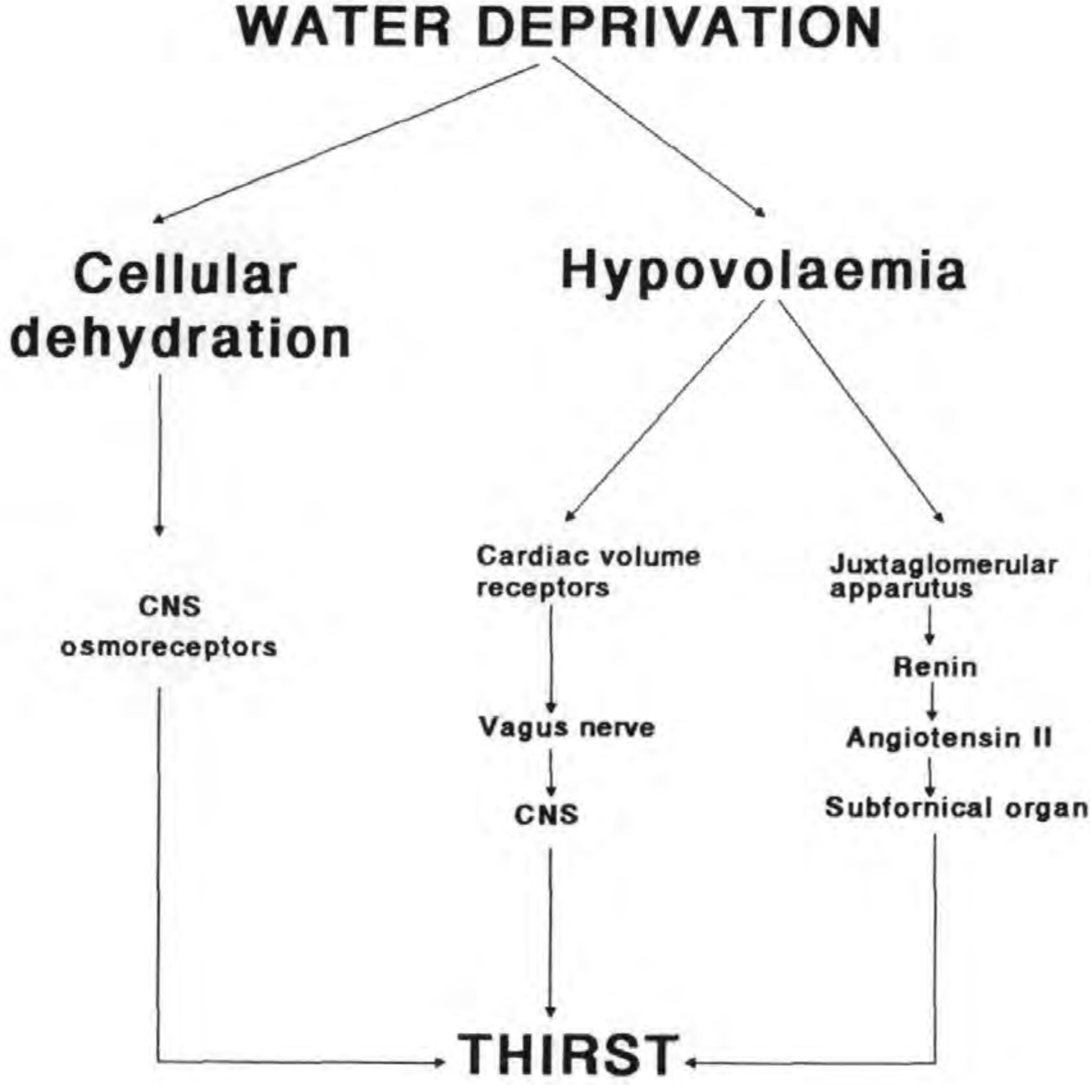
(Rolls 1971). It does however have an indirect affect on fluid intake through its influence on urinary water loss. The hormone renin is produced from the juxtaglomerular cells and is secreted when water or sodium need to be conserved. A reduction in blood volume results in a reduction in the pressure at the juxtaglomerular cells and a consequent release in renin. A fall in sodium level is sensed by the macula densa also resulting in the release of renin. Renin acts on a substance in the plasma called angiotensin I which in turn is converted into angiotensin II. The actions of angiotensin II are shown in Figure 2.2. The release of renin is controlled by a negative feed back mechanism, that is the increase in circulating angiotensin II arrests further release of renin. Angiotensin II stimulates both thirst and sodium appetite, (Rolls and Rolls, 1982)
In summary the kidney functions to maintain the volume and composition of the intracellular and extracellular compartments. Depletions of both compartments initiate mechanisms to conserve fluid.

Thirst:

Early reports concerning thirst attributed it to local dryness in the mouth, 'The dry mouth theory', (Haller 1764, cited in Rolls *et al.*, 1982). However later experiments suggested that thirst must also be due to more general fluid changes, (Wolf, 1958; Grossman,1967). Figure 2.3 summarises the factors which are presently thought to cause thirst following dehydration. Detailed reviews of the theory of thirst are given by Rolls *et al.*,(1982); Epstein, Fitzsimons and Simons, (1969); and Fitzsimons,(1969).

The renin-angiotensin system is thought to be the most important

Figure 2.3 A summary of the factors which may contribute to the initiation of drinking following water deprivation, (Rolls and Rolls, 1981)



internal mechanism in the control of thirst. Angiotensin II initiates drinking through its site of action in the subfornical organ. Fitzsimons and Simons, (1969), stimulated copious drinking in rats by intravenous infusions of angiotensin II. Epstein, Fitzsimons and Rolls (1970), found that direct application of angiotensin II to the brain caused rats in normal water balance to drink water in large amounts. The effect of angiotensin II is very specific, that is, drinking is the only response caused by its application,(Epstein *et al.*,1970; McFarland and Rolls 1972; Rolls and Rolls 1973). In pigs Baldwin and Thornton (1986) showed that the drinking response produced by intracerebroventricular injections of angiotensin II was increased in the presence of sodium ions.

The primary internal receptors for osmoregulation are located in the lateral preoptic area of the brain. These receptors are excited by increased osmolarity resulting from extracellular dehydration through water loss. Extracellular dehydration can be induced by intravenous injections of sodium chloride solution. Ingram and Stephens (1979), found that after such injections in pigs, drinking occurred in direct proportion to the concentration of the sodium chloride solution. In the same experiment Ingram *et al.*,(1979) were unable to initiate drinking having imposed mild hypovolaemia by removing 500 cm3 of blood from the main vein which would suggest that day to day variations in blood volume play only a very small part in the activation of the renin-angiotensin thirst response.

2.7 Thirst and the motivational mechanism of drinking

From the above it could be concluded that a drink may occur each time the body-fluid level falls below a threshold value. Figure 2.4 shows an early model of threshold level drinking of the laboratory rat put forward by Toates and Oatley (1970). A neural signal (negative) proportional to extracellular deficit is added to a neural signal proportional to cellular deficit (also negative). Inhibitory effects are due to positive signals from water in the mouth and water in the stomach. If the excitatory signals are significantly greater than the inhibitory signals then drinking occurs. A fluid imbalance above the threshold is necessary to evoke a drinking response. Without the concept of a threshold level the animal would be required to continually drink an infinite number of small quantities to maintain a constant body water level.

From the behaviour of the laboratory rat Toates et al., (1970), suggested that the threshold had characteristics of hysteresis, see Figure 2.5 .The drinking signal must reach a minimum value of T in this example and the action of drinking then continues until the drinking signal is equal to zero. At a drinking signal of zero the body fluids are assumed to be in balance. A signal of the value T causes the animal to seek water.

In a later modified theory Toates (1979), challenges the idea of a fixed set point and threshold appropriate to all environments and the theory that drinks only occur in response to shifts in body fluid content is also questioned. Toates (1979) also queries the validity of applying models that have been developed for laboratory animals to

Figure 2.4 The theory of Threshold Drinking, (Toates and Oatley, 1970)

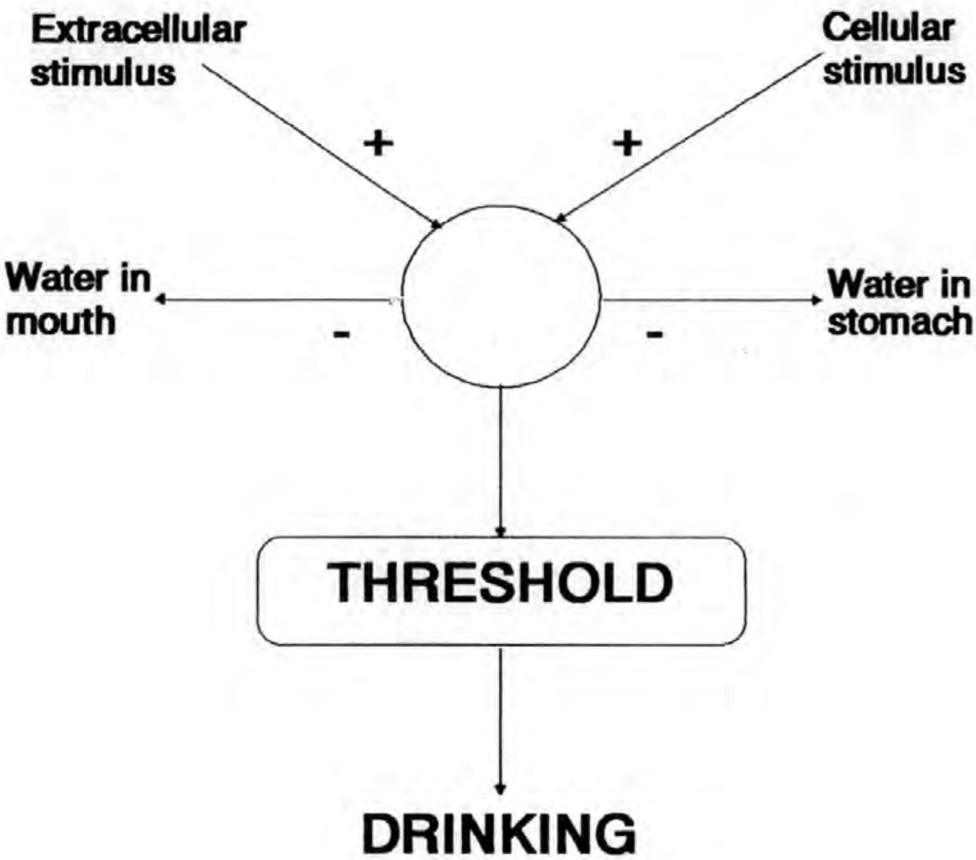
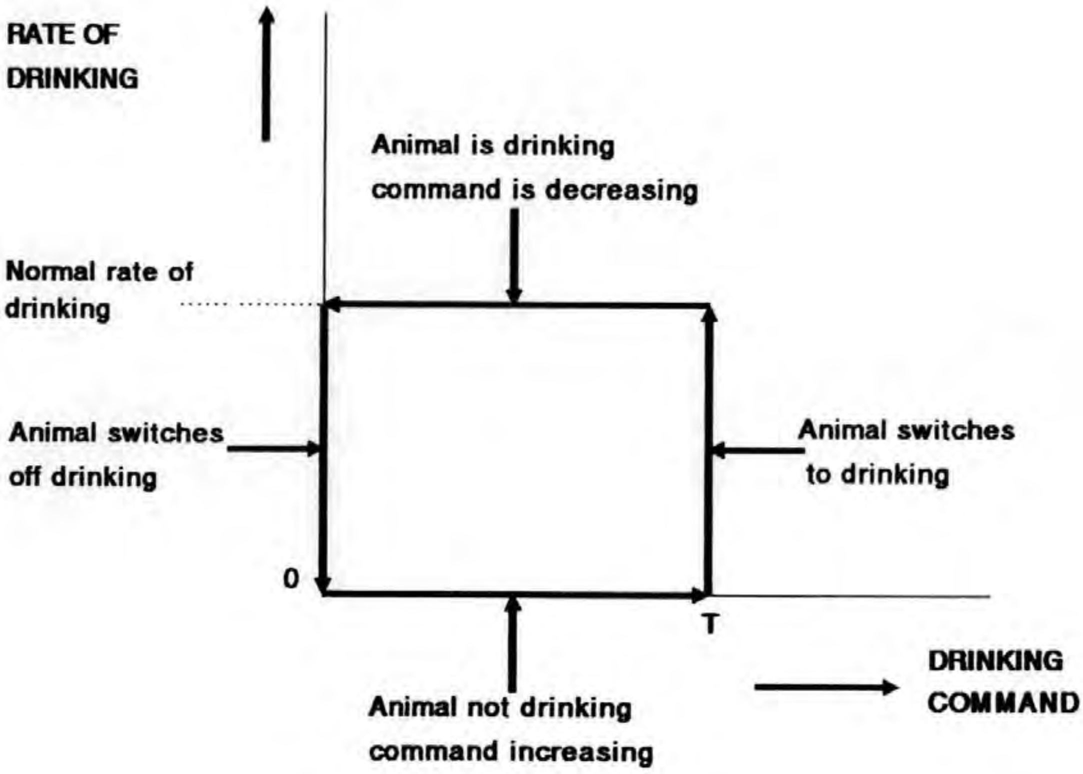


Figure 2.5 Hysteresis in the control of drinking, (Toates and Oatley, 1980).



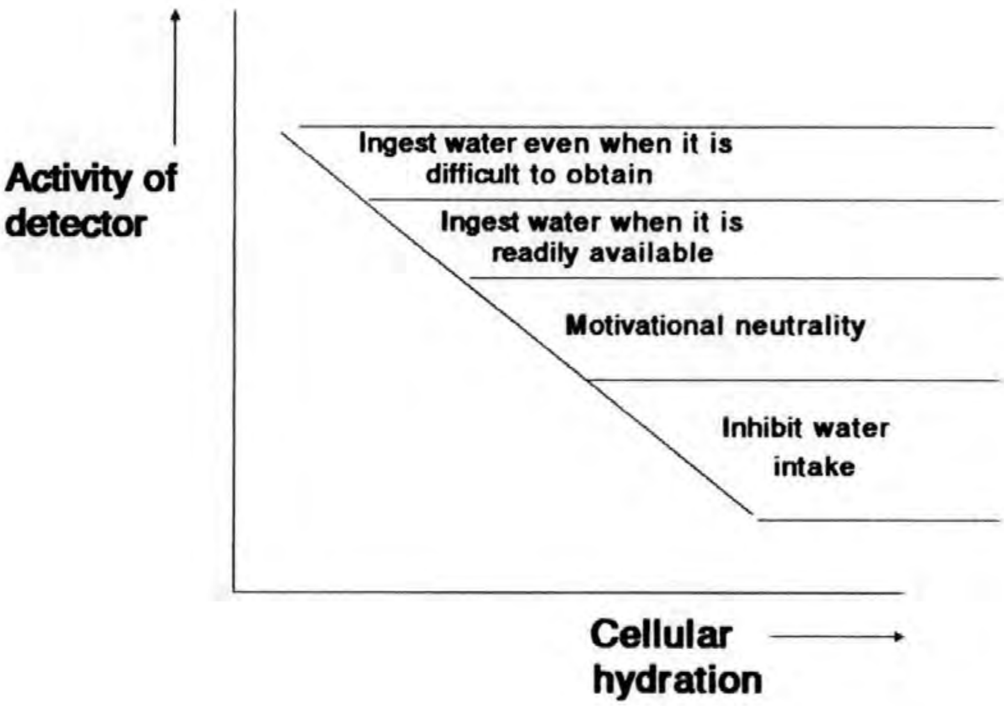
undomesticated animals where the environment may be somewhat different. It is suggested that a free ranging animal at a distance from a water supply may allow its body fluid level to fall below that regarded to be optimum when water is not so readily available. This may occur in the practical farm situation when there is competition for access to the drinkers. The theory is based on the fact that fluid ingestion is determined by at least two sets of causal factors; one set arising from the animal's internal regulation of its body fluid, and a second from the animals perception of water available in the environment. Figure 2.6 shows a simplified version of the proposed model.

In his commentary, Toates stresses the importance of the role of learning in the drinking process because although there are neural signals which elicit drinking, the animal will not drink unless it has some prior knowledge of where or how to look for water. This happens for instance, in the situation when weaned piglets are expected by farmers to know that drinkers are provided for them to restore their water balance. Toates' model also takes into account the relative availability of the water; thus if the water is difficult to obtain although still available, reduction in ingestion results in the body water level remaining below what is considered to be normal.

2.8 Causes and practical problems associated with water deprivation

The causes of water deprivation can be placed into two categories:
(a) those systems or production practices which by design impose limitations on how much water the pig may drink and when it may drink

Figure 2.6 A tentative model showing the conditions under which an animal would ingest water, (Toates, 1979).



it.

(b) those situations in which there appears to be an unrestricted water provision but where physical, environmental or behavioural factors render the supply inadequate, Brooks et al.,(1990).

Intentional restriction of water availability:

(1) Using a water to feed ratio for liquid fed pigs which is too low and where the liquid fraction of the feed is the only supply of water available to the animals.

(2) Deliberate rationing of water supplies by producers through the use of time controlled water valves on the supply lines.

(3) The traditional practice of not allowing sows a water supply at weaning to reduce milk production and consequently to reduce the incidence of mastitis.

(4) The failure to provide suckling piglets with a water supply in addition to the dam's milk. Milk, a product which is itself almost 90 % water, actually creates a water deficit because it is a high protein, high mineral material.

Unintentional restriction of the water supply:

(5) Incorrect delivery rates due to incorrect type of drinker fitted in relation to the supply pressure.

(6) Badly adjusted drinkers where adjustment is provided by the manufacturer.

(7) Reduced delivery rates due to dirt accumulating in the supply lines and blocking filters, nozzles and other important pipe fittings.

(8) Malfunctioning of dispensers.

(9) Overstretched rural water supplies unable to cope with large numbers of pigs requiring water at the same time.

(10) Insufficient number of dispensers to supply the animals in a pen, at times of peak demand.

(11) Poor positioning, causing greater competition for access.

(12) Water refusal due to dispenser contamination with faeces or feed residues.

(13) Dispenser types which require long periods of adaptation for easy utilization by the animals.

(14) Poor quality/flavour of water, inhibiting consumption.

2.8.1 Salt poisoning

Salt poisoning is a misnomer as it implies that the animal is suffering the effects of poisoning as a result of being fed excessive amounts of salt. Salt poisoning is commonly the result of water deprivation and is more correctly termed sodium ion toxicosis. Clinical and subclinical salt poisoning may be more common than generally appreciated, subclinical salt poisoning often going unnoticed, (Osweiler, Carson, Van Gelder and Buck, 1984). Water is needed to excrete sodium and other mineral ions form the blood. High dietary mineral levels can be tolerated by the pig providing it has adequate water available to detoxify itself. When water is not in adequate supply these minerals can build up to a toxic level as in sodium ion toxicosis. Growing/finishing pigs fed on a liquid feed system are at particular risk to sodium ion toxicosis if no additional source of water is available. Many materials used to replace water in liquid feeding systems such as whey, skim and silage effluent are of high mineral content. In order to excrete the higher levels of minerals a separate supply of water is needed.

Marks and Carr (1989) report a case of sodium ion toxicosis in a group of 30 day old pigs which had been deprived of water for four days. Ten percent of the weaners were recumbent and exhibited intermittent convulsions. Of the remainder many showed behavioural abnormalities. When treating animals suffering from sodium ion toxicosis, a restrictive reintroduction of the water supply is necessary as water intoxication can occur. Slow rehydration is preferred as rapid rehydration can exacerbate cerebral oedema, (Buck, 1981).

Death through water starvation must be regarded as the ultimate insult to the animal's welfare. Death occurs in the advanced stages of sodium ion toxicosis. Minor degrees of salt poisoning may result in a decreased performance. Pigs will generally consume sufficient water to keep themselves alive. However the pig cannot be relied upon to consume enough water to maximise biological performance.

2.8.2 Renal and urinary tract disease

In piglets the renal function is in a high state of activity due to the rapid growth rate and resulting high level of biochemical reactions. Thus, a high level of water turnover is necessary in order to eliminate the waste nitrogenous products of the growth process. High concentrations of nitrogenous material result in a higher incidence of nephritis (Albar et *al.*, 1985).

Intensively housed sows have a tendency to develop urinary problems.

This may be due to their unnatural confinement by tethers and in crates causing then to be reluctant to stand up and urinate. Boars and sows kept out doors are active and pass urine more often than restrained sows, (Smith 1983). Confined sows can void faeces whilst lying down but in order to urinate they need to adopt a proper stance. Cunningham and Friend, (1966).

Reluctance to urinate causes a change in the concentration and pH of the urine. In addition the sphincter valve linking the bladder to the urethra weakens. Both these changes allow bacteria to enter the bladder which multiply and reside in all sections of the urinary tract, (Smith 1983).

The kidneys of sows are relatively inefficient (Albar *et al.* 1985), and therefore in order to eliminate waste products the must drink a large quantity of water. A recent survey by the school of veterinary medicine at Liverpool University showed that 60-80% of sow deaths were caused by kidney trouble out of a total mortality level of 6-8% in the breeding herds studied, (Carr, 1989).

Cystitis is another common complaint in sows which is possibly caused by lack of water (Smith, 1983). Jones (1968), examined 81 dead sows and found that cystitis was responsible for 15% of the mortalities. Madec, Gillet and Irgens (1982), found uro-genital lesions in 43% of animals examined and reported that lesions were more numerous when sows were kept in restraining systems. Madec (1985), noted that pregnant sows from farms with a history of chronic urinary disease, and subject to a severe water restriction (down from 16-18 litres to 6-8 litres per day), produce an increased urine density along with bladder stones.

2.8.3 Reduced performance

A poor water supply to lactating sows is a major predisposing factor of agalactia and consequent nutritional deficiencies and health problems for the suckling piglets. Garner and Sanders (1937) questioned whether some cases of milk shortage were due to inadequate water intake.

For fattening pigs a poor water supply predisposes the pigs to reduced performance and deterioration in carcass quality. Cunningham *et al.* (1966), showed that restricting the water to feed ratio to 1.25:1 resulted in a significant decrease in gain and a diminished protein percentage of the carcass. The decreased protein percentage was made up for by an increase in fat content, see Table 2.3. In an experiment investigating the effects of four different water feed ratios, Gill, (1989) showed that a decrease in total water use resulted in a significant decrease in daily live weight gain.

In conclusion, there is a considerable amount of evidence to support that pigs are significantly affected by water deprivation.

Table 2.3 The effect of insufficient uptake of water

(From Cunningham and Friend, 1966)

Liveweight of pigs	38 kg		90 kg	
Water to feed ratio	3:1	1.25:1	3:1	1.25:1
Mean daily gain (g/pig)	531	516	721	625
Feed conversion ratio	2.75	2.85	3.31	3.83
Body composition				
Proteins (%)	17.1	17.3	16.5	15.3
Lipids (%)	40.3	38.4	32.2	29.2

CHAPTER 3 ESTIMATES OF WATER USE BY PIGS OF DIFFERENT CLASSES

3.1 Introduction

Despite the afore mentioned evidence, there is a shortage of information concerning the water requirement and water utilisation of modern strains of pig under contemporary systems of management. Much of the evidence available describing the water use of pigs has been produced as a 'by-product' of other experiments which were designed to investigate primarily other factors. Work has been published describing the water intake of pigs where water use was actually measured and the accuracy of water metering in some studies is of a dubious nature.

The factorial model put forward by Gill,(1989), suggested a range of values for water requirement. The range was dependent on the balance between the various gains and losses and the factors determining each gain and loss. That is, there can be no fixed requirement for a specific class of pig, it will vary according to the variability of the different losses and gains. Factors affecting the water are discussed in Chapter 4.

In addition to the requirement calculated by subtracting net water lost from net water gained, other needs must be considered. Water may also be required for the satisfaction of behavioral drives and for the achievement of satiety. Thus the classic requirement as calculated above should be regarded as a minimum value, where as the 'normal' can be expected to be greater than this.

"Requirements For Water" in the A.R.C. publication 'The Nutrient Requirements of Farm Livestock: Pigs', (1981), stated that the need for water is determined by the magnitude of the water depletions from the body together with the amounts which are included in milk, in new tissue formed during growth or pregnancy. However, this factorial method for the estimation of water requirement is later ignored in the publication. Instead the authors 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.

The A.R.C.,(1981) listed only 28 references on which it based its recommendations. Of these, only eight reported studies were conducted in the United Kingdom and only one of these was published within the last decade. Consequently changes that have occurred in the breeding, feeding and housing of pigs in recent years may have invalidated the conclusions reached from earlier studies.

In its conclusion the A.R.C., (1981) stated that:-

"From the various reports considered, it is apparent that in conditions of free access to water there are wide variations in individual consumption. Generally it is not possible to decide whether these represent unimportant idiosyncrasies or physiological needs which should be met if possible."

Having acknowledged the wide variations in individual consumption the report then recommends a requirement (excluding lactating sows) of about 2 parts of water by weight for each 1 part of feed. This recommended ratio is widened for recently weaned pigs and narrowed for older animals. A.R.C.(1981), make no allowance for any other requirement additional to the nutritional minimum nor did it make any allowance for potential individual variation.

3.2 Estimates of water use by various classes of pig

This topic has been extensively reviewed by Gill (1989). A summary of his main conclusions together with information from recent published work is presented below.

3.2.1 The suckling piglet

The water requirement of suckling piglets has been given little attention due to the assumption that their water needs are met by the sow's milk up until the fifth week of life, (Albar *et al.*,1985). Therefore the provision of a separate supply of water for suckling pigs has been regarded as little more than an unnecessary expense. Table 3.1 summarises various published estimates of the water use of suckling piglets.

A.R.C.(1981) state that sow's milk has a water:dry matter ratio of about 4.5:1 and that suckling piglets have a mean water intake during lactation of about 700 g/day. In an experiment reported by Barber, Braude and Mitchell, (1964) with suckling pigs which had access to water and creep feed, it was found that very little water was drunk during the first few weeks of life. Their daily water intake during the 3rd, 4th and 5th weeks was about 40, 45 and 75 g respectively and the consumption of creep feed was negligible in this period. For the 6th, 7th and 8th weeks, daily water intake was about 160, 300, and 480 g respectively with the water to feed ratio about 1:1. It was concluded that the water utilisation for creep feed may be no greater than that provided in the sow's milk. However, it was also noted that considerable variation existed between litters.

Table 3.1 Estimates of the use of water by suckling pigs (ml per piglet per day)

Age of piglets (days)			
1-7	8-14	15-24	Author
	5	100-140	Aumaitre, (1964)*
12	33	46	Friend *et al.*, (1966)
0			Bekaert *et al.*, (1970)
	10-90	50-130	Wojcik *et al.*, (1979)*
40			Svendsen *et al.*, (1989)
		140-450	Bauer, (1983)*
12			Fraser *et al.*, (1988)
4	8		Lobb, (1989)
19	2-110		Gill, (1989)

* Cited by Albar *et al.*, (1985).

Aumaitre, (1964), showed that 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 effect on the pattern of drinking water consumption which averaged 0.009 litres per piglet in week 5 and increased exponentially to 1.3 litres per piglet at 8 weeks of age.

Friend and Cunningham,(1966), reported that creep feed consumption was significantly less for piglets without water. Piglets receiving extra water made greater liveweight gains. Figures for average daily water intake given by Friend *et al.*,(1966), were in closer agreement with the values reported by Barber *et al.*,(1964) than those published by Aumaitre (1964).

Gill,(1989), investigated the effects of water and creep feed provision on the performance of growing pigs. He showed that the total amount of water used in week 1 averaged 0.13 litre/piglet. Litter groups offered creep feed had a significantly lower ($P<0.001$) average daily water use than those not offered creep feed,(0.02 compared to 0.05 litre/piglet). The provision of drinking water had no significant effect on creep feed intake. Gill noticed that there were large variations within and between litter groups in both creep intake and water use.

Lobb,(1989), showed that water intake increased exponentially from 3.5 ml/piglet at one day old to 27 ml/piglet at 19 days old. He also noticed considerable day to day variation within and between litters.

Fraser, Philips, Thompson and Peters Weem (1988), showed water use during the first 4 days after birth to vary greatly with an average use of 12 ml/piglet/day.

The main conclusion that can be drawn is that there is large variations in the water use of suckling piglets between the sources of information available.

3.2.2 The weaned piglet

Modern systems of pig production favour early weaning at between 3 and 4 weeks of age. Aumaitre,(1964), showed that milk-water comprises 80% of a suckling piglet's daily water requirements at 3 weeks of age, and this remains high at 80 and 68% respectively during weeks 4 and 5 of lactation. Therefore, weaning at 3 weeks of age which suddenly removes the piglets supply of water away from its source of nutrients exacerbates the stress of weaning. Although this period seems very important to the production process, there is very little information available describing the water use of weaned piglets. Table 3.2 shows various estimates of the use of water by weaned pigs.

Brooks, Russell and Carpenter (1984), studied the performance and daily water intake of pigs weaned at 3 weeks of age, fed one of two commercial diets. Average water intake increased from 0.71 litre/pig/day at 4 weeks of age to 2.58 litres/pig/day at 7 weeks of age. The initial average weight was 5.12 kg, increasing to 13.49 kg at 7 weeks of age. Weight gain and feed conversion improved with age with concurrent increases in water and feed intake. Feed intake was related to water intake. Water consumption in the first day after weaning was lower than expected but this increased noticeably on the second day to a level exceeding expectation.

In a recent study of pigs weaned at 3 weeks of age (Gill, 1989), the mean daily water use was observed to increase from 0.49 litre/piglet at 4 weeks of age to 1.46 litres/piglet at 6 weeks of age. Live-weight at weaning and at six weeks of age averaged 5.69 and 10.72 kg/piglet respectively. Water intake was found to be related to daily feed intake, mean live weight and the number of days post weaning.

Gill,(1989), like Brooks *et al.*,(1984), found that water use in the first day post weaning was consistently low amongst all litter groups. Water use increased greatly on days 2 and 3 which may be a compensatory mechanism as a result of dehydration incurred on day 1. Again a consistent pattern of water use was not established until the end of end of week 1. Gill stresses that his results are in close agreement with those of Brooks *et al.*,(1984). However, despite both experiments being conducted under identical conditions differences were noticeable in water use between the two studies. Gill suggests that these differences may be due to differences in the type of drinker used.
Table 3.2 shows that again large differences can be observed between the different reports.

3.2.3 The growing pig

Although the water needs of growing pigs have been studied more than those of piglets. There is considerable variation between published

Table 3.2 Estimates of the use of water by weaned pigs (litres per piglet per day)

Age of piglets (days)				
21-28	29-35	36-42	42-49	Author
	0.69-0.91	0.85-1.13		Wojcik et al., (1978)*
	0.55	0.67		Ehlert et al., (1979)*
	0.6-1.2	1.0-1.7	1.5-2.3	Bauer, (1983)*
0.73	1.20	1.90	2.37	Brooks et al., (1984)
0.49	0.89	1.46		Gill, (1989)

* Cited by Albar et al., (1985).

information concerning the water requirements of growing pigs. Table 3.3 summarises estimates of water use for growing pigs between 20 and 100 kg from various authors.

The relationship between live weight and water intake reported in some of these studies differ greatly. Gill reports that the study by Bauer Ober and Schlenker,(1978), indicated a linear relationship between water demand and live weight whereas information produced by Daelemans and Bekaert,(1971) and Braude, Clarke, Mitchell, Cray, Franke and Sedgwick, (1957) indicated a curvilinear pattern of water demand. Gill,(1989), showed that quadratic equations produced significantly better fits than linear equations for the relationship between live weight and water use.

Antoni,(1968), recorded a peak consumption of 11 litres/pig/day at about 56 kg live weight whereas Daelemans *et al.*,(1971) observed maximums of 5.1 litres/pig/day at 83.2 kg and 4.3 litres/pig/day at 75.8 kg live weight for the Belgian Landrace and Pietrain breeds respectively.

Comparing water use from two different types of drinker Gill,(1989), measured an average daily water use of between 2.47 and 4.3 litres/pig for pigs growing between 29 and 76 kg live weight according to the drinker utilised.

Table 3.3 Estimates of the use of water by growing pigs (litres per pig per day)

(Adapted from Gill, 1989)

	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
1	<----------------------5.7---------------------->							
2	7.5		10.4	11.1	10.2	9.3	9.0	10.1
3	3.0	3.4	3.5	3.8	4.4	4.7	5.1	4.6
4		2.4	2.9	3.7	4.3	4.3		
5	4.3		4.9	5.9	6.4	7.2	7.6	8.4
6	<----------------------6.92---------------------->							
7	<----------------------5.4-5.8---------------------->							
8	2.19	2.76	3.84	3.75	3.92			

Author 1 Barber *et al.*, (1963)

2 Antoni, (1968) *

3 Daelemans, (1971) Landrace *

4 Daelemans, (1971) Pietrain *

5 Bauer, (1978) *

6 Hepherd *et al.*, (1983)

7 Lightfoot, (1985)

8 Gill, (1989)

* Cited by Albar *et al.*, (1985).

3.2.4 The gestating sow

Table 3.4 summarizes the results of various authors who have studied the water use of pregnant sows. Again there is considerable variation in both the average and range of values between the different studies.

Lightfoot and Armsby, (1984), in an experiment to study the water consumption and slurry production of dry sows, recorded a range from 6.8 to 13.1 litres/sow/day and an average water use of 10.01 litres/sow/day. This study found that water intake during pregnancy was related to body weight. In another study by Riley,(1978), the average water intake for dry sows was 13.5 litres/sow/day during the gestation period.

Friend,(1971) recorded the water intake of pregnant gilts and sows offered ad *libitum* cereal and protein pellets under a selective feeding system. Over two reproductive cycles it was seen that water and feed intake increased during the first 3 weeks post conception, but decreased towards the end of pregnancy. 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 litres/sow/day after week 11 of pregnancy. Friend,(1971), suggested that this decrease in water demand during gestation may be due to a reduction in uterine fluids in late pregnancy as demonstrated by Pomeroy (1960).

A.R.C.,(1981) state that there is little indication of any progressive increase in the water requirements of sows during gestation. It is suggested that the needs of increased metabolic activity may be offset to some extent by an improved feed:gain ratio. It also stated that the

Table 3.4 Estimates of the use of water by gestating sows (litres per sow per day)

(Adapted from Gill, 1989)

Estimate	Author
13.5	Riley, (1978)
11.4-12.5	Fiedler, (1978)*
14.9	Bauer, (1981)*
22.0	Weckowicz, (1981)*
6.8-13.1	Lightfoot et al., (1984)
17.0	Madec, (1985)

* Cited by Albar *et al.*, (1985).

quantities of water usually fall within the range 3.5-8 litres/sow/day.

3.2.5 The lactating sow

In addition to the report of Gill, (1989), the water use of this class of pig has more recently been reviewed by Fraser, Patience, Philips and Mcleese, (1990).
Table 3.5 summarizes the results of various authors who have studied the water use of lactating sows. Again a feature of this compilation is the considerable variation in both the average and range of values between the different observations.

The water demands of a lactating sow are clearly greater than those of a pregnant sow. Water constitutes about 80% of sow's milk, Lodge,(1958).

Lightfoot,(1978), recorded water intakes of lactating sows over a 12 month period where the mean daily water intake was measured as 18 litres/sow. This figure was found to be similar in both summer and winter. After the fifth day of lactation the extremes of the water consumption range were 40 litres and 12 litres/sow respectively. In a later study, Lightfoot et al.,(1984), found that the mean daily water consumption ranged from 14 to 21.3 litres/day and averaged 17.7 litres/day. Riley,(1978), recorded the water intake for lactating sows during one month in winter to be 25.1 litres/sow/day.

Friend,(1971), showed that sows increased their demand for water and

Table 3.5 Estimates of the use of water by lactating sows (litres per sow per day)

(Adapted from Fraser *et al.*,1990)

Estimate	Author
19.4	Garner *et al.*, (1937)
8.1	Friend, (1971)
17.4-45.3	Fiedler, (1978)*
12.0-40.0	Lightfoot, (1978)
25.1	Riley, (1978)
19.9	Bauer, (1981)*
27.0	Weckowicz, (1981)*
14.0-21.3	Lightfoot *et al.*, (1984)
12.7	Diblik, (1986)
18.9	Gill, (1988)
14	Fraser *et al.*, (1989)

* Cited by Albar *et al.*, (1985).

feed immediately after farrowing and at a greater rate than the parallel increase in feed intake. A decline in water use was found to occur during week 4 of lactation. In this study water intake during lactation averaged 8.1 litres/day which is lower than recorded by others and considerably lower than the 14 litres/day estimated from heat and milk production data by Mitchell and Kelly (1938).

In a more recent study of the water use by lactating sows, Gill,(1988), total water use increased linearly over the week before farrowing and reached 12.2 litres/sow on the day prior to farrowing. On the day of farrowing total daily water demand decreased to 9.3 litres/sow and after farrowing increased curvilinearly before levelling off in week 3 of the lactation. Daily water use throughout the period from farrowing to weaning, averaged 18.9 litres/day. Water intake was found to be related to feed intake and the number of days post farrowing and the relationship could be described by the equations:

$$Y = 4.22 + 2.52\ X_1$$

$$Y = 7.63 + 1.81\ X_2 - 0.05\ X_2^2$$

Where: Y = Average daily water use (litres/sow)
X_1 = Feed intake (kg/sow/day)
X_2 = Number of days post weaning

Gill states that one of the main similarities between his findings and those of other authors is the considerable variation between daily water requirements of individual sows. The average value falls within the recommendations of the A.R.C.,(1981) of 15-20 litres/day however individuals were found to have used between 1 and 49 litres/day. Gill, suggests that this large variation shows that an unrestricted water supply is essential to ensure that each sow can meet its particular requirement.

3.2.6 Boars

Due to the fact that boars only account for a very small proportion of a pig herd, there have been few published studies on their water requirements.

Fevrier,(1977), suggested that boars could be maintained on the quantities which are adequate for growing pigs, that is 2 parts by weight of water per part of feed, without any adverse effect on their reproductive performance.

Recently in a study by Suss,(1985), an allowance of 8 litres/day was recommended, whereas Menguy,(1978) suggested the higher value of 11 litres/day.

3.3 The wet fed pig

Water can be supplied to pigs in the feed (wet fed), by a separate drinking system, or by a combination of both methods. It is estimated that 30% of U.K. commercial pig producers employ 'wet feeding systems' for their growing stock, (Gill,1989). This number is on the increase due to the established advantages in feed conversion efficiency over dry feeding techniques together with recent developments in computer controlled wet feeding systems.

Braude and Rowell, (1967) showed that pigs fed a restricted amount of dry feed (with ad *libitum* water) took an extra 10 days to reach bacon weight. Moreover their feed conversion ratio was improved by 20% by wet feeding. The amount of water added to the feed, however had only a very slight effect on pig performance. In contrast Forbes and Walker, (1968) found no significant difference in daily gain between wet and dry fed pigs, however some superiority in food conversion rate was demonstrated. Also there was a tendency for the pigs on the dry feeding system to produce better grading carcasses than those on wet feed.

3.3.1 The water to feed ratio

Opinions vary about the optimum water to feed ratio when the sole source of water for pigs is that in the feed. The A.R.C. report (1981) states,

"when pigs are given their water mixed with the feed in a wet feeding system, the following water : dry matter ratios by weight should meet the estimated requirements. Growing pigs 2 : 1, ...".

It is difficult to understand why a strict 2 : 1 water to feed ratio can be recommended in the light of recognition by the A.R.C. report (1981), that variation in the use of water is reported to occur between different authors.

The Code of Recommendations for the Welfare of Livestock : Pigs (1983) state that:

"where water is not freely available, for example by means of bowls or drinkers, at least 2.5 litres of water should be added to each kg of meal".

With the advent of the wet feed system there has been an increase in the use of the term 'water to feed ratio'. Table 3.6 lists water to feed ratios measured in various investigations. With few exceptions, workers investigating the water requirements of pigs insist on calculating a figure referred to as the water to feed ratio which takes no account of the fraction of water wasted. These computed figures should in practice be used with care as they are actually water use to feed ratios and may bear little relation to water intake to feed intake ratios prescribed in wet feed systems.

In wet feed systems the element of waste in water use is small and therefore the water to feed ratio is actually water intake to feed intake ratio. However in a production system where water is provided through separate drinkers, estimated water to feed ratios actually mean water use to feed intake ratios, due to the greater amount of wastage.

Table 3.6 shows the disparity that exists between published water to feed ratios. This variation is clearly related to that which occurs between published water intakes from the same authors. Differences in these published water to feed ratios may not be due to differences in water intake between the different sources but rather variations in the proportion of wasted water. The problem of wasted water will be discussed in the next chapter. Many water to feed ratios could be better used as a comparative measure of waste from different systems rather than a recommendation for wet fed pigs.

The use of the concept of water to feed ratio in estimating and evaluating water intake assumes that there is some constant relationship between water demand and feed intake. Anand,(1961), showed that the intake of water by mammals is usually correlated with

Table 3.6 Estimates of water to feed ratios of growing pigs (Adapted from Gill, 1989)

Estimate	Liveweight (kg)	Author
2.4:1	18-95	Barber *et al.*, (1963)
3.9-5.0:1	20-90	Bowland, (1965)
3.0:1	16-91	Holmes *et al.*, (1965)
3.86:1	35-100	Antoni, (1968)*
2.7:1	21-46	Mount *et al.*, (1971)
3.3:1	20-90	Hepherd *et al.*, (1983)
2.5-5.5:1	18-88	Gill, (1989)

* Cited by Albar *et al.*, (1985).

food intake. Chew,(1965), demonstrated that animals exhibit a close and positive relationship between the amount of a particular feed eaten and the amount of water ingested. Mount, Holmes, Close, Morrisson and Start, (1971) showed that the ratio of water to dry matter for pigs kept at 20^{0}C receiving 42 to 52 g of feed per kg live weight remained constant.

The water to feed ratio is sometimes calculated in experimental analysis to enable a comparison to be made between experiments where different ages of pigs have been used or pigs on different planes of nutrition. However the A.R.C.,(1981) acknowledges that the water to feed ratio is perhaps somewhat wider for recently weaned pigs and narrower for older animals which reduces the validity for doing this.

In contrast to the report of Anand (1961), Yang *et al.*,(1981) showed that there was not a constant relationship between water intake and feed intake nor was there a simple correlation between the two. Water intake was unchanged or slightly decreased when food intake was allowed to increase. Both reduction of food to half its usual amount and fasting significantly increased drinking and water turn over rate. From these results Yang suggested that the pig possesses a limited daily volumetric intake of food and water. Below this limit the pig will consume food as a first requirement and limit water to a minimum level. The ratio of water to feed is thus minimised when pigs are fed ad *libitum*. In addition Yang et al.,(1984), showed that pigs exhibited polydipsia when the daily dry matter feed intake decreased below 30 g/kg body weight.

There appears to be widespread belief among pig producers that when pigs are fed using liquid feeding systems there is no need or justification for providing a separate supply of drinking water. Gill, Brooks and Carpenter, (1986), showed that pigs on a water to feed ratio of 3.5:1 still consume further water from a separate water supply.. In this experiment average daily liveweight gain and feed conversion ratio were significantly improved at this higher water to feed ratio of 3.5:1, which suggests that the 2:1 ratio recommended by A.R.C., (1981) is unsatisfactory when applied to wet fed pigs with no other source of water available to them.

Barber, Braude and Mitchell, (1958), observed no differences in the rate of growth or efficiency of food utilisation of growing pigs given either 2, 2.5 or 3 to 1 water to feed ratios, but in this experiment no other supply of water was available. Barber *et al.*,(1963), subsequently confirmed that a water to feed ratio of 2 to 1 had no effect on performance or carcass measurements of the pigs. However when an *ad libitum* supply of water was given in addition to the water to feed ratio of 1.5 to 1 a significant increase in weight gain over all other treatments was seen. This is in agreement with the findings of Gill,(1986).

Where the only supply of water for growing pigs is the water with the feed, the water to feed ratio does not take into consideration individual animal variation which is known to exist, nor does it take into account differences in water use due to the factors affecting water use which are described in Chapter 4.

Thus the water needs of growing pigs published as guidelines in the Codes of Recommendations for the Welfare of Livestock : Pigs (1983) and the Nutrient Requirements of pigs, A.R.C.(1981) are unsatisfactory and do not safeguard either the physiological or welfare requirements of liquid fed pigs.

CHAPTER 4 THE FACTORS AFFECTING WATER INTAKE AND WATER USE.

4.1 Introduction

The tables of estimates of water use of the different classes of pig presented in Chapter 3 show the variability that exists in the figures for water use from the various authors. Gill, (1989), concluded his Thesis by saying:-

'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.'

The variation between reports referenced in Chapter 3 is likely to be due to the various factors affecting water use and requirement listed by Gill, (1989).

The factors affecting total water use can be divided into those which alter physiological demand such as diet and environmental temperature, and those which increase water use, such as behavioral factors and those conditions which increase the amount of water wasted.

4.2 The effects of diet composition

The A.R.C., (1981), recognised that the pigs' requirements for water will be modified by environmental factors, by increasing the dietary protein, by varying the intake of sodium and potassium salts and probably to a limited extent the dietary fibre content. However despite this there is little specific information on the effects of nutritional factors on the water demands of pigs.

4.2.1 Protein

Water is required for the removal of Nitrogen from the blood via the kidneys. Therefore feeding an excess and/or an unbalanced protein will increase water demand. Wahlstrom, Taylor and Seerley, (1970), found that the water intake of growing pigs was greater when they were fed a 16% protein ration compared with a 12% crude protein diet. Garrigus,(1948) showed that pigs receiving a good quality protein in their ration used less water per unit of feed than those on a poorer quality protein ration, indicating that poorer quality protein may increase renal water demand for excess urea excretion.
Aumaitre,(1964) found an average correlation of r=0.43 between the amount of nitrogenous material in the food and the water uptake.

4.2.2 Sodium

Hagsten and Perry, (1976), showed an increase of between 10-20% in water use when the NaCl content of the diet was increased from 0.06 to 0.2%. Additions of salt above 0.2% produced only very small increases in water use because feed intake was depressed and therefore total salt intake remained approximately the same. Although this study suggests that water intake is increased when NaCl is added to the diet little is known of the relative importance of the sodium and chloride ions. Patterson,(1984), indicated that the sodium ion alone could produce the same response in increased water intake as sodium chloride.

4.2.3 Potassium

There is some evidence to indicate that high concentrations of dietary potassium may increase the water requirements of pigs. Farries (cited by A.R.C.,1981) investigated the effects of increasing the potassium intake on the metabolism of growing pigs and pregnant sows, and found a positive correlation between potassium intake and water use. Gill, (1989) showed no significant increase in water demand with 3-5 week old piglets, when dietary potassium was increased from 7 g/kg to 15 g/kg. However, he showed a 25% increase in water intake for growing pigs when the potassium level was increased from 8 g/kg to 17 g/kg.

4.2.4 Antibiotics

Antibiotics are thought to affect the pigs requirement for water. The type of antibiotic and the circumstances in which it is fed may produce differing results. Braude and Johnson, (1953), found that a diet containing aureomycin caused increased urination. However Robinson, Coey and Burnett (1953), recorded a reduction in water use and an increase in liveweight gain for pigs receiving penicillin in the feed. In a later experiment Holmes and Robinson,(1965) found no consistent differences in the water consumption of pigs fed diets with and without penicillin.

Brooks et al., (1990) suggest that the effect of antibiotics on water demand will depend upon the relative extent to which water loss is reduced by the control of gastrointestinal disruption and water demand is increased to enable renal clearance of the antibiotic.

4.3 The effects of environmental temperature

As ambient temperature increases, there is a corresponding increase in the water consumption of pigs. Mount *et al.*,(1971), investigated the effects of several environmental temperatures (7 to 33^{0}C) on the water intake of growing pigs by means of a calorimeter. Within the temperature range 7 to 20^{0}C there was no significant increase in water use. Water use was reported to increase significantly at temperatures over 30^{0}C. These results are in agreement with those of Close, Mount and Start, (1971).

In an earlier experiment Holmes and Mount, (1967), exposed growing pigs of either 20 or 60 kg live weight in a calorimeter to ambient temperatures of either 9, 20 or 30^{0}C for 2 weeks. Although water use per kg of feed was highest at 30^{0}C they found that the water requirements per kg body weight increased linearly with increasing temperature.

Studying growing pigs, Steinhardt, Schloss and Ronicke, (1970) measured water consumption as 88 ml/kg liveweight at 35^{0}C, 68 ml/kg for 20^{0}C and 57 ml/kg at 1^{0}C.

Nienaber and Hahn, (1984) investigated the effects of environmental temperature and water flow rate from nipple drinkers on water use by young pigs and discovered that there was a significant interaction between the two factors. Water use was increased at 35^{0}C compared to 5^{0}C.

Gill,(1989) suggests that variations in ambient temperature within the thermoneutral zone are unlikely to have any significant effects on the water demand of pigs. However temperatures above 30^0C may result in a notable increase.

4.4 The effects of water temperature

There is very little information available on the effects of water temperature on the water use of pigs. Vajrabukka, Thwaites and Farrel, (1987) showed that for pigs of between 45 and 90 kg, water use was increased from 6.7 litres/pig/day at 30^0C to 10.6 litres/pig/day at 11^0C at an ambient temperature of $25\text{-}35^0C$.

4.5 The effects of the water delivery system

This section examines the effects of the various components of the water delivery system.

4.5.1 The type of drinker

There are many different types of pig drinker available to the commercial producer. These broadly fall into three main categories: bowl drinkers, bite drinkers and nose operated drinkers. Producers are now becoming more interested in the effects on performance and water wastage of different drinker types but there are varied reports regarding their influence on water use.

In an experiment involving growing pigs, Fiedler,(1982), found that water usage was higher from a nipple drinker than from a bowl drinker

(16.2 as opposed to 14.2 litres/pig/day. Lightfoot,(1985), reported no significant differences in the water usage and performance of growing pigs 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 or a bite drinker.

Gill,(1989), undertook several experiments on the effects of drinker type on water usage and performance. The results are summarised here. In one experiment with growing pigs, water use was significantly higher (74%) from the 'Mono-flo' nipple drinker ($p<0.001$) than the 'Arato 80' bite drinker. There was no significant differences in feed intake, live weight gain and feed conversion ratio between the pigs using the two different types of drinker.

In a comparison between 4 different types of drinker for growing pigs, water use was significantly higher ($p<0.001$) from the Mono-flo nipple drinker than the Arato 80, Lubing Type I and Type II bite drinkers. Gill attributed this difference to differences in wastage. Water use was higher with ad *libitum* than scale fed pigs for the three types of bite drinker. Drinker type was shown to have a significant effect on feed intake ($p<0.001$).

In a third experiment with early weaned piglets, comparing five drinker types, water usage was significantly higher ($p<0.001$) from the Mono-flo nipple drinker than from the Arato 76 tube, Alvin bowl, Lubing Type I and Type II bite drinkers. Drinker treatment had no significant effect on feed intake however liveweight gain was significantly higher ($p<0.05$) for replicate groups in pens fitted with Arato 76 nipple drinkers.

4.5.2 The drinker position within the pen

Studies by Olsson,(1983), suggested that the location of bite drinkers within the dunging area of growing pig pens affected the amount of water that was 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 the lying area, the amount of wasted water was reduced from 2.33 to 1.44 litres/pig/day.

4.5.3 The influence of drinker number

The effect of using one or two bite drinkers per pen of pigs was evaluated in a herd using restricted floor feeding by Simonsson, Olsson and Gustafsson, (1977). The Jalmarson drinkers used were located in the dunging area. The pig performance for the two groups of pigs were similar, however the pens with one valve per 5 pigs used approximately 8% less water. It is suggested that difference was due to less wastage as a result of less competition for water in pens having two drinkers for 10 pigs.

4.5.4 The effects of water delivery rate.

Water delivery rate may be defined as the rate of water flow from the drinker when the drinker valve is fully opened. Few manufacturers suggest the optimum rate at which water should be delivered to different classes of stock, although an increasing number do provide facilities by which the delivery rate of the drinkers can be adjusted.

When recommendations are made for water delivery rates these are not generally based on the results of research projects but rather on subjective observation.

The water delivery rate for a given drinker is dependent upon the water pressure and the drinker inlet valve aperture. Stansbury, Hancock, Tunmire, Tribble and Orr, (1981), showed that water use by growing pigs from nipple drinkers with inlet valve apertures of 0.89, 1.17 and 2.54 mm in diameter averaged 6.46, 9.64 and 10.14 litres/day respectively. There was a little improvement in the growth rate of pigs provided with water from drinkers with the larger inlet valve aperture.

Nienaber *et al.*,(1984), studied the effects of water flow rates from nipple drinkers on the water use and performance of weaned pigs. At an ambient temperature of 5°C using the delivery rates of 100, 600, and 1500 cm3/min water use was measured as 3,26, 4.43 and 4.62 litres/pig/day respectively for 10 week old pigs. In a second experiment with 4 week weaned pigs reared at 30°C water use increased with increasing water delivery rate from 1.57 litres/pig/day at 100 cm3/min to 5.2 litres/pig/day at 1100 cm3/min. However there were no significant effects on growth.

4.6 Water wastage

Some of the large differences seen between independent studies already mentioned may be due to differences in water wasted from the drinkers. Few researchers have attempted to quantify the amount of water wasted from the drinkers. This is probably due to the difficulties arising from trying to do so. Bekaert *et al.*,(1970), claim that directly activated bite drinkers have an average spillage of 66% of that water dispensed. Using tritiated water, Yang *et al.*,(1981), found that intake accounted for 80-90% of the volume recorded for bowl drinkers. These differences were presumed to be a measure of waste. Olsson,(1983) estimated that water spillage accounted for 20% of the total volume of drinking water used by pigs.

4.7 The accuracy of water metering in experimentation

The wide variations in water consumption of pigs described by A.R.C. (1981) may be partly accounted for by variation in the accuracy of metering systems. The majority of researchers have omitted to describe their metering systems but it is suspected that conventional turbine meters have been most commonly used.

The use of water by pigs is generally intermittent and at low delivery rates. Conventional turbine meters are not suitable for this type of measurement as they only respond accurately at relatively high and constant flow rates resulting in underestimation of water use in pig units. Conventional turbine meters have been reported to be as much as 90% inaccurate, (Brooks, Carpenter, Gill and Barber 1987).

A second method of metering water which has been described in earlier research work and overcomes the problem of low and intermittent flows is the use of calibrated tanks which are refilled at intervals manually to a constant volume mark, (Brooks *et al.*,1984).

Gill,(1989), attempted to overcome the problem of low delivery rates, intermittent flows and the effects on accuracy by the use and development of a calibrated tank which automatically fills at intervals to a constant volume mark. In filling at a high rate of flow, an associated turbine meter recorded the volume of water passing into the tank, with a reasonable degree of accuracy.

The mode of operation however of these latter two systems still creates further practical deficiencies which makes the data resulting from their use suspect. Both devices operate on a changing fluid head which consequently alters the water delivery rate at the pig drinker. As the fluid head commonly available in pig buildings is approximately 2 m a change in head of 0.5 m represents a considerable reduction in water delivery rate at the drinker. Experimentation described later shows that water delivery rate can have a significant effect on water use. Therefore, for the accurate assessment of water use the water delivery rate should be constant.

4.8 Conclusions

There are still quite major complications in determining the water requirement and quantifying water use for different classes of pigs. The voluntary water intake of pigs has not yet been measured accurately as researchers find problems in avoiding waste in these type of studies. Hence the factorial model of water requirement, (Gill, 1989), cannot be tested.

Different reports have shown wide variations in the measured water use for similar classes of pigs. Due to the vast number of parameters which can affect water use together with the inaccuracies in metering water, it is not possible to state the water use of a particular class of pig. It is fairly easy to determine how a change in a single parameter alters water demand, but it is very difficult to produce a predictive model for water use in all circumstances. As yet a model has not been produced to produce definitive figures.

Despite the information available on the use of drinking water by pigs, this chapter can only be concluded by agreeing with a statement from The Codes of Welfare of Livestock: Pigs, (1983) 'It is important for pigs to have sufficient fresh clean water for their daily needs'.

OBJECTIVES OF STUDY AND RATIONALE FOR RESEARCH PROGRAMME

PRINCIPAL OBJECTIVES

1 To produce an accurate assessment of the drinking water needs of pigs, managed under various environmental conditions, from which reliable recommendations for water supply can be made.

2 To identify the factors which have a significant effect on the drinking water use of housed pigs.

3 To predict the water use of pigs according to their environment and conditions of management.

4 To identify when and why peak demand periods occur.

5 To determine the adequacy of existing common pig housing water supply systems in relation the to identified peak demand periods, predictive equations for water requirements and the principles of fluid flow through closed pipes.

6 To recommend alterations that can be made to existing pig housing supply systems to increase their efficiency and decrease the gap between demand and supply.

RATIONALE FOR THE RESEARCH PROGRAMME

The main conclusion that can be drawn from Chapters 3 and 4 is that there is considerable variation between different reports describing the water use of pigs. It is unknown whether this variation is due to actual differences in physiological requirement, inaccuracies in experimentation, poor interpretation of results or non-standardisation of experimentation.

Gill *et al.*,(1986) and Brooks *et al.*,(1984) showed large variations between daily water use of early weaned pigs, using the same equipment for their experimentation. It is suspected that this variation may be due to inaccuracies caused by the water metering devices used. The first stage of this research programme was concerned with the finding and testing of an accurate water meter which was to be used in this research project to produce reliable data.

Variations that occur between published recommendations for the water requirements of pigs may be a result of the differences in the proportion of water wasted between different experiments. If it were possible to determine accurately the proportion of water wasted, then recommendations for water allowances could be made with a greater degree of precision and the factorial model of gains and losses could be tested. Although it has been acknowledged that water is wasted from drinking utensils, rarely have researchers attempted to measure this waste because of the problems encountered in doing so. Simple subtraction of the wasted fraction from the value of gross water use would give the net water intake. In this research programme methods of quantifying the wasted water were investigated.

It is clear that water use is affected by many different factors. When considering the supply of drinking water to pig housing it is imperative to know how these factors effect water use. It is now well established that dispenser type significantly influences the amount of water used by pigs (Gill 1989). Further experiments have been undertaken to confirm this using accurate calibrated metering devices.

One parameter affecting water use which has received little attention is that of water delivery rate. A drinker with a high water delivery rate will allow more water to flow through it than one with a low delivery rate. The large variation in estimations of water demand, reported by different authors (Chapter 4) may have resulted from differences in the delivery rates in the drinkers used.

Most authors have omitted to make reference to the water delivery rate of the drinkers used. Gill,(1989) specified the water delivery rate for the drinker types examined but did not consider this parameter any further. It was suspected that the significant difference in water use between Mono-flo nipple drinkers and Arato bite drinkers identified by Gill, (1989) was more likely to be due to the large differences in water delivery rate (specified by Gill) between the drinkers rather than differences in the drinker types themselves. A major part of the current research programme comprised a series of experiments which aimed to investigate the effects of water delivery rate on water use and performance for different classes of pig.

In previous research on the water requirements of pigs, workers have attempted to standardise experimental results, by expressing water use in terms of feed intake. The use of feed intake as a predictor in this way is doubted and therefore an experiment was undertaken to consider whether body weight would be a more accurate predictor.

An increasing number of pigs are being wet-fed on U.K. units. The water to feed ratio recommended to producers has been based mainly on experiments which have been undertaken on non wet-feed systems and consequently may not be applicable to wet systems where the proportion of waste water is negligible. An experiment was carried out to measure the water to feed ratio of wet-fed pigs which were able to select their own water to feed ratio with out water wastage.

It has been reported that demand for water by pigs is not constant throughout the day, (Hepherd *et al.*,1983; Albar *et al.*,1985). Periods of maximum demand may have significant disruptive effects on rural supply networks. Peak demand periods have been determined by measuring the pattern of water use of different classes of pigs.

THE RESEARCH PROGRAMME

Part 1: Initial experiments including water metering, wastage assessment and verification of contemporary studies.

Experiment 1: The testing of water meters to be used throughout the research programme.

Experiment 2: The evaluation of two indirect methods of determining the water intake of pigs.

Experiment 3: The effects of water to feed ratio on the feed value of a grower ration.

Experiment 4: The water use of early weaned pigs from 3 to 5 weeks of age fed on four different diets.

Experiment 5: A comparison of water use between four bite type drinkers by growing pigs on a scale based on metabolic body weight.

Part 2: An investigation into water delivery rate as a major factor affecting the water use of pigs of different classes.

Experiment 6: The effects of drinker type and water delivery rate on the water use of growing pigs fed on a scale based on metabolic body weight.

Experiment 7: The effects of water delivery rate and drinker number on the water use of growing pigs fed on a scale based on metabolic body weight.

Experiment 8: A comparison of water use between four water delivery rates by growing pigs fed ad libitum.

Experiment 8A: A comparison of water use between two flow rates on growing pigs kept under commercial production conditions fed ad libitum and on a scale based on metabolic body weight.

Experiment 9: A comparison of water use between four water delivery rates by early weaned pigs from 3 to 6 weeks of age.

Experiment 10: A comparison of water use between four water delivery rates by group housed dry sows.

Part 3: An evaluation of the use of feed intake as a predictor of water use.

Experiment 11: A comparison of water use between four levels of feed intake by growing pigs.

Experiment 12: A comparison of water use and water to feed ratio between four levels of feed intake by growing pigs, allowed to self select water to feed ratio.

Part 4: Determination of the peak water demand periods

Experiment 13: The pattern of water use of growing pigs fed on a scale based on metabolic body weight.

Experiment 14: The pattern of water use of lactating sows.

SECTION 2 THE RESEARCH PROGRAMME

Part 1: Initial investigatory experiments including water metering, wastage assessment and verification of contemporary studies.

Experiment 1: The testing of water meters to be used throughout the research programme.

Introduction

Differences in estimates of water use between earlier research work may have been due to inaccuracies in the method of water metering. In order for the current research programme to produce accurate and valid results it was necessary, to find a meter which was accurate and reliable under the conditions in which it was expected to function (low and intermittent flows), and for each meter to be tested and calibrated. In order for a meter to start recording it requires a minimum flow (energy). Conventional turbine meters require a high minimum flow to start recording and therefore at low flows water can pass through the meter without being recorded, (Brooks *et al*., 1987). If the flow of water ceases suddenly, the turbine meters will over run, particularly at the higher flow rates, resulting in over estimation. In a situation where the flow is intermittent the meter is repeatedly stopping and starting, increasing the likelihood of errors occurring due to the reasons above (end effects).

Materials and Methods

The performance characteristics of twenty-four Kent PSM-L water meters were evaluated. The Kent PSM-L water meter is an improved turbine meter designed specifically to operate accurately under conditions of low flows. The meters were tested at nine different water flow rates between 125 cm^3/min and 2000 cm^3/min. At the different flow rates the meters were tested under two test conditions:-

(i) Constant Flow: at each flow rate the meters were tested ten times for a period of sixty seconds. The volume recorded by the meter was noted, and the water which had passed through the meter was collected and weighed using a top-loading balance. For the flow rates below 500 cm^3/min the test period was increased to 180 seconds.

(ii) Intermittent Flow: at each flow rate the meters were tested by turning the water on for one second and off for two seconds. This sequence was repeated sixty times. Again the volume recorded by the meter and that which passed through it were measured and noted.

A Sinclair Spectrum+ personal computer was used to vary the flow rate by remotely opening and shutting solenoid water valves by the use of an analogue/digital converter. Four solenoid water valves each with a different flow could enable a possible maximum of fifteen different flow rates.

Results

Having weighed the actual amount of water that passed through the meter and recorded the meter reading, it was possible to calculate the accuracy of the meters at different flow rates for both constant and intermittent

Table 5.1 The accuracy of meters tested at different flow rates for constant and intermittent flow.

Constant Flow

Flow Rate cm^3/min	Mean % Error	S.D.	$S.E._M$	Range
125	-0.5	1.72	0.54	-3.4 to +1.5
250	+0.7	2.02	0.64	-1.7 to +2.7
500	0.0	2.05	0.65	-3.1 to +3.4
750	+1.7	2.20	0.40	0.0 to +3.6
1000	+1.3	1.20	0.99	-2.2 to +3.8
1250	+1.2	1.58	0.56	-2.4 to +3.7
1500	+1.1	1.23	0.39	-0.6 to +2.6
1750	+0.9	0.86	0.27	-0.4 to +2.5
2000	+1.0	0.71	0.22	-0.5 to +2.1

Intermittent Flow

Flow Rate cm^3/min	Mean % Error	S.D.	$S.E._M$	Range
125	-3.0	4.93	1.56	-6.2 to +6.9
250	-0.10	2.53	0.80	-3.8 to +4.5
500	+1.20	1.62	0.50	-0.9 to +3.2
750	+1.50	0.97	0.31	0.0 to +2.3
1000	+1.60	1.32	0.42	0.0 to +2.9
1250	+1.80	0.99	0.31	-0.4 to +2.8
1500	+2.20	0.38	0.12	+0.9 to +3.5
1750	+2.30	1.03	0.33	+0.9 to +3.7
2000	+2.5	0.47	0.15	+1.8 to +3.1

flows. The results are presented in Table 5.1.

For the constant flow rate tests, the mean percentage error varied between -0.5% and +1.7%. For the intermittent flow tests the mean percentage error was greater varying from -3.0% to +2.5%. The variation in the range of accuracy for the intermittent flow tests was considerably greater than those of the constant flow tests. This is because the error due to end effects is maximised by increasing the number of times the valve is open and shut.

Below are the performance results of the Kent PSM-L meter published by the manufacturers.

Peak flow at 10 M head loss	Qmax	± 2%	2.0 m^3/hour
Maximum continuous flow 2.5 M	Qn	± 2%	1.0 m^3/hour
Transitional flow	Qt	± 2%	192 cm^3/min
Minimum accurate flow	Qmin	± 2%	125 cm^3/min
Starting flow	Qs		65 cm^3/min

Discussion

Subjecting the meters to intermittent flow rates would be the worst possible conditions that a meter might be expected to function under. The average percentage errors were, in most cases, within the manufacturers quoted tolerances, however certain individual meters were outside these tolerances (shown by the size of the ranges). For both intermittent and constant flows on average the meters were under reading at the very low flows. Having tested the meters individually it was possible to calibrate them where necessary according to the circumstances in which they were to be used.

Once installed in the performance test houses the accuracy of the meters was checked periodically. During the course of the experiments it was found that a build up of dirt particles caused by low velocity water flow occasionally accumulated within the meters. Where meters were found to give a mean % error of greater than +/- 3% they were cleaned and replaced. Through out the research programme, the Kent PSM-L meter was found to be a reliable meter. Having tested the meters in the above fashion it is assumed that the recordings throughout the research programme were +/- 3% accurate. However the accuracy of the water meter does not standardise the variation in recordings due to differences in the proportions wasted.

Experiment 2: An evaluation of two indirect methods of determining the water intake of growing pigs.

Introduction

Waste water is that water which enters the slurry stores without serving any physiological purpose, that is water spilt from drinking utensils. The amount of water wasted by pigs from drinking utensils remains unknown, although some researchers have suggested approximate figures with little supportive evidence. Bekaert *et al.*, (1970) claim that directly activated bite drinkers on average spill 66% of the water they dispense. However Olsson, (1983) estimated that water spillage accounts for 20% of the total volume of water used by pigs. If it is possible to determine indirectly the water intake of pigs, this value subtracted from the gross consumption value (metered) would give the amount of wastage. Knowing the proportion of wastage it would be possible to compare the efficiency of different drinker types.

Methods which have been used for measuring wastage fall into two categories; those which directly measure wastage by collection and those which indirectly measure it by techniques which involve prediction of actual intake from certain urinary characteristics. Olsson (1983), studied water wastage by direct measurement using a collection bin placed under a slatted floor below a drinker. This method is unreliable because it fails to take account of water which runs under the animal's jaw and drops from the base of the sternum, by-passing the collection vessel. Madec (1984), compared four indirect methods of estimating the water intake of pregnant sows. He found the most accurate methods to be the measurement of urinary creatinine concentration and urine relative density. These two methods have been used in this experiment to indirectly determine the water intake of growing pigs.

Relative density is a measure of the urine concentration, that is, a measure of dissolved solute (salts). Under constant environmental conditions, where water intake is controlled, the greater the water allowance (intake), the greater the volume of urine produced, the lower the concentration of dissolved solute and therefore the lower the value for relative density.

Creatinine is a breakdown product of muscle protein excreted in the urine at a relatively constant rate depending on the animal's physiological state. Duggal et al.,(1978) found with growing pigs highly significant correlations between body weight and urinary creatinine (r=0.98). Murlin et al.,(1953) showed that creatinine excretion is positively correlated with biological protein value. Under constant environmental conditions where water intake is controlled, the greater the water intake the greater the volume of urine produced and therefore the lower the concentration of creatinine in the urine.

Materials and Methods

Experimental design and treatments

Four treatments with four replicates were arranged within a metabolism test house in a completely randomised design. The four treatments were as follows:

A water to feed ratio 1.63:1
B water to feed ratio 2.13:1
C water to feed ratio 2.63:1
D water to feed ratio 3.25:1

The water to feed ratios stated above are water to fresh weight of feed ratios assuming the feed is air dried and has a dry matter of 85%. The water to dry matter feed ratios are given below.

A water to DM feed ratio 2:1
B water to DM feed ratio 2.67:1
C water to DM feed ratio 3.33:1
D water to DM feed ratio 4:1

Animals and housing

Sixteen Large White (Large White x Landrace) entire males were taken from the second stage weaner accommodation and randomly assigned to the four treatments. Boars were selected in order that urine could be collected separately from the faeces. The pigs were kept in metabolism crates in a test room maintained at 22^{0}C for a total period of twenty days. The first ten day period was a preliminary period in order for the pigs to grow accustomed to the confinement of the metabolism crate and the wet feeding system. The second ten day period was the trial period in which the samplings were made. The initial weight at the beginning of the trial period was 30.9 ± 2.45 kg. The pigs were fed a meal ration formulated from wheat, barley and soya according to a scale which allowed 115 g food/kg $W^{0.75}$. Mineral and proximate analysis of the feed are given in Table 6.1. The ration was split into two feeds per day, 09.00 hrs and 16.00 hrs. During the trial period there were no feed refusals. The only water available to the pigs was that provided with the feed.

Table 6.1 Proximate and mineral analyses of the feed used in Experiment 2

Dry matter (%)	85.2
Digestible energy (MJ/kg DM)	15.4
Crude protein (g/kg DM)	20.8
Crude fibre (g/kg DM)	29.0
Neutral detergent fibre (g/kg DM)	129
Oil (Acid hydrolysis) (g/kg DM)	25.0
Total ash (g/kg DM)	71.0
Calcium (g/kg DM)	15.0
Phosphorous (g/kg DM)	10.3
Magnesium (g/kg DM)	1.5
Sodium (g/kg DM)	2.6
Potassium (g/kg DM)	5.5
Chloride (g/kg DM)	3.1

Experimental procedures

On six of the ten trial days, urine samples of two types were taken from each animal. Firstly each morning at 09.00 hrs a representative sample of the previous day's urine (24 hrs) was taken. Secondly at 12.00 another sample was taken which was therefore from the period 09.00 - 12.00 hrs that morning. Preliminary investigation with different hydrometers showed them to be in sufficiently sensitive. Therefore the relative density of the urine samples was measured using a relative density bottle and weighed to the nearest 0.001 g. The bottle was air dried and weighed. It was then filled with distilled water at 16^{0}C and reweighed. The weight of the volume of water contained by the bottle could then be calculated. (All relative density measurements were done at 16^{0}C to prevent variations in density due to temperature fluctuations). The bottle was dried again and filled with urine (replicated three times to give a mean value). The weight of the volume of urine contained by the bottle could then be calculated. The weight of urine divided by the weight of water gave the relative density of the urine. This procedure was repeated for each urine sample.

Estimation of urine creatinine was based on the reaction of creatinine with alkaline picrate to give a red colour. For each urine sample taken (replicated three times) the red colour produced was compared in a spectrophotometer at 520 nm with a known standard creatinine concentration. The absorbance of the test solution divided by that of the standard multiplied by 10 gave the urine creatinine concentration (mmol/litre).

Table 6.2 Urine relative densities and creatinine concentrations for the 24 hour samplings.

Water to DM feed ratio	2:1	2.67:1	3.33:1	4:1		
Water intake (litres)	2.84	3.64	4.44	5.44	$S.E._D$	P
Relative density	1.021a	1.015b	1.010c	1.008c	0.002	0.001
Coefficient of variation (%)	4.76	6.6	10.0	12.5		
Creatinine concentration (mmol/l)	8.18a	6.29a	3.54b	1.98b	0.98	0.001
Coefficient of variation (%)	14.6	18.3	11.3	25.2		

a,b and c means bearing the same superscript are not significantly different.

Table 6.3 Urine relative densities and creatinine concentrations for the 3 hour samplings.

Water to DM feed ratio	2:1	2.67:1	3.33:1	4:1		
Water intake (litres)	2.84	3.64	4.44	5.44	$S.E._D$	P
Relative density	1.016a	1.010b	1.007bc	1.005c	0.002	0.001
Coefficient of variation (%)	12.5	33.0	14.0	20.0		
Creatinine concentration (mmol/l)	5.77a	3.59b	2.29b	1.63b	0.98	0.001
Coefficient of variation (%)	12.1	45.0	23.0	29.0		

a,b and c means bearing the same superscript are not significantly different.

Results

With one exception, the health of the pigs was good. One pig had to be removed from the metabolism crate during the preliminary period suffering from a rectal prolapse. As the only water available to the pigs was that in the food, water wastage was negligible and therefore total water intake could be calculated. For the four treatments, total water intake was as follows:

2 : 1	2840 cm^3/day
2.67 : 1	3640 cm^3/day
3.33 : 1	4440 cm^3/day
4 : 1	5440 cm^3/day

Analysis of urine creatinine concentrations and relative densities for the 24 hr data are summarised in Table 6.2. Analysis of urine creatinine concentrations and relative densities for the 3 hr data are summarised in Table 6.3.

A oneway analysis of variance of relative density and creatinine concentration for both 24 hour and 3 hour samplings showed their to be a significant difference ($P < 0.001$). The coefficients of variation were much greater for the three hour data indicating that the 24 hour data would be more reliable for prediction of water intake. T tests showed that urine voided in the period 09.00 hrs to 12.00 hrs had a significantly lower relative density and the creatinine content for than that voided in the total 24 hour period, for all four treatments (Table 6.4). This suggests that the concentration of urine is related to the time it is voided.

Linear regression of water intake on urine relative density and urine creatinine concentration gave the following equations:

24 hour samplings:

$Y1 = 1.034 - 0.00497\ X$ $\quad R^2 = 91.3\%$ $\quad (P<0.001)$

Table 6.4 A comparison of urine relative densities and creatinine concentrations for the 3 hour samplings and 24 hour totals for the four levels of water intake.

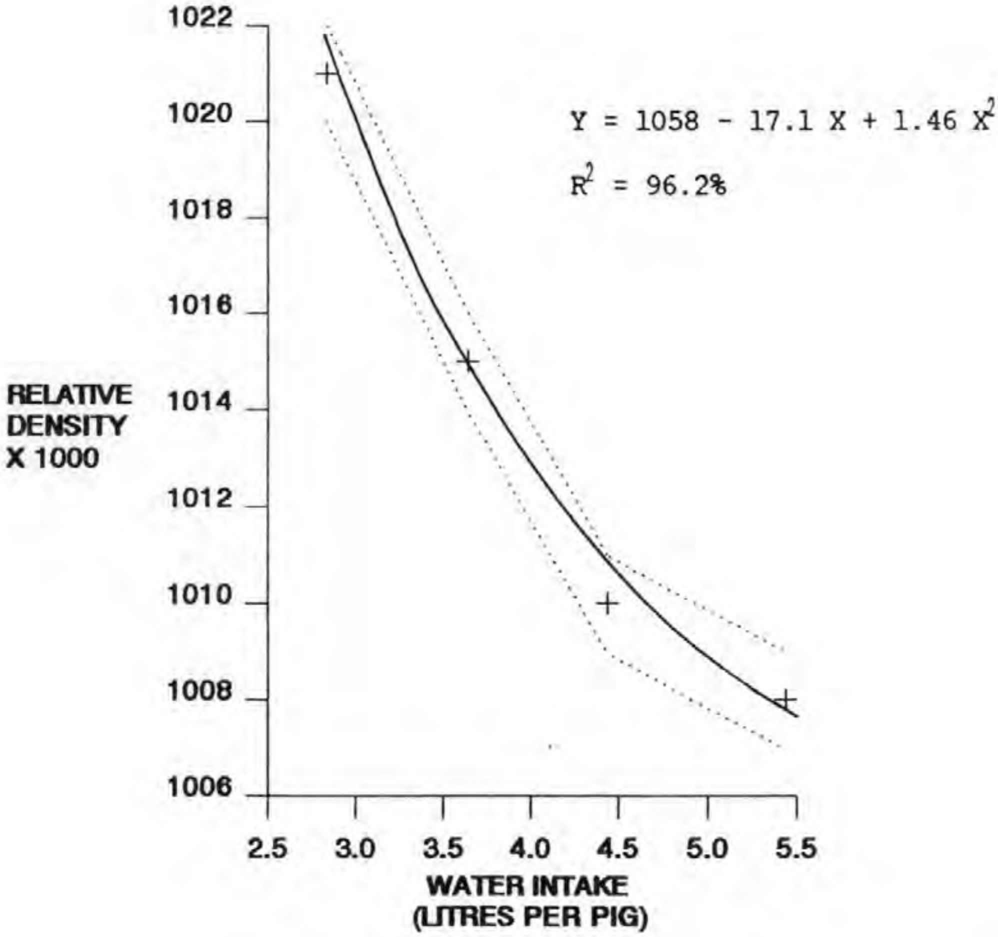
Relative density

Water intake (litres)	24 hr sample	3hr sample	probability
2.84	1.021	1.016	0.0190
3.64	1.015	1.010	0.0025
4.44	1.010	1.007	0.0001
5.44	1.008	1.005	0.0001

Creatinine concentration (mmol/litre)

Water intake (litres)	24 hr sample	3hr sample	probability
2.84	8.18	5.77	0.0029
3.64	6.29	3.59	0.0090
4.44	3.54	2.29	0.0020
5.44	1.98	1.63	0.2300

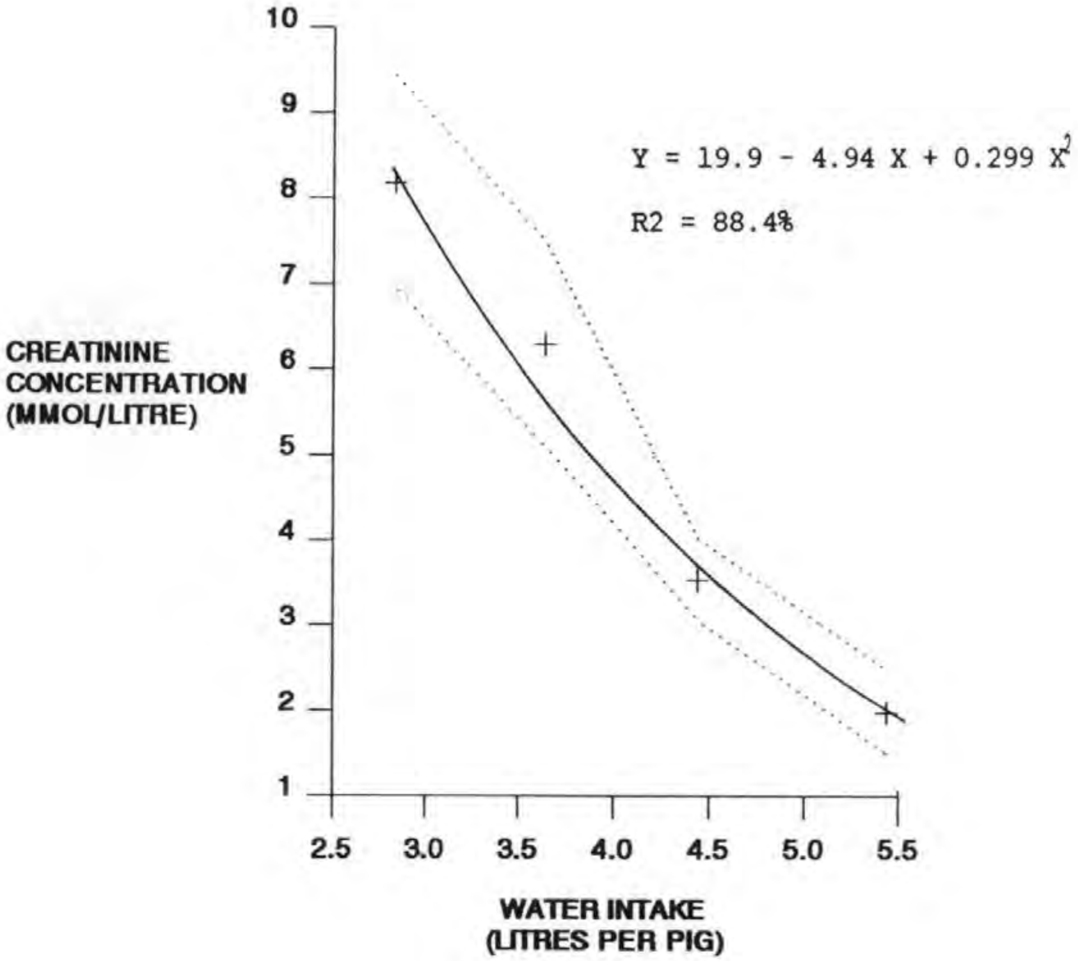
Figure 6.1 The relationship between 24 hr urine relative density and total daily water intake per pig for growing pigs.



(......) 99% confidence limits for individual values of relative density.

(——) Quadratic regression line.

Figure 6.2 The relationship between 24 hr urine creatinine concentration and total daily water intake per pig for growing pigs.



(......) 99% confidence limits for individual values of creatinine concentration.

(——) Quadratic regression line.

$Y2 = 15.1 - 2.46\ X$ $\quad R^2 = 87.6\%$ $\quad (P<0.001)$

3 hour samplings:
$Y1 = 1.027 - 0.00417\ X$ $\quad R^2 = 71.9\%$ $\quad (P<0.001)$
$Y2 = 9.75 - 1.57\ X$ $\quad R^2 = 70.3\%$ $\quad (P<0.001)$

where Y1 = urine relative density
Y2 = urine creatinine concentration (mmol/l)
X = water intake (litres)

Analysis of variance of all four regression equations showed that they were significant representations of the data, those for the 24 hour periods having a higher probability. The larger coefficients of variation for the creatinine concentrations together with the lower coefficients of determination suggests that relative density is the better determinant of water intake particularly where total urine can be collected over 24 hour periods.

When the data was examined more closely it was found that a curvilinear equation would produce a better fit than a simple linear regression line. Quadratic regression of urine relative density and urine creatinine concentration on water intake gave the following equations:

24 hour samplings:
$Y1 = 1.058 - 0.0171\ X + 0.00146\ X^2$ $\quad R^2 = 96.2\%$ $\quad (P<0.001)$
$Y2 = 19.9 - 4.94\ X + 0.299\ X^2$ $\quad R^2 = 88.4\%$ $\quad (P<0.001)$

3 hour samplings:
$Y1 = 1.06 - 0.021\ X + 0.00204\ X^2$ $\quad R^2 = 82.7\%$ $\quad (P<0.001)$
$Y2 = 19.5 - 6.56\ X + 0.601\ X^2$ $\quad R^2 = 76.7\%$ $\quad (P<0.001)$

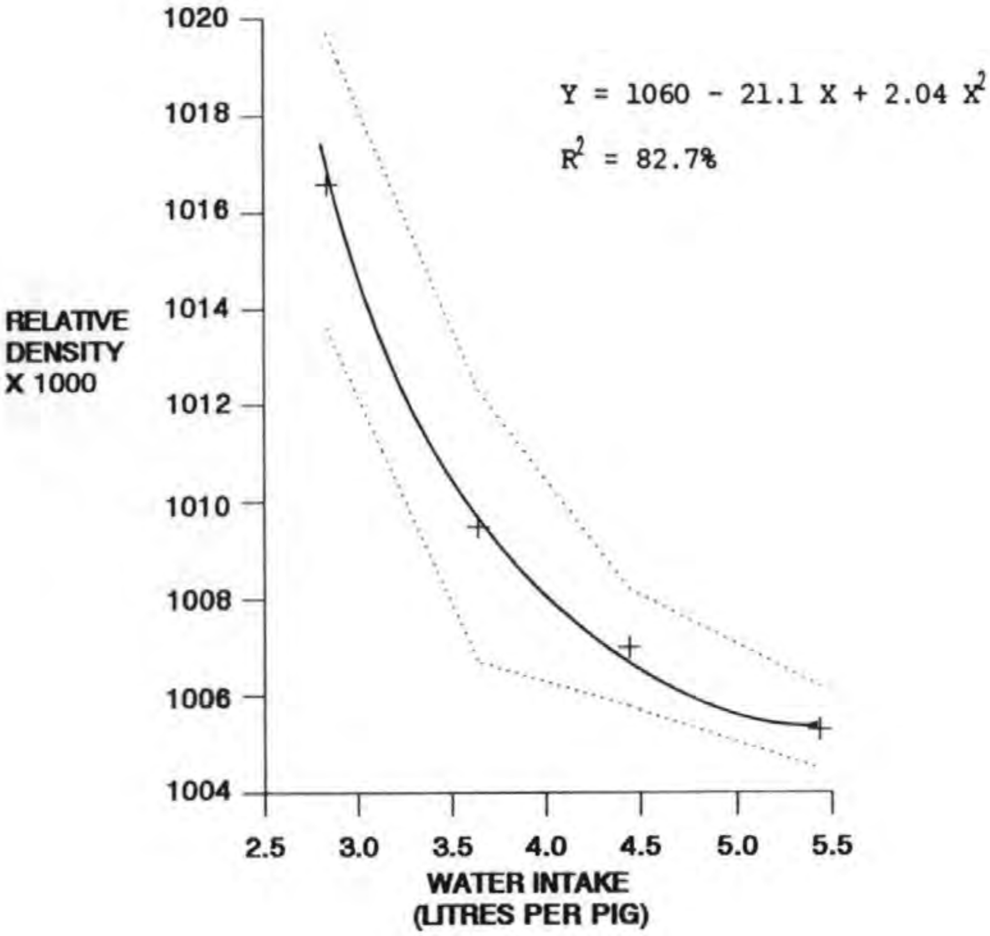
where Y1 = urine relative density
Y2 = urine creatinine concentration (mmol/l)
X = water intake (litres)

The above relationships are described by Figures 6.1,6.2,6.3 and 6.4.

Discussion

For pregnant sows Madec (1984), found the correlations between water

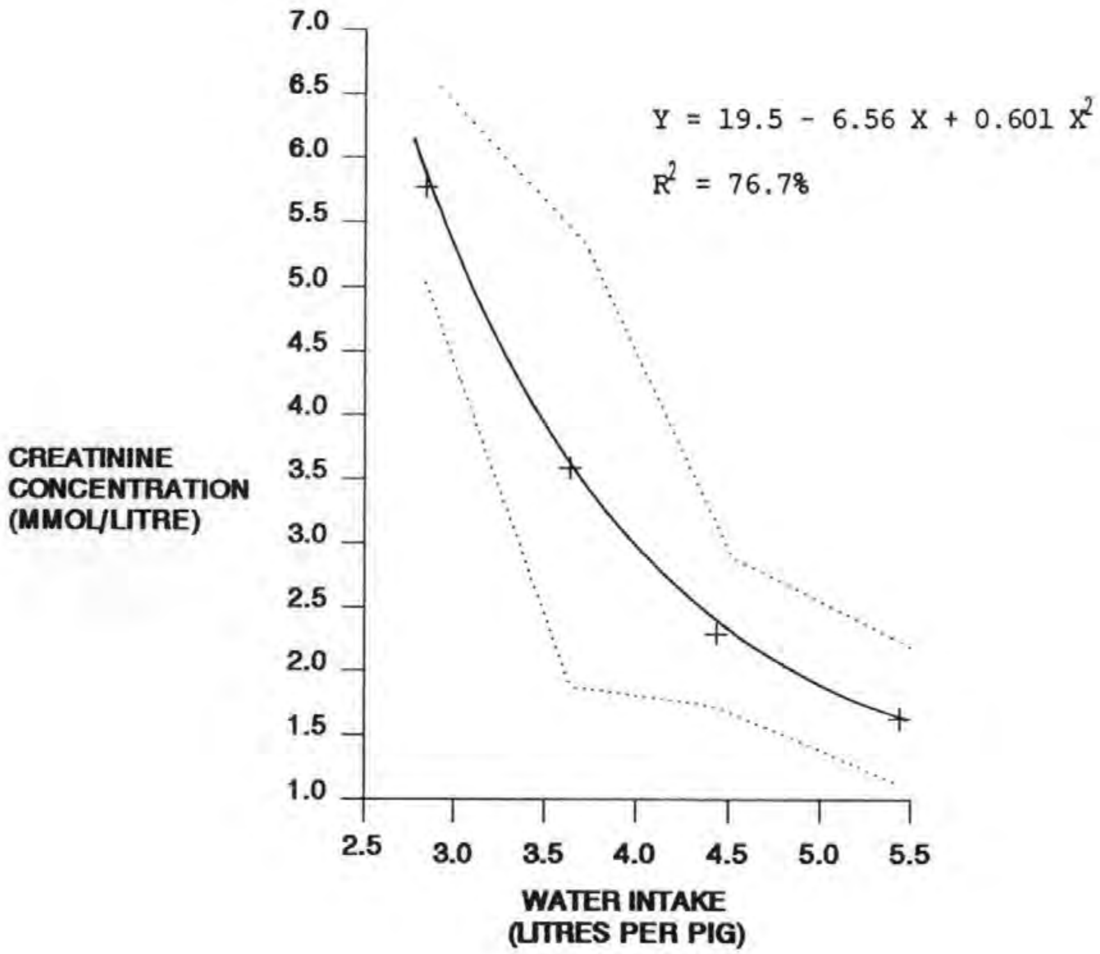
Figure 6.3 The relationship between 3 hr sample urine relative density and total daily water intake per pig for growing pigs.



(......) 99% confidence limits for individual values of relative density.

(——) Quadratic regression line.

Figure 6.4 The relationship between 3 hr sample urine creatinine concentration and total daily water intake per pig for growing pigs.



(......) 99% confidence limits for individual values of creatinine concentration.

(——) Quadratic regression line.

intake and urine relative density and water intake and creatinine concentration to be 0.65 and 0.56 respectively for the first urine collected in the morning. When the correlation coefficients are calculated from the coefficients of determination for the three hour samplings, they are all greater than 0.8. As the results showed the degree of correlation is dependent upon the type of sample taken. The difference in correlation coefficients between the two experiments may be due to the time of sampling.

Bate and Hacker, (1981) in investigating the effect of parturition on sow urinary creatinine found there to be large differences ($p<0.001$) between individual sows. Madec (1984) found that the correlation between water intake and urine concentration was decreased if the animal was suffering from any urinary infection. Pregnant sows are more likely to be suffering from urinary disorders than growing pigs as used in this experiment.
Water is lost from the body through the lungs, intestines, skin and kidneys. Water requirement is determined by the magnitude of these losses. The continuous loss of water vapour from the upper respiratory tract and the insensible perspiration of the skin varies according to the surface area of the animal, its temperature, metabolic rate and environmental conditions, (refer to Chapter 2).

In a situation where water is restricted, water may continue to be lost from the skin reducing, the amount of water lost in the urine and therefore producing a more concentrated urine. Given free access to water, an animal will tend to drink sufficient so as to enable the elimination of urea or excess sodium or potassium salts as the volume of urine tends to increase with the amount of waste material, (Frandson, 1986). Therefore the concentration of dissolved solute (relative density) would remain constant under these circumstances.

The predictive equations produced from this experiment can only be applied to pigs between 30 - 36 kg kept under similar environmental conditions, feeding regime and where water was restricted. A change in temperature or salt concentration of the diet will produce different urine relative densities at the same water intakes.

It is unknown how relative density varies with age. Duggal and Eggum, (1978) showed that total urinary creatinine excreted was higher in heavier pigs (75 kg) compared with pigs at 25 kg. There was little variation in relative density and creatinine concentration between individuals on the same treatment water intake.

In a situation where access to water was unrestricted, urine relative density could not be used as a means for determining water intake because homeostasis dictates that animals will drink enough water to excrete waste products producing urine of relatively constant concentration.

It is therefore concluded that the method could only be used in comparative situations to determine whether water was more restricted in one situation. Provided creatinine is excreted at a constant rate, its concentration would be useful as a predictor of water intake in conditions of free access to water in comparative situations. However, Paterson (1967), concluded that 24 hour creatinine output in humans is not sufficiently constant enough to justify its use as a reference standard against which to compare the excretion of other substances. It would therefore not be constant enough to be used as an accurate determinant of water intake and the case for pigs is taken to be the same.

Experiment 3: The effects of water to feed ratio on the feed value of a grower ration.

Introduction

With the increase in the use of wet feeding systems there has been a controversy over the optimum water to feed ratio that should be employed. Braude *et al.*,(1967) showed that pigs fed a restricted amount of dry feed (with *ad libitum* water) took an extra 10 days to reach bacon weight. Moreover feed conversion ratio was improved by 20% wet feeding. The amounts of water added to the feed when fed wet had only very slight effects on pig performance. Forbes *et al.*,(1968) found no significant difference in daily gain between wet and dry fed pigs in contrast to the higher growth rates reported by Braude *et al.*,(1967).

It is common for liquid fed pigs to have no other supply of drinking water. Gill (1989) conducted an experiment to investigate the effects of different water to feed ratios on the performance of growing pigs provided with an additional water supply. He showed that live weight gain and feed conversion improved significantly ($p<0.05$) as the water to feed ratio of the liquid feed was increased from 2:1 to 3.5:1. Pigs fed at the lower water to feed ratio used more additional water than those on the higher water to feed ratios.

The objective of this experiment was to investigate further the improvement in performance noted by Gill, (1989), by studying how efficiently feed is utilised by growing pigs at different water to feed ratios.

Materials and Methods

Experimental design and treatments

Four treatments with four replicates were arranged within the metabolism test house in a completely randomised design. The four treatments were as follows:

A water to feed ratio 1.63:1
B water to feed ratio 2.13:1
C water to feed ratio 2.63:1
D water to feed ratio 3.25:1

The water to feed ratios stated above are water to fresh weight of feed ratios assuming the feed is air dried and has a dry matter of 85%. The water to dry matter feed ratios are given below.

A water to DM feed ratio 2:1
B water to DM feed ratio 2.67:1
C water to DM feed ratio 3.33:1
D water to DM feed ratio 4:1

Animals and housing

Sixteen Large White (Large White x Landrace) entire males were taken from the second stage weaner accommodation ear tagged for identification purposes and randomly assigned to the four treatments. The pigs were kept in metabolism crates in a test room maintained at 22^{0}C for a total period of twenty days. Boars were selected in order that faeces and urine could be collected separately as the metabolism crates were not adapted for gilts. The pigs were weighed before entering the crates, at the beginning of the experimental period and again at the end of the trial period. The first ten day period was a preliminary period in order for the pigs to

Table 7.1 Proximate and mineral analyses of the feed used in Experiment 3

Dry matter (%)	85.2
Digestible energy (MJ/kg DM)	15.4
Crude protein (g/kg DM)	20.8
Crude fibre (g/kg DM)	29.0
Neutral detergent fibre (g/kg DM)	129
Oil (Acid hydrolysis) (g/kg DM)	25.0
Total ash (g/kg DM)	71.0
Calcium (g/kg DM)	15.0
Phosphorous (g/kg DM)	10.3
Magnesium (g/kg DM)	1.5
Sodium (g/kg DM)	2.6
Potassium (g/kg DM)	5.5
Chloride (g/kg DM)	3.1

grow accustomed to the confinement of the metabolism crate and the wet feeding system. The second ten day period was the trial period in which the samplings were made. The initial weight at the beginning of the trial period was 30.9 ± 2.45 kg. The pigs were fed a meal ration formulated from wheat, barley and soya, according to a scale which allowed 115 g food/kg $W^{0.75}$. Mineral and proximate analysis of the feed are given in Table 7.1. The ration was split into two feeds per day, 09.00 hrs and 16.00 hrs. During the trial period there were no feed refusals. The only water available to the pigs was that provided with the feed.

Experimental procedures

Samples of the feed were taken at the beginning and end of the experiment. The feed was analysed for percentage dry matter, percentage crude protein and gross energy content.

Faeces were collected under sulphuric acid, maintaining the acidity at pH 5, over the 10 day trial period. The collection of faeces was weighed, mixed thoroughly and a sample taken. The faeces were analysed for percentage dry matter, percentage crude protein and gross energy content.

Urine was filtered through a copper gauze and collected under sulphuric acid maintaining the pH at 2-3. Two 100 ml samples were retained for analysis. The urine was analysed for percentage crude protein.

Results

With one exception, the health of the pigs was good. One pig was removed from the crates during the preliminary period suffering from a rectal prolapse. Treatment means are presented in Table 7.2. The data shows that digestibility is significantly increased as water to feed ratio is increased ($p<0.05$). There were no significant differences between treatments for digestible energy and nitrogen retention, however both D.E. and nitrogen retention increased numerically as water to feed ratio increased. Between 2.13:1 and 3.25:1, there was a difference in estimated D.E. of 0.84 MJ/kg DM. There were no significant differences in average daily live weight gain.

Linear regression of individual pig values of digestibility, estimated digestible energy and nitrogen retention against water to feed ratio gave the following equations:

$Y1 = 74.3 + 2.44\ X1$	$R^2 = 29.9\%$	($p<0.05$)
$Y2 = 14.3 + 0.437\ X1$	$R^2 = 31.5\%$	($p<0.05$)
$Y3 = 1.15 + 0.176\ X1$	$R^2 = 10.1\%$	($p>0.05$)

Where Y1 = digestibility (%)
Y2 = estimated D.E. (MJ/kg DM)
Y3 = nitrogen retention (MJ/kg $W^{0.75}$/day)
X1 = water to feed ratio

Analysis of variance of the above regression lines showed that for digestibility and estimated digestible energy the lines were significant representations of the data, however they only accounted for 29.9% and 31.5 % of the variation respectively. The regression equation for nitrogen retention on water to feed ratio was not a significant representation of the variation which is also reflected by the lower coefficient of determination.

Table 7.2 The effect of water to feed ratio on dry matter digestibility estimated D.E., nitrogen retention and pig performance.

	Water to feed ratio (fresh weight) 1.63:1	2.13:1	2.63:1	3.25:1	$S.E._D$	P
Digestibility (%)	79.12[a]	77.78[a]	80.30[ab]	82.93[b]	1.48	*
Estimated D.E. (Mj/kg DM)	15.16	14.96	15.41	15.80	0.26	N.S.
Nitrogen retention (Mj/kg W0.75/day)	1.49	1.40	1.63	1.74	0.19	N.S.
Mean daily live-weight gain (g)	572	536	580	517	31.7	N.S.
Mean initial weight (kg)	31.3	30.8	30.2	31.4	1.98	N.S.

Means bearing the same superscript are not significantly different

When the regression analysis is extended to include a second predictor variable, namely pig average live weight, the following regression equations are produced:

$$Y1 = 59.6 + 2.50\ X1 + 0.434\ X2 \qquad R^2 = 44.2\% \qquad (p<0.01)$$
$$Y2 = 11.7 + 0.446\ X1 + 0.0769\ X2 \qquad R^2 = 46.4\% \qquad (p<0.01)$$
$$Y3 = 1.73 = 0.174\ X1 + 0.0171\ X2 \qquad R^2 = 5.4\% \qquad (p>0.05)$$

where Y1 = digestibility (%)
Y2 = estimated D.E. (MJ/kg DM)
Y3 = nitrogen retention (MJ/kg $W^{0.75}$/day)
X1 = water to feed ratio
X2 = average live weight (kg)

By including average live weight as a predictor, it can be seen that the regression lines for digestibility and estimated D.E. are now more significant representations of the data ($p<0.01$). The coefficients of determination have correspondingly increased. The regression line for nitrogen retention has remained non significant.

Discussion

The results show that by changing the water to feed ratio of the feed, the mean dry matter digestibility was significantly affected with the highest digestibility being recorded at the highest water to feed ratio. Average estimated D.E. was not significantly affected, however when individual values were used in a regression against water to feed ratio the regression equation obtained was a significant representation of the data.

The increase in the significance of the analysis of variance of the regression lines when average live weight is included as a predictor would suggest that not only is digestibility and estimated D.E. of the feed affected by water to feed ratio but also by average live weight. There was no significant difference in the mean average live weights of the pigs on trial. However the significant regression line shows that within treatment differences in digestibility and estimated D.E. were associated with corresponding within treatment differences in average weight.

No differences in pig performance were recorded although differences in the biological value of the food were detected. The experiment was not undertaken over a long enough period in order that differences in pig performance, resulting from the better utilisation of the feed, could be detected. The experiment conducted by Gill, (1986) shows a significant difference in pig performance for pigs fed at higher water to feed ratios.

These results support the work of Gill, (1986), suggesting that the reason for increased live weight gain and F.C.R. with increasing water to feed ratio was due to greater digestibility and digestible energy value of the feed.

In a study on the effect of the amount of water on the rate of passage of food, Castle and Castle, (1956) reported that between water to feed ratios of 1.5:1 to 3.75:1 there was no significant difference in the digestibility of the dry matter of the faeces or crude protein of the ration. Between the treatment water to feed ratios of 1.5:1 to 2.25:1 there was no significant difference in mean retention time. When the water to feed ratio increased to 3.75:1 there was a significant decrease in mean retention time.

The main conclusion that can be drawn from the results of this experiment (and that of Gill et al.,1986) is that there is still a lack of reliable data concerning the water to feed ratios that should be recommended for the wet fed pig. The recommendations published by the A.R.C (1981) and the Codes of Recommendations for the Welfare of Livestock : Pigs (1983) are unsatisfactory.

The results of this experiment suggest that the digestibility and digestible energy of a feed may depend on the water to feed ratio at which the feed is fed. Consequently the results from experiments conducted to evaluate the digestibility and D.E. of feeds may have attributed incorrect values to raw materials or values which apply to one set of circumstances. Experiments which have been conducted using fixed (and low) water to feed ratios and denying pigs additional water may have resulted in significant underestimation of nutrient value. The problem will have been exacerbated where raw materials under test were of high mineral content or contained excess/or unbalanced protein, both of whom would increase water demand.

Experiment 4: A comparison of water use by early weaned pigs from 3 to 5 weeks of age fed on four different diets.

Introduction

The early weaning of piglets at 3 weeks of age is now a relatively common practice. Suckling piglets at 3 weeks of age obtain as much as 80% of their water requirements from water in the milk, Aumaitre (1964). The process of weaning abruptly separates the piglet's water supply away from their source of nourishment. The intake of drinking water during this period is therefore of great importance and has until recently been ignored as the relative quantities involved are small. In two recently published studies by Brooks *et al.*,(1984) and Gill *et al.*,(1986) the estimated water requirements of early weaned pigs differed by as much as 30% (see Table 3.2). The objective of this experiment was to increase the amount of data available on the water requirements of early weaned pigs and to evaluate the effects of four different feeds on the these requirements.

Materials and methods

Experimental design and treatments

The performance and water use of early weaned pigs fed one of four diets was evaluated. The treatment diets from here on referred to as A,B,C and D were replicated through four pens replicates in space and in time according to a Latin Square Design. Therefore at the end of the experiment each treatment would have occurred once in each pen and once in each time period.

Animals and housing

Sixteen groups consisting of 5 entire male and 5 female Large white x (Large White x Landrace) were selected. The piglets weaned at 21 ± 2 days, were ear tagged for identification and weighed. The average weaning weight was 5.86 ± 0.18 kg. As far as possible the groups were balanced for litter and weaning weight. At the beginning of each time period 4 groups were randomly allocated to one of the four treatment pens in a flat-deck early weaner house. The house was maintained at a near constant temperature (nominally 27°C throughout the period of the trial.

Each pen, measuring 1.45 x 1.25 m, was supplied with water from a low pressure water system via two Arato 76 tube drinkers (Figure 1.5) mounted 0.25 m above the wire mesh floors, allowing *ad libitum* access to the water. The pressure head of water was 1.3 m producing a water delivery rate at the drinkers of 175 cm^3/min.

The piglets were fed in troughs measuring 1.43 m x 0.2 m. In order to maintain a supply of fresh feed, additions were made at 0830 hours and 1630 hours each day. The proximate and mineral analysis of the treatment feeds are presented in Table 8.1. This piece of research was undertaken for Dalgety Agriculture Ltd. and therefore the raw material composition of the diets is confidential.

Table 8.1 Proximate and mineral analyses of the four feeds used in Experiment 4

	A	B	C	D
Dry matter (%)	91.9	90.7	91.3	91.0
Digestible energy (MJ/kg DM)	17.0	17.0	16.8	16.7
Crude protein (g/kg DM)	24.8	24.3	24.1	23.6
Crude fibre (g/kg DM)	26.0	28.0	22.0	22.0
Neutral detergent fibre (g/kg DM)	75.0	93.0	87.0	91.0
Oil (Acid hydrolysis) (g/kg DM)	63.0	72.0	71.0	72.0
Total ash (g/kg DM)	73.0	66.0	79.0	77.0
Calcium (g/kg DM)	9.9	7.6	12.8	12.6
Phosphorous (g/kg DM)	7.8	6.7	9.0	9.5
Magnesium (g/kg DM)	1.5	1.5	1.5	1.3
Sodium (g/kg DM)	3.6	2.9	3.6	3.4
Potassium (g/kg DM)	9.7	8.6	9.2	8.8
Chloride (g/kg DM)	7.9	5.4	6.0	5.9

Experimental procedures

All feed inputs were recorded and soiled feed was removed and weighed when necessary. Water use was metered using previously calibrated Kent PSM-L waters and was recorded daily at 0830 hours. Piglets were individually weighed weekly and remained on trial for 2 weeks. The temperature of the flat deck house was monitored using a previously calibrated Thermograph.

Results

The health of all experimental animals was good, with no deaths nor incidence of scour. Mean daily temperature in the building varied between 21.15 ^{0}C and 26.73 ^{0}C, significantly less than the prescribed temperature. This was probably due to a faulty or inaccurate thermostat, or the difference between the location of the thermostat and the Thermograph. The Thermograph was placed 1 m above the pen floors whereas the thermostat probe was above the central passage. Although absolute temperature is very important for comparison between different experiments data from the Thermograph can be used to show relative differences between different days.

Water use, feed intake and performance data for each treatment feed are presented in Table 8.2. There were no significant differences between the four treatments for water use feed intake, or for any other of the parameters measured.

As there was no significant difference in water use between the

Table 8.2 Water use, feed intake and performance of early weaned piglets from 3 to 5 weeks of age fed on four different feeds.

	Treatment Feed					
	A	B	C	D	$S.E._D$	P
Water use (litres/piglet/day)	0.600	0.638	0.558	0.620	0.056	N.S.
Mean live weight gain (kg/day)	0.179	0.189	0.155	0.185	0.013	N.S.
Mean F.C.R.	1.19	1.24	1.43	1.23	0.103	N.S.
Mean feed intake (kg/day)	0.209	0.229	0.205	0.225	0.009	N.S.
Mean weight (kg) (trial period)	7.09	7.22	7.00	7.10	0.18	N.S.

treatment diets, the daily data for the four treatments (four replicates of each), was pooled to give figures of mean daily water use which were used in an analysis of regression against the number of days post weaning. These mean daily values are presented in Table 8.3.

Linear regression of the pooled water use data against the number of days post weaning gave the following equation:

$Y = 0.215 + 0.0517\ X \qquad R^2 = 93.6\% \qquad (p<0.001)$

Where Y = water use (litres/pig)
X = number of days post weaning

Analysis of variance of the above regression line showed that it was a highly significant representation of the data ($p<0.001$) and accounted for 93.6 % of the variation. When the data was examined more closely it was found that a curvilinear equation would produce a better fit than a simple linear regression line. Quadratic regression of the pooled water use data against the number of days post weaning produced the following equation:

$Y = 0.311 + 0.0158\ X + 0.00239\ X^2 \qquad R^2 = 96.1\% \qquad (p<0.001)$

Where Y = daily water use (litres/pig)
X = number of days post weaning

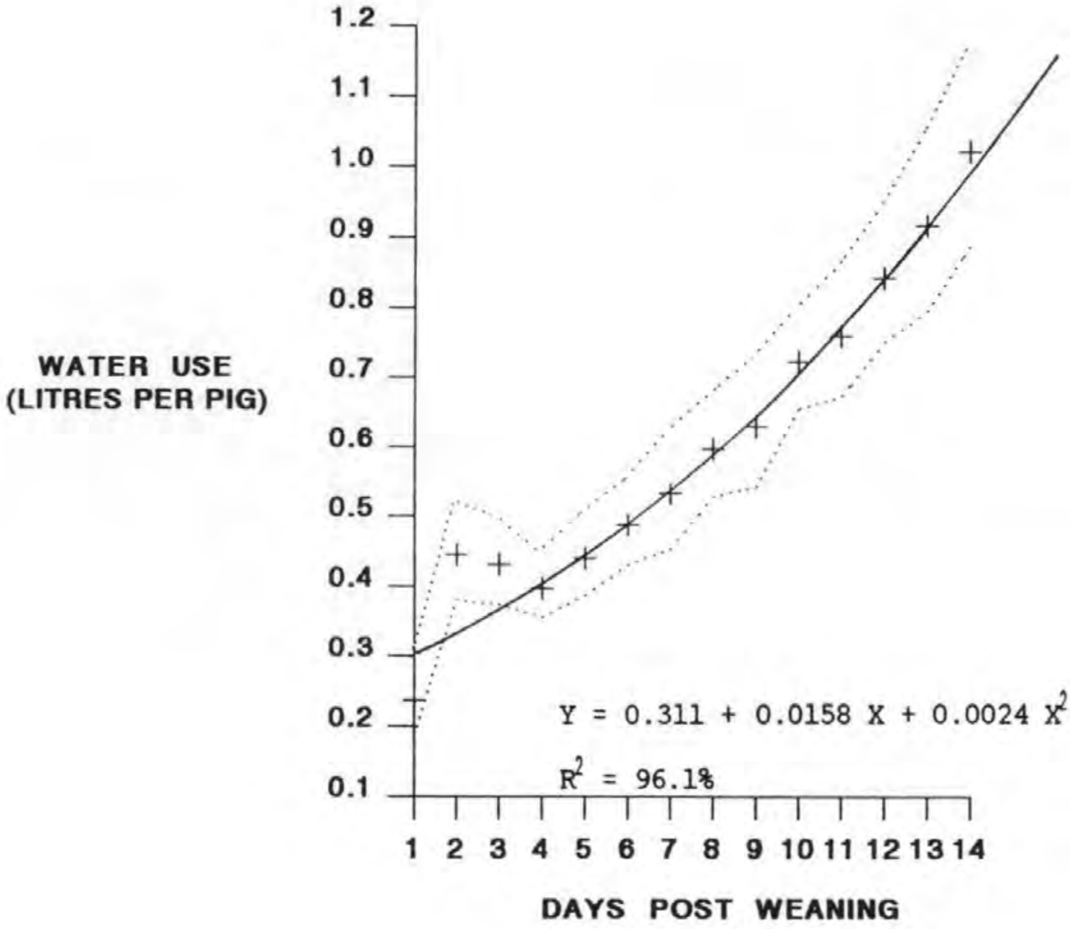
Analysis of variance of the above regression line again showed that it was a highly significant representation of the data, ($p<0.001$), the coefficient of determination increasing to 96.1 %. This relationship is shown in Figure 8.1 along with 99% confidence limits for mean values of water use.

Means from the 16 replicates have been used in a further analysis of regression to investigate the effects of feed intake and varying house temperature on water intake:

Table 8.3 Mean daily water use data from the four treatments for the 14 days post weaning period.

Days post weaning	Water use (litres/pig)	S.E.
1	0.236	0.020
2	0.444	0.026
3	0.431	0.023
4	0.396	0.016
5	0.439	0.021
6	0.486	0.022
7	0.531	0.031
8	0.596	0.027
9	0.629	0.034
10	0.721	0.026
11	0.758	0.034
12	0.840	0.035
13	0.916	0.047
14	1.022	0.052

Figure 8.1 The relationship between mean daily water use of the four treatments and the number of days post weaning.



(......) 99% confidence limits for mean values of water use

(———) Quadratic regression line

$$Y = 0.136 + 2.16\,X1 \qquad R^2 = 48.1\% \qquad p<0.002$$
$$Y = -0.083 + 0.0295\,X2 \qquad R^2 = 46.7\% \qquad p<0.002$$

Where Y = daily water use (litres/pig)
X1 = daily feed intake (kg/pig)
X2 = average daily temperature (^{0}C)

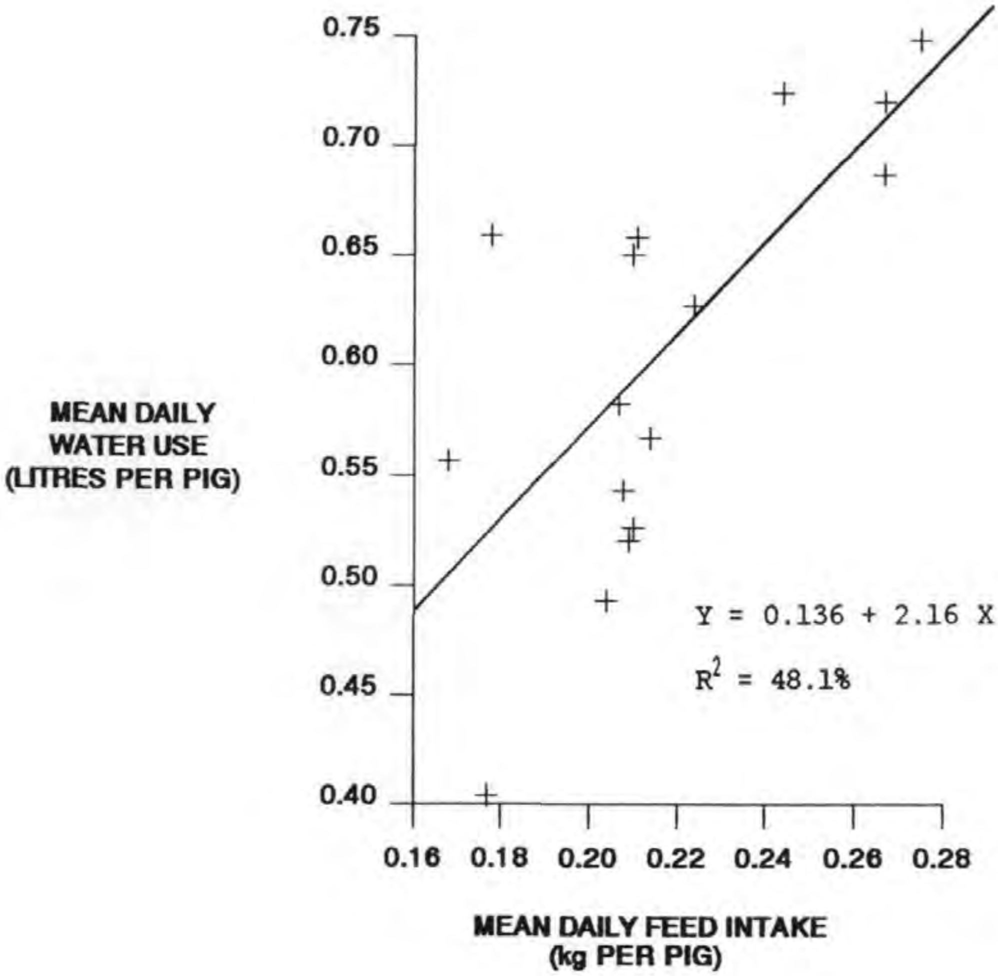
Although the coefficients of determination of the above two linear regression equations are not very high, analysis of variance of the lines showed that the equations accounted for a significant amount of the variation. These relationships are illustrated in Figures 8.2 and 8.3.

Discussion

The data in Table 8.2 showed that the diet type did not have a significant effect on the water use, feed intake or performance of the early weaned pigs in this study. However this study has produced a large amount of data on the daily water use of early weaned pigs.

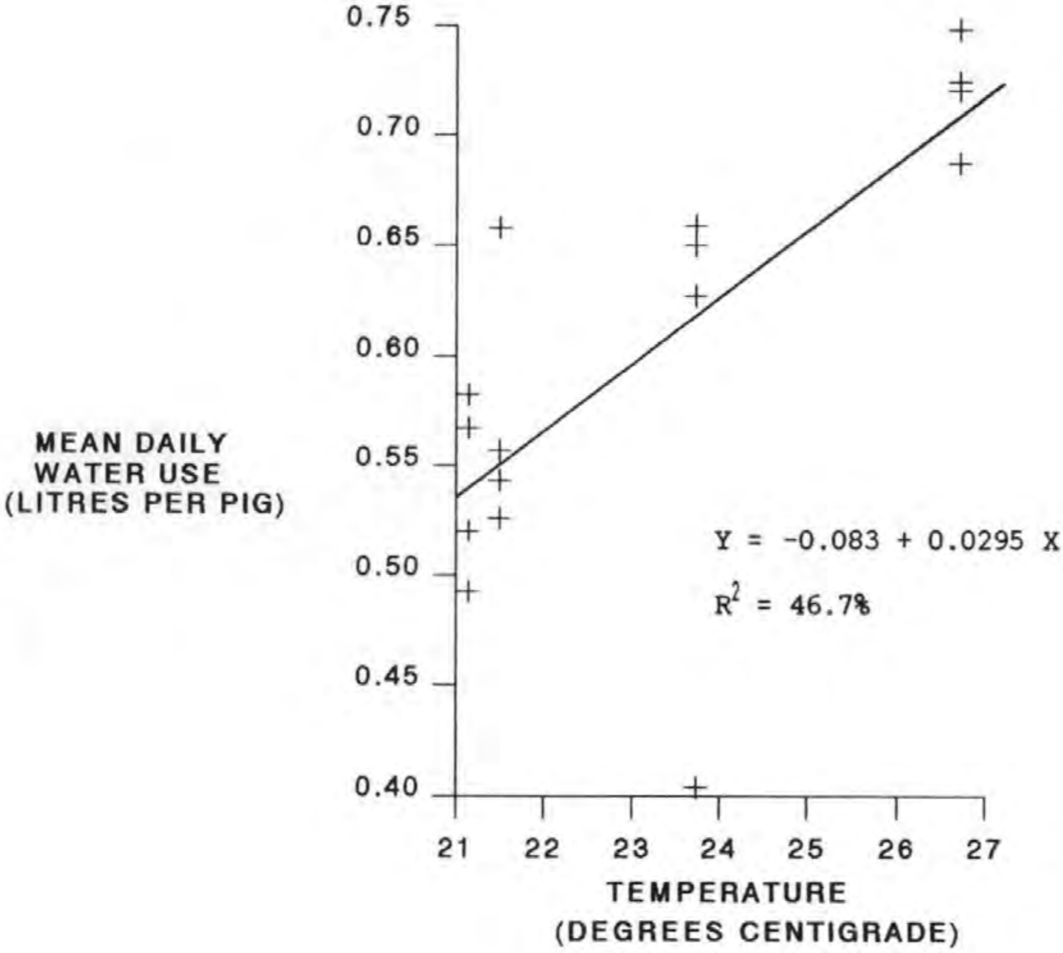
The pattern of daily water use immediately after weaning depicted by Figure 8.1 shows that the piglets required a long time to adapt to their new means of total water supply. Prior to weaning the piglets had been in farrowing pens where drinking water was available from similar type drinkers as used in this experiment. This was deliberate in order to try and minimise the problems associated with finding and learning to use drinkers or different type of drinkers. Water use in the first 24 hours after weaning was consistently low amongst replicate groups which does indicate that the piglets may have experienced difficulty in locating the drinkers or they just did not attempt to. Water use was then increased on days 2 and 3 indicating an over compensation as a result of the dehydration incurred on the first day. After day 4, a consistent pattern

Figure 8.2 The relationship between mean daily water use and mean daily feed intake.



(———) Linear regression line

Figure 8.3 The relationship between mean daily water use and mean daily temperature.



(———) Linear regression line

of water intake was established.The pattern of daily water use is similar to that reported by Brooks *et al.*,(1984) who investigated the 3 to 7 weeks period and Gill *et al.*,(1986) who worked with pigs of 3 to 6 weeks of age. In the 1984 experiment water use over the 3 to 5 week period averaged 0.97 litres/pig/day and for the 1986 experiment was 0.69 litres/pig/day compared to a mean value of 0.6 litres/pig/day. These results appear to be most similar to those of Gill *et al.*,(1986). This could be because the drinker type used in this experiment was the same as that used by Gill *et al.*,(1986). Gill suggests that the disparity between his results and those of Brooks *et al.*,(1984), is most likely due to the fact that Brooks *et al.* used a different type of drinker which was designed to minimise losses through leakage, however the manufacturers of the Arato 76 used by Gill and in this study claim that their product reduces water losses by directing a correct stream of water to the rear of the piglet's mouth. In all three studies it was not possible to measure the proportion of water wasted. Gill suggested that the differences in the values for water use could be attributed to differences in water wastage from the two types of drinker as a result of leakage and spillage during play. In both of the earlier studies no reference is made to the water delivery rate.

Both this experiment and that of Gill *et al.*,(1986), produced equations from linear regression analysis which can be tested to establish whether they are significantly different.

$Y = 0.19 + 0.07\ X$ $\quad R^2 = 67.4\%$ $\quad$ (Gill)

$Y = 0.215 + 0.0517\ X$ $\quad R^2 = 93.6\%$ $\quad$ (Experiment 4)

where Y = water use (litres/pig/day)
X = number of days post weaning

Both of the above regression lines account for a significant amount of the variation. The equation calculated from the data from this experiment has a higher coefficient of determination than that of Gill. Without calculating the variance for Gill's data it is only possible to compare the intercepts and regression coefficients of the two equations. T-ratios are calculated using the following expressions:

$$\text{t-ratio intercept} = \frac{a-h0}{\text{standard deviation of the intercept}}$$

$$\text{t-ratio gradient} = \frac{b-h1}{\text{standard deviation of the gradient}}$$

where a = calculated intercept
b = calculated gradient
h0 = intercept from Gill's equation
h1 = gradient from Gill's equation

t-ratio intercept = 0.785 ($p>0.05$)
t-ratio gradient = -4.89 ($p<0.001$)

From this analysis it can be seen that the intercepts of the two lines do not differ significantly however, the regression coefficients are significantly different ($p<0.001$) indicating that the rate of increase in water use with days post weaning was different. This may be due to the fact that the regression line produced by Gill was derived from data for 3 to 6 weeks of age compared to Experiment 4 which was for 3 to 5 weeks of age.

The regression of mean water use against mean daily feed intake produced a regression line which was a significant representation of the data. Gill made a detailed regression analysis of water use against feed intake concluding that a curvilinear regression equation gave a better representation of his data. However such a detailed analysis has not been carried out with the data from Experiment 4 as daily feed intakes were not recorded. Despite this, it is still possible to compare the linear regression equation of water use against feed intake produced by Gill with that of this experiment.

$Y = 0.05 + 2.18 X$	$R^2 = 79\%$	(Gill)
$Y = 0.136 + 2.16 X$	$R^2 = 51.1\%$	(Experiment 4)

Both of the above regression lines account for a significant amount of the variation ($p<0.002$). The coefficient of determination of this experiment is lower because the analysis has not involved daily feed intakes and mean values for the whole period have been used.

t-ratio intercept = 0.0703 ($p>0.05$)
t-ratio gradient = - 0.143 ($p>0.05$)

From this analysis it can be seen that neither the intercepts nor the gradients of the two lines differ significantly.

Figure 8.3 showed that mean daily water use was significantly affected by the mean environmental temperature over the experimental period.

This experiment produced data which is largely in agreement with other authors and which can be built on in later experiments. It showed that water requirement does depend on feed intake and varies according to temperature. Therefore when making recommendations for the water requirements of early weaned pigs these two factors must be taken into account.

Experiment 5: A comparison of water use between four bite type drinkers by growing pigs fed on a scale based on metabolic body weight.

Introduction

Some of the differences in water use between independent studies on the same class of pigs could be due to differences in water wastage attributable to the type of drinker used. Gill,(1989) showed that water use was significantly higher (74%) from Mono-flo nose operated drinkers ($p<0.001$) than from Arato 80 bite drinkers.

The aim of this experiment was to investigate the water use of growing pigs and to determine the extent to which water use was affected by drinker type.

Materials and methods

Experimental design and treatments

The water use and performance of growing pigs supplied with water from one of four bite drinker types was investigated. The four treatment drinkers evaluated were as follows:

1 Jalmarson 1760 (Figure 1.5)
2 Arato 80 (Figure 1.3)
3 Lubing 6026 (Figure 1.4)
4 Arato 76 (Figure 1.6)

The treatments were replicated through four pens and in time according to a 4 X 4 Latin Square design. At the start of the trial one drinker was randomly allocated to each pen. They were then rotated around the pens every 14 days according to the design so that at the end of the experiment each drinker treatment would have occurred once in each pen.

Animals and Housing

The pigs were individually weighed at the start of the trial and ear tagged for identification purposes. Four groups of Large White X (Large White X Landrace) pigs consisting of four gilts and three boars (initial mean weight 28.5 ± 3.6 kg) were assigned to the four treatment pens, balancing the groups according to weight, in a performance test house. The pigs where housed in the pens for four days prior to the commencement of the trial in order to accustom them to the environment and the feeding regime.

Water was available *ad libitum* to each pen group from a single drinker mounted on a variable height bracket. The height was initially set at 0.5 m from the ground as specified by the manufacturer, drinker height being increased by an equal amount in each pen to maintain recommended drinking attitude as the pigs grew. The drinkers were aligned at a 15^0 decline from the ground. The water was supplied from the mains supply (via an anti back siphon device) and metered through previously calibrated Kent PSM-L water meters. The pressure head of water was maintained at 10 m by the use of a pressure regulator and the regulating devices within the treatment drinkers were altered to give an average water delivery rate of 600 cm^3/min.

Table 9.1 Proximate and mineral analyses of the feed used in Experiment 5

Dry matter (%)	86.4
Digestible energy (MJ/kg DM)	14.5
Crude protein (g/kg DM)	21.0
Crude fibre (g/kg DM)	41.0
Neutral detergent fibre (g/kg DM)	140
Oil (Acid hydrolysis) (g/kg DM)	32.0
Total ash (g/kg DM)	96.0
Calcium (g/kg DM)	16.2
Phosphorous (g/kg DM)	7.2
Magnesium (g/kg DM)	2.2
Sodium (g/kg DM)	2.2
Potassium (g/kg DM)	8.3
Chloride (g/kg DM)	2.9

The pigs were fed individually in troughs twice per day on metabolic body weight scale of 100 g/kg $W^{0.75}$. The feed was formulated from wheat, barley and soya. Proximate and mineral analysis of the feed is given in Table 9.1. The daily meal allowance was mixed with an equivalent weight of water immediately before feeding. This was necessary in order for the pigs to consume all of their ration.

A maximum and minimum thermometer was used to record temperature and was positioned as close to the pigs as possible whilst remaining out of their reach.

Experimental procedures

Pigs were weighed at the start of the experiment and then every week in order to determine their ration allowance.

Water use was recorded daily at 8.45 am. Water delivery rates were checked once per week to prevent fluctuations throughout the trial.

The pigs were fed at 0830 hrs and 1600 hrs, the amount of feed given was recorded. The pigs were allowed 30 minutes to eat their allocated ration after which the rejected feed was removed from the troughs and weighed. A small sample of the rejected feed was kept, weighed and oven dried at 100^{0}C for 24 hours to determine the unconsumed fractions of meal and water.

Maximum and minimum temperatures were recorded daily at 0845 hrs.

Table 9.2 Water use, feed intake and performance of growing pigs offered water from four different bite drinker types.

	Treatment Drinker					
	1	2	3	4	$S.E._D$	P
Water use (litres/pig/day)	3.57	4.37	3.26	3.63	0.32	N.S.
Mean live weight gain (kg/day)	0.753	0.732	0.722	0.722	0.028	N.S.
Mean F.C.R.	2.28	2.29	2.34	2.33	0.074	N.S.
Mean weight (kg)	47.21	47.93	51.97	46.65	3.88	N.S.

Treatment drinkers:

1 Jalmarson 1760
2 Arato 80
3 Lubing 6026
4 Arato 76

Results

The health of all experimental animals was good, with no deaths nor any incidence of scour. Mean daily temperature in the test building decreased from 17.8 ^{0} C during the first 14 day period to 15.7 ^{0} C in the fourth 14 day period. This was due to a fall in the external environmental temperature from October to December, (see Table 9.3).

Water use and performance data for each drinker treatment are presented in Table 9.2. Analysis of variance showed that the type of bite drinker employed had no significant effect on the amount of water used by the pigs ($p>0.05$). There were no significant differences in mean live weight gain nor feed conversion ratio ($p>0.05$). There was no significant difference between mean weight during the experiment and as feed ration was dependent on a live weight scale there were no significant difference in feed intakes (feed refusals were minimal).

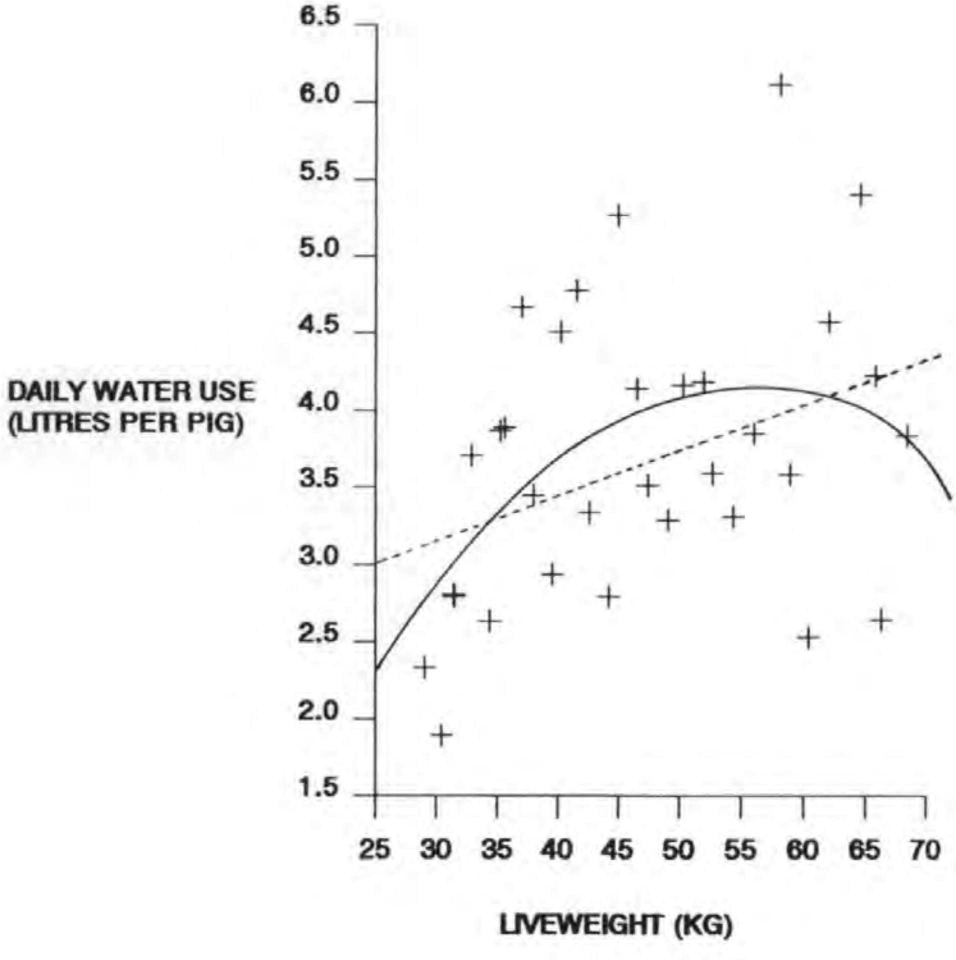
As there was no significant difference in water use between the four treatments, the treatment weekly data was used in an analysis of regression against weight:

$$Y = 2.38 + 0.0282\,X \qquad R^2 = 9.7\% \qquad (p=0.046)$$

Where Y = water use (litres/pig/day)
X = body weight (kg)

Analysis of variance of the above regression line showed that it was a significant representation of the data, however it only accounted for 9.7% of the variation ($p<0.05$). When the data was examined more closely it was found that a curvilinear equation would produce a better fit than a simple linear regression line. Quadratic regression of the pooled water

Figure 9.1 The relationship between mean daily water use and mean live weight for all the four treatments.



(-----) Linear regression line
$Y = 2.38 + 0.00282\ X$

(——) Quadratic regression line
$Y = -2.58 + 0.247\ X - 0.00226\ X^2$

Where Y = water use (litres/pig/day)

X = body weight (kg)

use data against mean weight produced the following equation:

$Y = -2.58 + 0.247\,X - 0.00226\,X^2$ $R^2 = 16.0\%$ $(p=0.03)$

Where Y = water use (litres/pig/day)
X = body weight (kg)

Analysis of variance of the above regression line showed that it was a significant representation of the data, the coefficient of variation increasing from 9.7% to 16.0%. Both the above relationships are illustrated in Figure 9.1.

The data in Table 9.3 shows that the weekly increase in water use is greater at the start of the experimental period than towards the end and the mean house temperature slowly reduces. This suggests that the reduction in temperature is possibly having an effect on the water use as live weight increases linearly. In Experiment 4, temperature was found to have a significant negative effect on water use, that is less water was used at the lower temperatures.

Regressing the water use against mean live weight and mean house temperature gave the following equation:

$Y = -4.13 + 0.0497\,X1 + 0.327\,X2$ $R^2 = 8.3\%$ $(p=0.109)$

Where Y = water use (litres/pig/day)
X1 = body weight (kg)
X2 = temperature (^{0} C)

Analysis of variance of the above regression line showed that the line was not a significant representation of the data. This shows that house temperature did not have a significant effect on water use in this analysis. However the equation does show that the trend was for water use to increase as temperature increased which is similar to the findings of Experiment 4.

Table 9.3 Water use data pooled from the four treatments for the 8 weeks of the trial period.

Weeks of trial	Water use (litres/pig/day)	S.E	Mean weight (kg)	S.E.	Temperature (degrees C)
1	2.46	0.33	30.5	0.53	17.36
2	3.53	0.50	34.54	0.55	18.29
3	3.89	0.46	38.72	0.61	17.64
4	4.05	0.54	43.45	0.62	16.78
5	3.78	0.33	48.38	0.65	16.86
6	3.73	0.30	53.80	0.68	16.50
7	4.20	0.62	59.94	0.66	15.71
8	4.04	0.53	66.37	0.63	15.64

Discussion

The results of this experiment support the findings of Lightfoot, (1985), and Gill (1989). Lightfoot compared the water use from the Arato, Jalmarson and Lubing bite drinkers for pigs of mean weight of approximately 60 kg. No significant difference in water use or pig performance were found. When actual values of water consumption are compared, from the data available, Lightfoot found that at a mean live weight of 60 kg water use was 5.5 litres/pig/day compared with 4.2 litres/pig/day for this experiment. The house temperature in Lightfoot's experiment was set at 18 ^{0}C compared to a mean measured temperature of 16.8 ^{0}C in this experiment. This might account for the difference in water use figures between the two experiments. There may also have been differences in water delivery rate between the two experiments but Lightfoot provides no information on delivery rates in his study. Also Lightfoot makes no mention of his metering methods nor their accuracy.

In a comparison between four different types of drinker, Gill,(1989) showed no significant difference between the Lubing 6026 and the Arato 80. When actual values of water use are compared, Gill,(1989) recorded water use for both the Lubing and Arato drinkers at a mean live weight of 55 kg to be 5.0 litres/pig/day as opposed to 3.9 litres/pig/day at the same weight for this experiment.

This apparent difference in water use may be a result of different house temperatures but Gill makes no reference to temperature. Also the water delivery rate in Gill's experiment was 670 cm^3/min compared to 600 cm^3/min in this experiment which may have contributed to the difference in water use.

It is difficult to compare results from similar experiments such as these when authors omit what now appears to be important reference data.

Mount et al.,(1971) showed that as temperature increased there was a corresponding increase in water consumption. Within the temperature range 7 to 20^{0}C there was no significant increase in water use. At temperatures in excess of 30^{0}C water consumption increased significantly. In this experiment temperature did not have a significant effect on water use but this was probably due to the fact that the temperature range only varied between 15.6 and 18.3^{0}C.

Part 2: An investigation into water delivery rate as a major factor affecting the water use of pigs of different classes.

Experiment 6: The effects of drinker type and water delivery rate on the water use of growing pigs fed on a scale based on metabolic body weight.

Introduction

It has been reported that drinking utensil type has a significant effect on water use. Gill, (1986) showed that scale fed pigs used 75.6% more water from Mono-flo drinkers (nose operated drinkers) than from Arato 80 drinkers (bite type drinkers). When making an examination of the drinkers, it was noticed that at a water pressure head of 2 m, water delivery from Mono-flo drinkers was considerably greater than from unrestricted Arato 80 drinkers (2000 cm^3/min compared with 1000 cm^3/min).

The U.K. is unusual in having low pressure drinking water supply systems due to the use of header tanks, (see section 5.6). Most of the rest of the World use high pressure systems. A large proportion of the drinkers used in this country have been imported and were developed for use with high water pressure. Therefore when used at lower pressures, they may not deliver as much water as required.

Mono-flo drinkers are relatively cheap and are sold without any means of regulating the water delivery rate however most bite drinkers have a means of delivery rate adjustment, either by the use of different sized plastic restricter apertures as in the case of the Arato 80 or a screw which adjusts the size of the aperture.

It was considered that the difference in water use observed by Gill, (1989) may have resulted from differences in water delivery rate from different drinkers rather than or in addition to differences in the design of the drinker. The objective of this experiment was to investigate the effects of two different flow rates in Mono-flo nose operated drinkers and Arato 80 bite drinkers.

Materials and methods

Experimental design and treatments

The water use and performance of growing pigs supplied with water from either Arato 80 or Mono-flo drinkers at water delivery rates of either 300 cm^3/min or 900 cm^3/min was investigated. The four treatments were therefore as follows:

1 Arato 80, 300 cm^3/min
2 Mono-flo, 300 cm^3/min
3 Arato 80, 900 cm^3/min
4 Mono-flo, 900 cm^3/min

Diagrams of the drinkers used are given in Chapter 1. The treatments were replicated through four pens and in time according to a 4 X 4 Latin Square design. At the start of the trial the treatments were randomly assigned to a specific pen and remained in that treatment pen throughout the trial period. The four groups of animals were rotated around the pens every 14 days according to the design so that at the end of the experiment each group of animals had spent two weeks on each treatment.

Animals and housing

The pigs were individually weighed at the start of the trial and ear tagged for identification purposes. Four groups of Large White X (Large White X Landrace) pigs consisting of four gilts and four boars (initial mean weight 25.2 ± 1.9 kg) were assigned to the four treatment groups, balancing groups according to weight, in a performance test house. The pigs were housed in the test house for four days prior to the start of the trial in order to accustom them to the environment and the feeding regime.

Water was available *ad libitum* to each pen from a single treatment drinker mounted on a variable height bracket. The height was initially set at 0.4 m from the ground as specified by the manufacturer, drinker height being increased by an equal amount in each pen to maintain the recommended drinking attitude as the pigs grew. The drinkers were aligned at a 15° decline from the ground. Different water delivery rates in the Arato drinkers were achieved by varying the internally fitted plastic restricter apertures. To vary the water delivery rate in the Mono-flo drinkers the mounting bracket had to be altered to accommodate similar restricter apertures. The delivery rates selected were checked weekly and remained within 5% of the nominal values. The water was supplied from a low pressure header tank system and metered through previously calibrated Kent PSM-L water meters. The pressure head of water was 2 m.

Table 10.1 Proximate and mineral analyses of the feed used in Experiment 6

Dry matter (%)	85.2
Digestible energy (MJ/kg DM)	15.4
Crude protein (g/kg DM)	20.8
Crude fibre (g/kg DM)	29.0
Neutral detergent fibre (g/kg DM)	129
Oil (Acid hydrolysis) (g/kg DM)	25.0
Total ash (g/kg DM)	71.0
Calcium (g/kg DM)	15.0
Phosphorous (g/kg DM)	10.3
Magnesium (g/kg DM)	1.5
Sodium (g/kg DM)	2.6
Potassium (g/kg DM)	5.5
Chloride (g/kg DM)	3.1

The pigs were fed individually in troughs a ration based on a metabolic weight scale of 110 g/kg $W^{0.75}$ twice per day. The feed was formulated from wheat, barley and soya to meet A.R.C. (1981) nutrient requirements for growing pigs. Proximate and mineral analyses of the feed is given in Table 10.1. The daily meal allowance was mixed with an equivalent weight of water immediately before feeding. This was necessary in order for the pigs to consume all of their ration.

The temperature of the test house was recorded using two previously calibrated Thermographs positioned as close to the pigs as possible whilst remaining out of their reach.

Experimental procedures

The pigs were weighed at the start of the experiment and then every week in order to determine their ration allowance.

Water use was recorded daily at 0845 hrs. The pigs were fed at 0830 hrs and 1600 hrs, recording the amount of feed given. The pigs were allowed 30 minutes to eat their allocated ration after which the rejected feed was removed from the troughs and weighed. A small sample of the rejected feed was kept, weighed, oven dried at 100°C for 24 hrs and weighed again to determine the unconsumed fractions of meal and water.

Results

The health of all the experimental animals was good, with no deaths nor incidence of scour. There were no feed refusals during the trial period. Mean daily temperature increased from 14.0°C at the start of the trial to 17.6°C at the finish. This was due to the seasonal increase in external environmental temperature and the inability of the house ventilation system to maintain low temperatures in hotter weather.

Pig performance and water use data is presented in Table 10.2. Analysis of variance showed that neither drinker type nor water delivery rate had a significant effect on feed intake, daily live weight gain or feed conversion ratio (P>0.05).

There was no significant difference in voluntary water use at the lower delivery rate between the two drinker types nor was there a significant difference between the Arato drinker at the high delivery rate and the Mono-flo drinker at the lower delivery rate (P>0.05). However voluntary water use was significantly different for the Arato drinker type between the two water delivery rates (P<0.01). The Mono-flo drinker employed at the higher water delivery rate dispensed significantly more water than any of the other three treatment combinations (P<0.01).

Treatment differences in total water use mirror those of voluntary water use as there was no significant difference in feed intake (water with the feed was given in a ratio of 1:1).

Factorial analysis of the voluntary water use data showed that both drinker type and water delivery rate were significant factors affecting water use. Water delivery rate had a more significant effect (P<0.001) than drinker type (P<0.01). The interaction between drinker type and water delivery rate was not significant (P>0.05).

Table 10.2 Water use, feed intake and performance of growing pigs offered water from Mono-flo and Arato 80 drinkers a 300 and 900 cm^3/min.

Drinker type Water delivery rate (cm^3/min)	Arato 300	Monoflo 300	Arato 900	Monoflo 900	S.E.$_D$	P
Voluntary water use (litres/pig/day)	2.25^{a}	2.68^{ab}	2.97^{b}	4.00^{c}	0.24	0.002
Mean live weight gain (kg/day)	0.802	0.806	0.794	0.812	0.06	N.S.
Mean F.C.R.	2.43	2.38	2.39	2.36	0.08	N.S.
Mean feed intake (kg/pig/day)	1.92	1.91	1.91	1.91	0.1	N.S.
Total water use (litres/pig/day)	4.18^{a}	4.59^{ab}	4.88^{b}	5.91^{c}	0.23	0.002
Mean weight (kg)	45.2	45.0	45.0	44.9	0.28	N.S.

a,b,c means bearing the same superscript are not significantly different.

A detailed analysis was undertaken for each treatment consisting of linear regression and curvilinear quadratic regression of voluntary water use against live weight and with the additional parameter of house temperature. Daily voluntary water use was averaged for each week for regression against mean weekly live weight. The following equations were produced:

1 Arato 80, 300 cm^3/min

(a) $Y = 0.575 + 0.0372\ X1$	$R^2 = 75.2\%$	$(P=0.03)$
(b) $Y = -2.27 + 0.167\ X1 - 0.00137\ X1^2$	$R^2 = 90.3\%$	$(P=0.01)$
(c) $Y = -2.04 + 0.172\ X1 - 0.00140\ X1^2 - 0.023\ X2$	$R^2 = 87.9\%$	$(P=0.09)$

2 Mono-flo, 300 cm^3/min

(a) $Y = 1.07 + 0.0358\ X1$	$R^2 = 67.3\%$	$(P=0.008)$
(b) $Y = -1.75 + 0.168\ X1 - 0.00144\ X1^2$	$R^2 = 80.9\%$	$(P=0.007)$
(c) $Y = -4.57 + 0.124\ X1 - 0.001200\ X1^2 + 0.271\ X2$	$R^2 = 78.9\%$	$(P=0.026)$

3 Arato 80, 900 cm^3/min

(a) $Y = 1.24 + 0.0384\ X1$	$R^2 = 57.7\%$	$(P=0.018)$
(b) $Y = -2.13 + 0.195\ X1 - 0.00169\ X1^2$	$R^2 = 69.6\%$	$(P=0.022)$
(c) $Y = -3.34 + 0.173\ X1 - 0.00156\ X1^2 + 0.123\ X2$	$R^2 = 62.4\%$	$(P=0.08)$

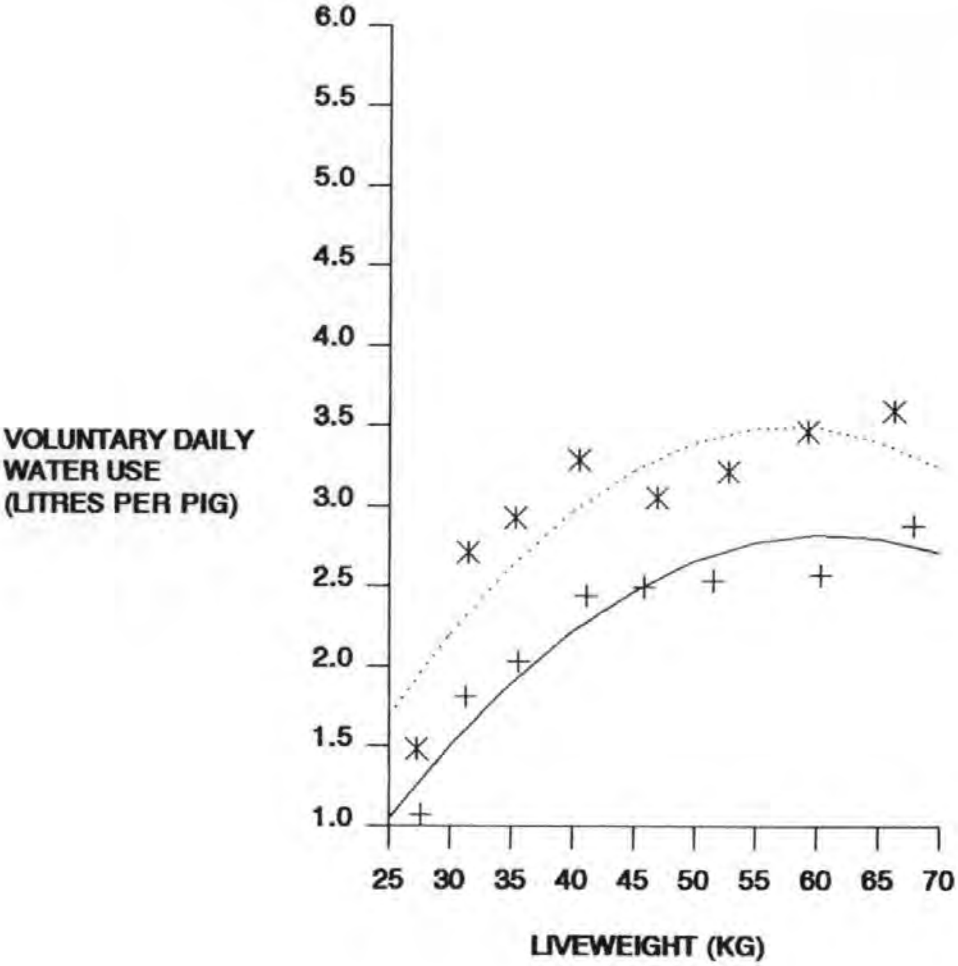
4 Mono-flo, 900 cm^3/min

(a) $Y = 0.073 + 0.0877\ X1$	$R^2 = 90.7\%$	$(P=0.000)$
(b) $Y = -2.89 + 0.228\ X1 - 0.00152\ X1^2$	$R^2 = 93.5\%$	$(P=0.000)$
(c) $Y = -9.16 + 0.126\ X1 - 0.00101\ X1^2 - 0.610\ X2$	$R^2 = 95.2\%$	$(P=0.001)$

Where Y = voluntary water use(litres/pig/day)
X1 = body live weight (kg)
X2 = Temperature (°C)

It can be seen from the regression analysis that the curvilinear quadratic regression lines in all four treatments account for a greater proportion of the measured variation, that is the coefficients of variation are greater in the case of the quadratic regression. The curvilinear relationship between mean daily voluntary water use and mean live weight at both the high and low water delivery rates for the Arato 80 drinker is illustrated in Figure 10.1 and for the Mono-flo drinker in Figure 10.2. Analysis of variance of the regression lines of water use against by weight proved them all to be significant representations of the data, some being more significant than others.

Figure 10.1 The relationship between mean daily water use and mean live weight for the Arato 80 drinker at operating 300 and 900 cm^3/min.

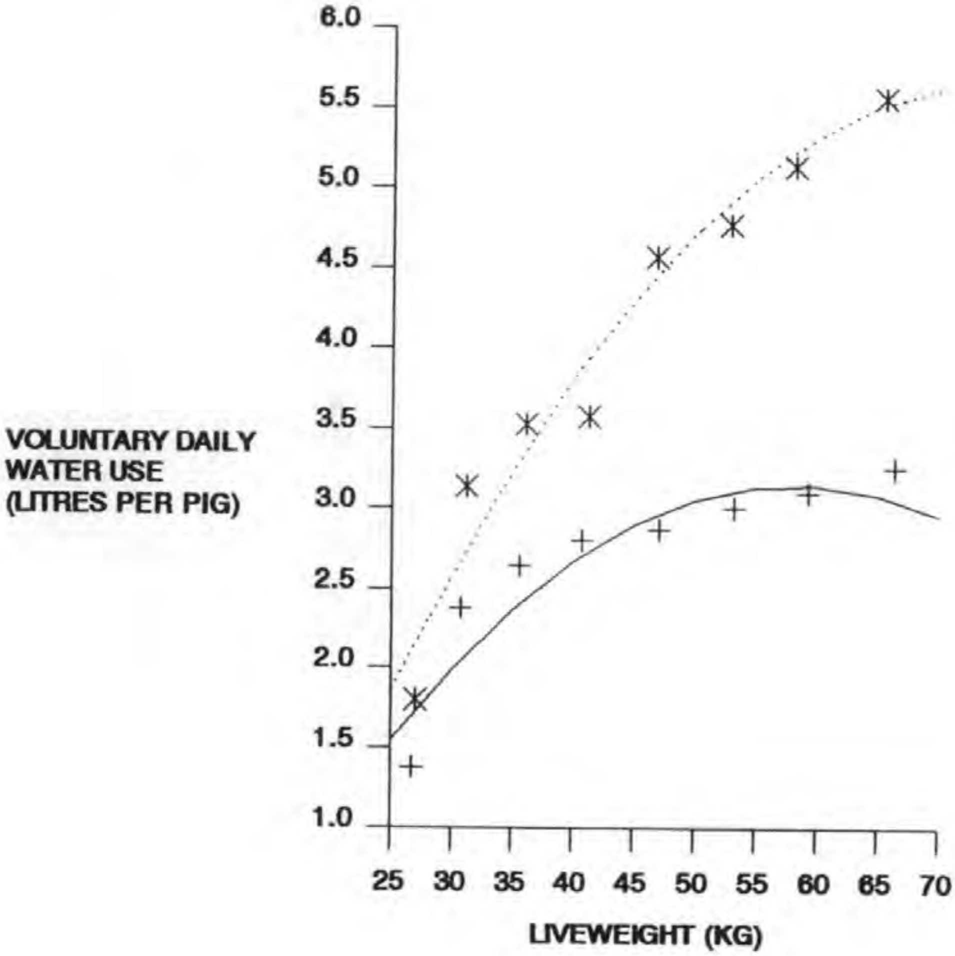


(——) Regression line for 300 cm^3/min
$Y = -2.27 + 0.167\ X - 0.001377\ X^2$

(.....) Regression line for 900 cm^3/min
$Y = -2.13 + 0.195\ X - 0.00169\ X^2$

Where Y = water use (litres/pig/day)
X = body weight (kg)

Figure 10.2 The relationship between mean daily water use and mean live weight for the Mono flo drinker operating at 300 and 900cm^3/min.



(——) Regression line for 300 cm^3/min,
$Y = -1.75 + 0.168\,X - 0.00144\,X^2$

(.....) Regression line for 900 cm^3/min,
$Y = -2.89 + 0.228\,X - 0.00152\,X^2$

Where Y = water use (litres/pig/day)
X = body weight (kg)

According to the fitted equations for the Arato 80 drinker, the point of maximum average daily voluntary water use (when $dY/dX=0$), was reached at 60.6 and 57.7 kg live weight respectively for delivery rates of 300 and 900 cm3/min respectively. For the Mono-flo drinker, the points of maximum average daily voluntary water use was reached at 58.3 and 75.0 kg live weight respectively for the delivery rates of 300 and 900 cm^3/min.

When the effect of temperature was also included in the regression analysis the coefficients of variation were only fractionally increased and analysis of variance of the regression lines showed the lines to be a less significant representation of the data. The analysis showed that temperature *per se* did not have a significant effect on the voluntary water use of the pigs, although the trend would seem to be that more water was used at higher temperatures. This is in agreement with the trends found in experiments 4 and 5.

A temperature variation of only 3.5 °C, is not really sufficient to produce conclusive predictive equations for the effects of temperature on voluntary water use.

As one of the main objectives of this study is to be able to predict total water use of pigs, a further regression analysis was undertaken investigating the relationship between live weight and total water use for the four treatments. The results are presented below:

1 Arato 80, 300 cm^3/min

(a) $Y = 1.07 + 0.0686\ X1$ — $R^2 = 89.1\%$ (p=0.000)

(b) $Y = -2.32 + 0.224\ X1 - 0.00163\ X1^2$ — $R^2 = 96.6\%$ (P=0.000)

2 Mono-flo, 300 cm^3/min

(a) $Y = 1.55 + 0.0675\ X1$ — $R^2 = 87.3\%$ (P=0.000)

(b) $Y = -1.46 + 0.210\ X1 - 0.00154\ X1^2$ — $R^2 = 92.8\%$ (P=0.001)

3 Arato 80, 900 cm^3/min

(a) $Y = 1.70 + 0.0707\ X1$ — $R^2 = 81.6\%$ (P=0.001)

(b) $Y = -1.99 + 0.243\ X1 - 0.00185\ X1^2$ — $R^2 = 87.4\%$ (P=0.002)

4 Mono-flo, 900 cm^3/min

(a) $Y = 0.499 + 0.121\ X1$ $R^2 = 94.5\%$ (P=0.000)

(b) $Y = -2.63 + 0.268\ X1 - 0.00160\ X1^2$ $R^2 = 96.3\%$ (P=0.000)

Where Y = total water use (litres/pig/day)
X1 = body live weight (kg)

The analyses of regression showed that quadratic equations produced better fits than linear equations between live weight and total water use for all four treatments (higher coefficients of determination). Analysis of variance of all the regression lines showed them all to be highly significant representations of the data ($P<0.002$).

Discussion

The above results indicate that it is inappropriate to compare voluntary water use from drinkers of different design without reference to the rate at which they deliver water. It is clear from this experiment that both drinker type and delivery rate have a significant effect on water use.

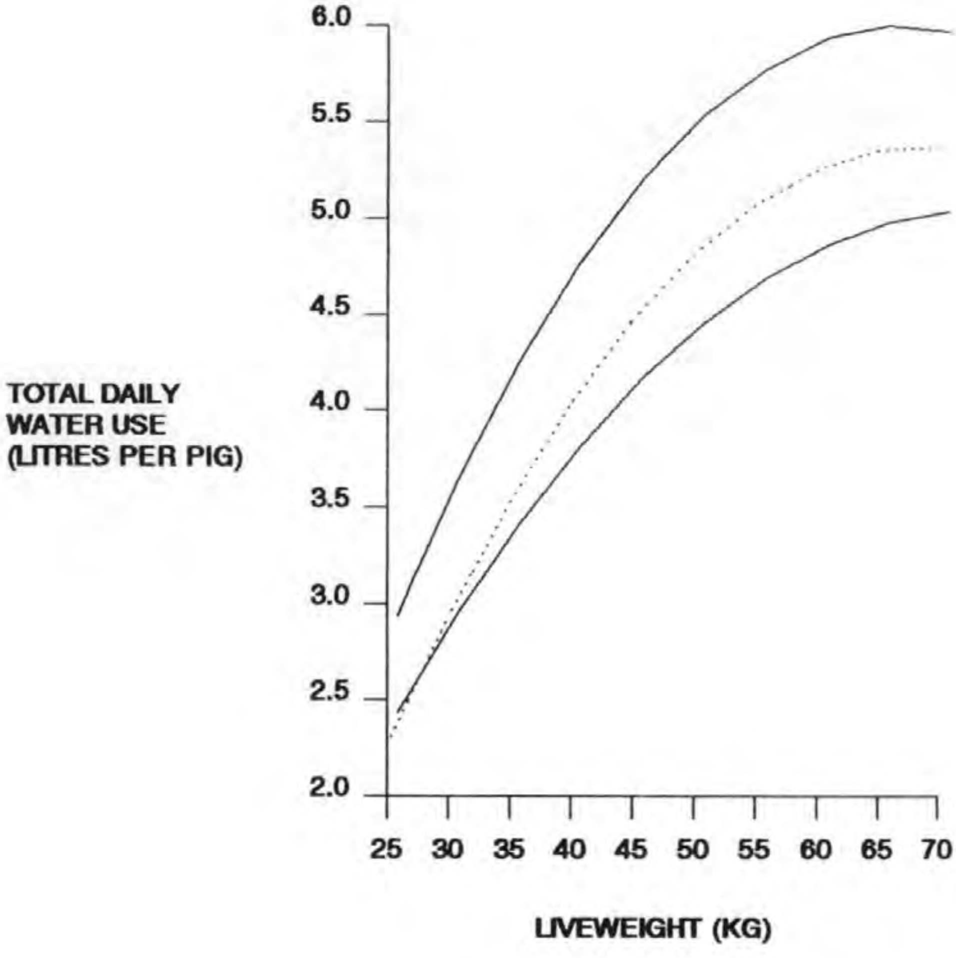
As pig performance for all four treatments was similar, differences in voluntary water use may be attributable to increased wastage. This wastage was increased at the higher delivery rates where the type of drinker also became more important. Gill, (1989), suggested that the difference he observed in voluntary water use was due only to the difference in drinker type, however this experiment has shown that both drinker type and more importantly delivery rate have a significant effect.

From the regression equations produced by Gill, (1989) it is possible to calculate total daily water use at a live weight of 45 kg in order to make a comparison with the results of this experiment (mean weight in this experiment was 45 kg, see Table 10.2). At a live weight of 45 kg, Gill's regression equations predict total daily water use to be 6.23 litres/pig for the Mono-flo drinker and 4.17 litres/pig for the Arato 80 drinker compared with 4.87 and 6.19 litres/pig for the Mono-flo drinker at 300 and 900 cm3/min respectively, and 4.45 and 5.19 litres/pig for the Arato 80 at 300 and 900 cm3/min respectively. Figure 10.3 compares the quadratic regression lines obtained in this experiment for the Arato 80 with the line produced from Gill's work. Figure 10.4 compares the quadratic regression lines obtained in this experiment for the Mono-flo drinker with the line produced from Gill's work.

It is difficult to make a comparison of this nature when there is no reference water delivery rate to compare against. However it could be deduced that the water delivery rates used by Gill lie somewhere between the two delivery rates used in this experiment. More precisely, the delivery rate of the Mono-flo would be close to 900 cm3/min and that of the Arato, lies somewhere between 300 an 900 cm3/min. This deduction would suggest that the delivery rates used by Gill for the different drinker types were not similar and the difference in delivery rate between them may have contributed to the observed difference in water use. This deduction is only valid providing all other factors which are known to effect water use are the same in both experiments, such as diet and environmental temperature. The diets are similar both in their proximate and mineral analysis, and the house temperatures are unlikely to have been sufficiently different to produce a significant effect.

An important conclusion that must be drawn from this data is that tank systems of water metering are clearly an unsatisfactory means of measuring water use. As the level of water in the tank falls, the water delivery rate will decrease. The data reported here show that this in

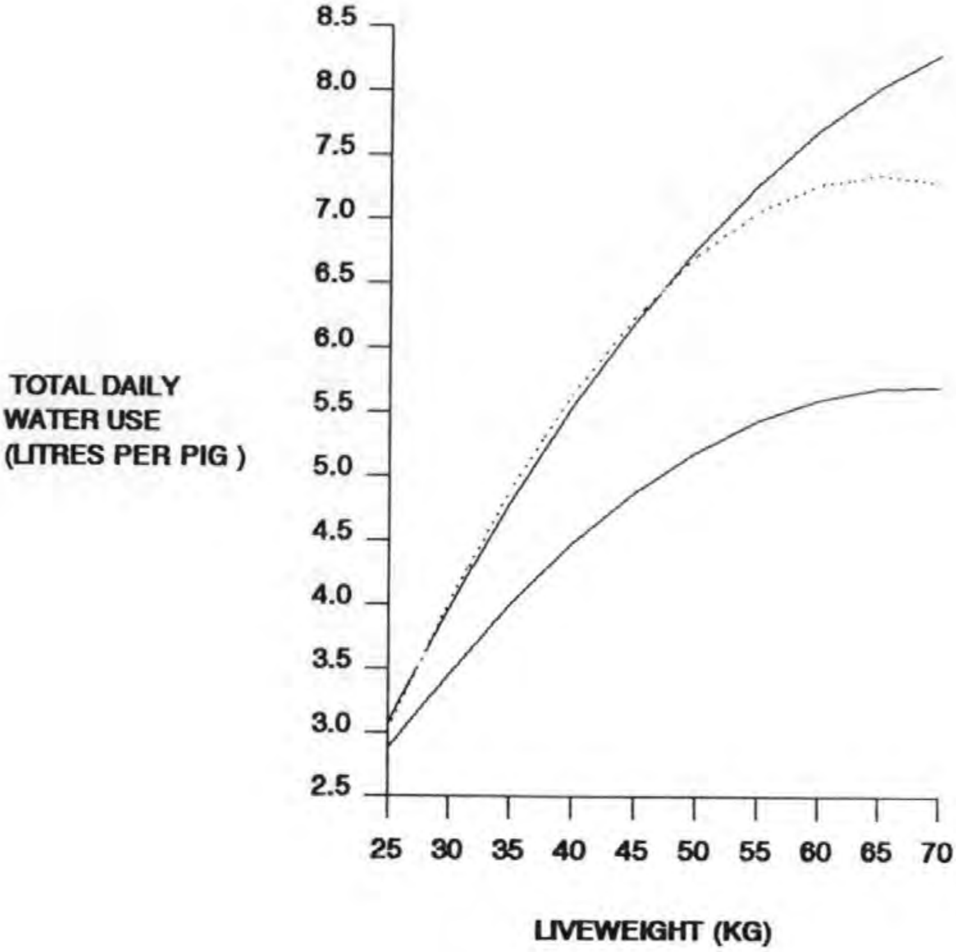
Figure 10.3 A comparison between the regression lines obtained for the Arato 80 drinker at 300 and 900 cm^3/min with the line produced by Gill, (1989).



(.....) Regression line produced by Gill,(1989)

(——) Regression lines for 300 and 900 cm^3/min

Figure 10.4 A comparison between the regression lines obtained for the Mono-flo drinker at 300 and 900 cm^3/min with the line produced by Gill,(1989).



(.....) Regression line produced by Gill, (1989)

(———) Regression lines for 300 and 900 cm^3/min turn will create variations in the water use of the experimental animals.

Having completed this experiment with different water delivery rates an additional parameter for investigating water use and the drinking behaviour of pigs was introduced. This was 'apparent time spent drinking'. This was calculated by dividing the measured water use (litres) by the known water delivery rate (litres/min). It is referred to as 'apparent' because what is actually calculated is the amount of time the valve in the drinker is fully open. It does not take into account the opening and closing of the valve nor does it differentiate between drinking or playing activity. It is an interesting concept as it provides an estimate of the length of time an animal is prepared to spend in drinking behaviour and the ease by which that animal obtains water.

The data in Table 10.3 shows that at the higher water delivery rates significantly less time was spent drinking from both drinker types, ($P<0.001$). The data in Table 10.2 showed that there was no significant difference in voluntary water use at 300 cm^3/min for the two drinker types, however the data in Table 10.3 shows that there was a significant difference in the amount of time the pigs spent drinking, ($P<0.01$). Similarly Table 10.2 shows that there was a significant difference in voluntary water use between the two drinkers at 900 cm3/min ($P<0.01$), whereas Table 10.3 shows that there was no significant difference in the time the animals spent drinking.

As pig performance was unaffected by water delivery rate, it is assumed that the reduced voluntary water use at the lower delivery rate was attributable to less waste water. This outcome is supported by the report of Olsson, (1983). The experiment has shown that decreasing the water

Table 10.3 Apparent time spent drinking fo all four treatments.

Drinker type	Arato	Mono-flo	Arato	Mono-flo		
Water delivery rate (cm^3/min)	300	300	900	900	$S.E._D$	P
Mean daily time spent drinking (s)	451[a]	536[b]	198[c]	267[c]	29	0.001

Means bearing the same superscript are not significantly different (P>0.05).

delivery rate increases the amount of time the animal spends drinking and decreases the amount of voluntary water use, without having any apparent detrimental effects on the pigs. It is evident that the pigs had adapted to a certain extent to the lower delivery rates by spending a greater amount of time drinking. This is supported by Nienaber et al.,(1984). The concept of time spent drinking will be further investigated in Experiment 8. It does however raise another question, namely what is the limit to the pigs willingness to compensate for reduced delivery rate by increased drinking activity?

It must be noted that these findings are relevant to the circumstances under which the experiment was performed and may not apply to the commercial situation where competition for drinkers and drinking time is increased (in commercial units there may be as many as 20 pigs per drinker compared to the 8 pigs per drinker as in this experiment). It is well reported that social facilitation is common in the drinking and feeding behaviours of pigs, (Hsia and Woodgush, 1984). In a commercial unit where the numbers of drinkers are restricted, some pigs may have to delay drinking for a period of time post feeding, the effects of which are not known. There may be a good case for placing more drinkers in a pen to allow more of the group of pigs to drink at any one time.

Experiment 7: The effects of drinker number and water delivery rate on the water use of growing pigs fed on a scale based on metabolic body weight.

Introduction

In Experiment 6 it was shown that water delivery rate significantly affected the water use of growing pigs. It was thought that the number of drinkers per pen of pigs might affect water use and performance. The aim of this study was to examine the effects on water use brought about by variation of delivery rate and the number of drinkers per pen.

Materials and methods

Experimental design and treatments

The water use and performance of growing pigs supplied with water from either one Arato 80 or two Arato 80 drinkers at water delivery rates of either 300 cm^3/min or 900 cm^3/min was investigated. The four treatments were therefore as follows:

1 One drinker, 300 cm^3/min

2 Two drinkers, 300 cm^3/min

3 One drinker, 900 cm^3/min

4 Two drinkers, 900 cm^3/min

A diagram of the type of drinker used is given in Figure 1.3. The treatments were replicated through four pens and in time according to were randomly assigned to a treatment pen and remained in that treatment pen throughout the trial period. The four groups of animals were rotated around the pens every 10 days according to the design so that at the end of the experiment each group of animals would have spent 10 days on each treatment.

Animals and housing

The pigs were individually weighed at the start of the trial and ear tagged for identification purposes. Four groups of Large White X (Large White X Landrace) pigs consisting of four gilts and four boars (initial mean weight 32.0 ± 2.2 kg) were assigned to the four treatment pens, balancing groups according to weight, in a performance test house. The pigs were housed in the test house for four days prior to the start of the trial in order to accustom them to the environment and the feeding regime.

Water was available *ad libitum* to each pen from one or two treatment drinkers (according to treatment), mounted on variable height brackets. The height was initially set at 0.5 m from the ground as specified by the manufacturer, drinker height being increased by an equal amount in each pen to maintain the recommended drinking attitude as the pigs grew. The drinkers were aligned at a 15°C decline from the ground.

Different water delivery rates in the drinkers were achieved by varying the internally fitted plastic restricter apertures in the drinkers. The delivery rates selected were checked weekly and remained within 5% of the nominal values. The water was supplied from the mains supply, via an anti-siphon back device and metered through previously calibrated Kent PSM-L water meters. The pressure head of water was maintained at 10 m by the use of a pressure regulator.

The pigs were fed individually in troughs twice per day on a scale based on metabolic weight of 100 g/kg $W^{0.75}$. The feed was formulated from wheat, barley and soya to meet A.R.C. (1981) nutrient requirements for growing pigs. Proximate and mineral analysis of the feed is given in Table 11.1. The daily meal allowance was mixed with an equivalent weight of water immediately before feeding. This was necessary in order for the pigs to consume all of their ration.

The temperature of the test house was recorded using two previously calibrated Thermographs positioned as close to the pigs as possible whilst remaining out of their reach.

Experimental procedures

The pigs were weighed at the start of the experiment and then every five days in order to determine their ration allowance.

Water use was recorded daily at 0845 hrs. The pigs were fed at 0830 hrs and 1600 hrs, recording the amount of feed given. The pigs were allowed 30 minutes to eat their allocated ration after which the rejected feed was removed from the troughs and weighed. A small sample of the rejected feed was kept, weighed, oven dried at 100°C for 24 hrs

Table 11.1 Proximate and mineral analyses of the feed used in Experiment 7

Dry matter (%)	86.4
Digestible energy (MJ/kg DM)	14.5
Crude protein (g/kg DM)	21.0
Crude fibre (g/kg DM)	41.0
Neutral detergent fibre (g/kg DM)	140
Oil (Acid hydrolysis) (g/kg DM)	32.0
Total ash (g/kg DM)	96.0
Calcium (g/kg DM)	16.2
Phosphorous (g/kg DM)	7.2
Magnesium (g/kg DM)	2.2
Sodium (g/kg DM)	2.2
Potassium (g/kg DM)	8.3
Chloride (g/kg DM)	2.9

and weighed again to determine the unconsumed fractions of meal and water.

Results

The health of all the experimental animals was good, with no deaths nor incidence of scour. There were few feed refusals during the trial period. The mean daily temperature varied from 15.1°C to 19.7°C throughout the trial period. The lower temperatures were recorded during the first half of the trial. Mean daily temperature of the five day periods is presented in Figure 11.1

Pig performance and water use data is presented in Table 11.2. Analysis of variance showed that neither drinker number nor water delivery rate had a significant effect on feed intake, daily liveweight gain or feed conversion ratio ($P>0.05$).

There was no significant difference in voluntary water use at the lower delivery rate between one or two drinkers nor was there a significant difference between them at the high delivery rate.
However for both drinker combinations significantly more water was used at 900 cm^3/min than at 300 cm^3/min ($P<0.001$).

Treatment differences in total water use reflect those of voluntary water use as there was no significant difference in feed intake (water with the feed was given in a ratio of 1:1).

Factorial analysis of the voluntary water use data showed that only water delivery rate was a significant factor in determining the amount

Figure 11.1 The variation in mean house temperature between the eight five day periods.

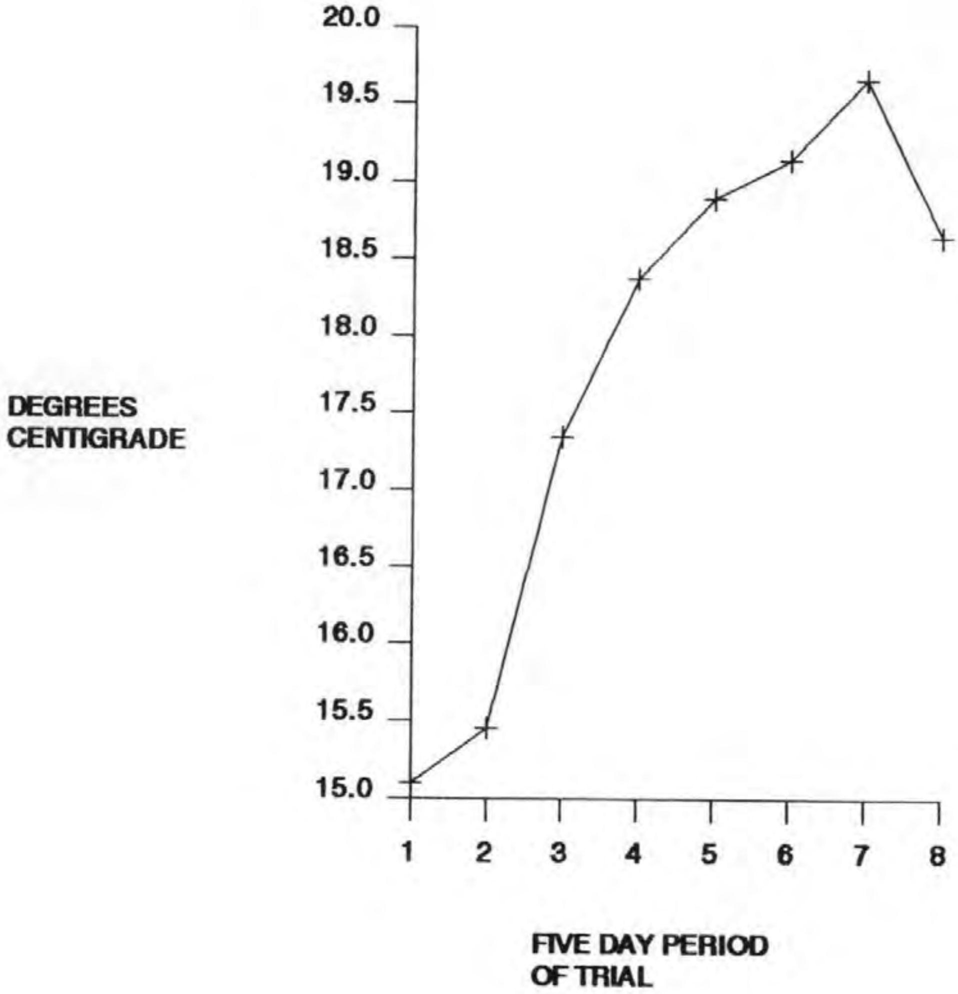


Table 11.2 Water use, feed intake and performance of growing pigs offered water from one or two Arato 80 drinkers at 300 and 900 cm^3/min.

Drinker number Water delivery rate (cm^3/min)	1 300	2 300	1 900	2 900	$S.E._D$	P
Voluntary water use (litres/pig/day)	2.01^a	1.69^a	3.62^b	3.95^b	0.18	0.001
Mean live weight gain (kg/day)	0.724	0.696	0.701	0.695	55.8	N.S.
Mean F.C.R.	2.33	2.40	2.40	2.42	0.08	N.S.
Mean feed intake (kg/pig/day)	1.69	1.67	1.68	1.68	0.10	N.S.
Total water use (litres/pig/day)	3.7^a	3.36^a	5.30^b	5.63^b	0.18	0.001
Mean weight (kg)	45.34	45.4	45.4	45.34	0.13	N.S.
Apparent time spent drinking (S/pig/day)	400^a	340^b	240^c	266^c	22.3	0.01

a,b,c means bearing the same superscript are not significantly different (P>0.05).

of water used. The number of drinkers supplying the water was not a significant factor nor was the interaction between the two factors.

Table 11.2 shows that there was a significant difference between the two delivery rates in the apparent time spent drinking ($P<0.01$). At the lower water delivery rate the pigs spent significantly less time drinking with two drinkers in the pen compared to one ($P<0.01$). There was no significant difference in apparent time spent drinking between one and two drinkers at the higher delivery rate.

Factorial analysis of the time spent drinking showed that water delivery rate was a significant factor ($P<0.001$). Drinker number was not significant in affecting the apparent time spent drinking ($P>0.05$). The interaction between the two factors however was found to be significant ($P<0.05$).

A detailed regression analysis was undertaken for each treatment. This consisted of linear and curvilinear quadratic regression of both mean daily voluntary water use and mean daily total water use against mean weight. Daily voluntary and total water use figures were averaged for each five day period for regression against the mean weight for the same period. The results of this analysis are given in Table 11.3.

For all four treatments, the respective equations describing total water use were more significant representations of the data than those describing voluntary water use. This was reflected in the increase in the values of the coefficient of determination. For the low water delivery rate treatments the equations produced from linear regression were more representative of the data than those from the quadratic

Table 11.3 Regression of average voluntary water use and total average daily water use against average weight of growing pigs provided with water from one or to water delivery rates at either 300 or 900 cm3/min.

Treatment	Regression equation	P	R^2	Standard deviation of: intercept	b1	b2
300 cm3/min 1 drinker	$Y1 = -1.30 + 0.0731X$	0.003	75.5%	0.707	0.015	
	$Y1 = -2.93 + 0.1470X - 0.00082X^2$	0.019	71.2%	5.06	0.229	0.0025
	$Y2 = -1.06 + 0.1050X$	0.001	86.9%	0.698	0.015	
	$Y2 = -3.71 + 0.2250X - 0.00134X^2$	0.004	85.2%	4.91	0.222	0.0024
300 cm3/min 2 drinkers	$Y1 = -0.525 + 0.0488X$	0.001	83.6%	0.372	0.008	
	$Y1 = -1.670 + 0.1010X - 0.00058X^2$	0.006	81.4%	2.26	0.102	0.0011
	$Y2 = -0.343 + 0.0810X$	0.001	92.5%	0.402	0.009	
	$Y2 = -2.300 + 0.1710X - 0.00098X^2$	0.001	92.1%	2.35	0.106	0.0012
900 cm3/min 1 drinker	$Y1 = 0.94 + 0.059X$	0.097	29.1%	1.383	0.029	
	$Y1 = -19.7 + 0.976X - 0.00987X^2$	0.005	83.6%	4.56	0.201	0.0022
	$Y2 = 1.27 + 0.0889X$	0.025	52.6%	1.385	0.030	
	$Y2 = -19.4 + 1.01X - 0.00988X^2$	0.002	89.0%	4.563	0.201	0.0022
900 cm3/min 2 drinkers	$Y1 = -1.81 + 0.127X$	0.006	70.3%	1.395	0.030	
	$Y1 = -20.2 + 0.948X - 0.00898X^2$	0.001	91.6%	4.626	0.204	0.0022
	$Y2 = -1.50 + 0.157X$	0.002	78.1%	1.419	0.031	
	$Y2 = -20.6 + 1.01X - 0.0092X^2$	0.001	94.5%	4.456	0.197	0.0021

Where Y1 = Voluntary water use (litres/pig/day)
Y2 = Total water use (litres/pig/day)
X = Liveweight (kg)

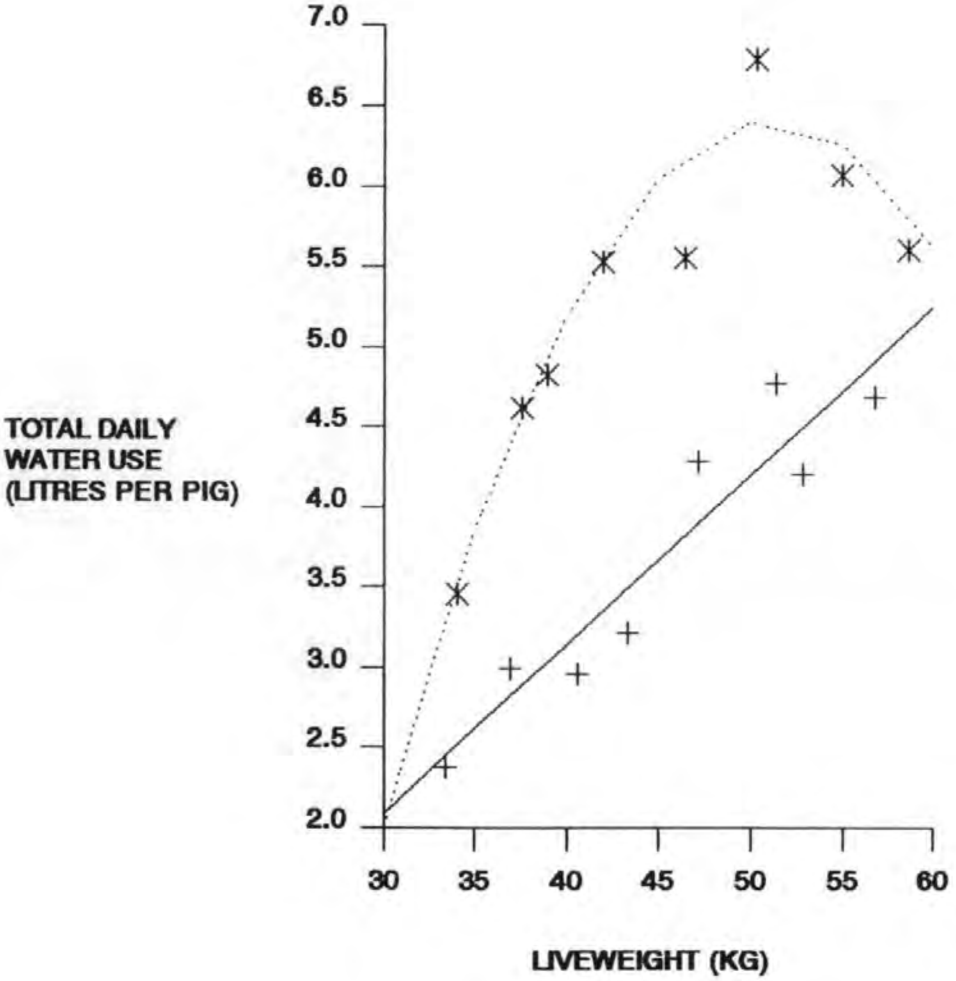
regression. This was shown by the higher coefficients of determination and the higher levels of significance. In contrast for the high delivery rate treatments curvilinear regression produced lines which fitted the data to a more significant extent in comparison with equations of linear regression. The relationships between mean total daily water intake and mean liveweight for one drinker operating at 300 and 900 cm^3/min and two drinkers operating at the same delivery rates are illustrated in Figures 11.2 and 11.3 respectively. The regression equations giving the best fit to each set of data have been used.

For completeness a multiple regression was undertaken for each treatment of total water use against liveweight and temperature.
The results of this analysis are given in Table 11.4. For all treatments except for 900 cm^3/min with two drinkers the introduction of temperature into the regression decreased both the coefficient of determination and the level of significance of the line. However for the higher flow rate and two drinkers the coefficient of determination was increased when temperature was included in the regression. It must be noted that this experiment was not conducted with the aim of evaluating the effects of temperature on water use and therefore a variation of only 4.6°C is not really sufficient to produce predictive equations for the effects of temperature on water use.

Discussion

To summarise: water use was once again significantly affected by water delivery rate supporting the results of Experiment 6. The number of

Figure 11.2 The relationship between mean total daily water use and mean live weight for one drinker operating at 300 and 900cm^3/min.

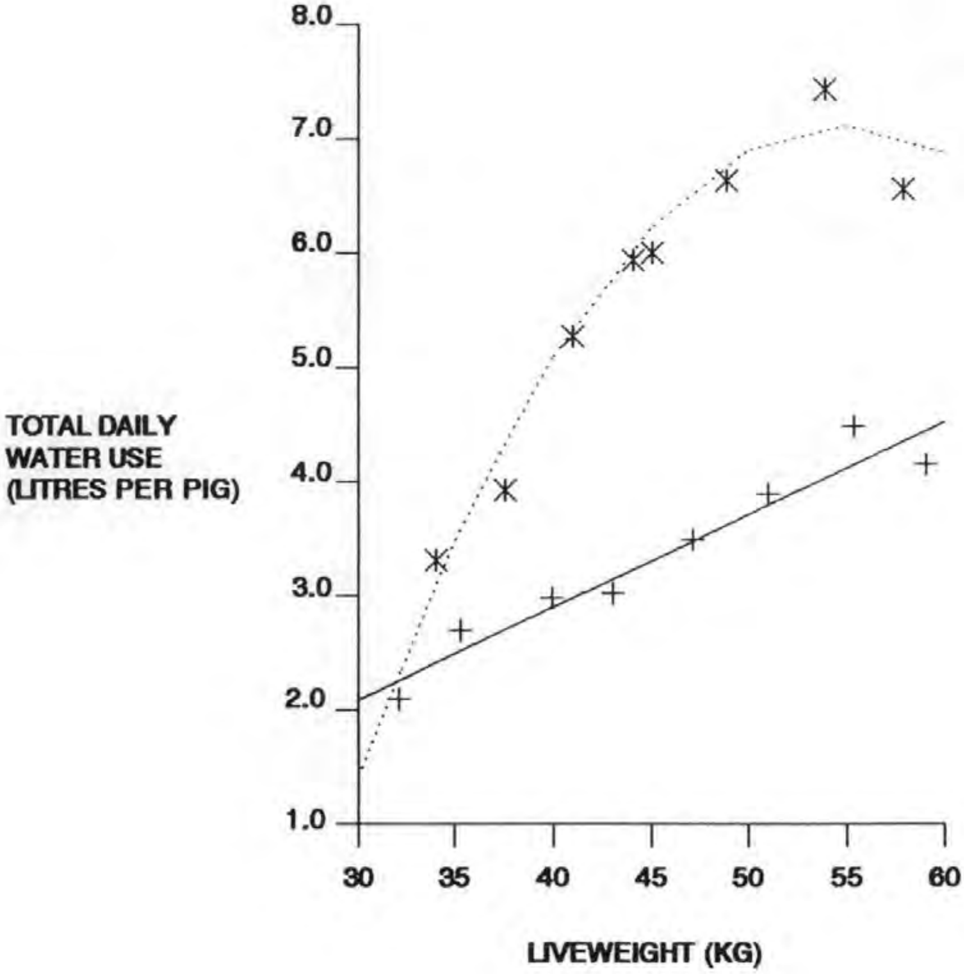


(———) Regression line for 300 cm^3/min
$Y = -1.06 + 0.105 X$

(.....) Regression line for 900 cm^3/min
$Y = -19.4 + 1.01 X - 0.00988 X^2$

Where Y = water use (litres/pig/day)
X = body weight (kg)

Figure 11.3 The relationship between mean total daily water use and mean live weight for two drinkers operating at 300 and $900 cm^3$/min.



(———) Regression line for 300 cm^3/min
$Y = -0.343 + 0.081 X$

(.....) Regression line for 900 cm^3/min
$Y = -20.6 + 1.01 X - 0.0092 X^2$

Where Y = water use (litres/pig/day)
X = body weight (kg)

Table 11.4 Regression of average voluntary water use and total average daily water use against mean house temperature and the average weight of growing pigs provided with water from one or to water delivery rates at either 300 or 900 cm3/min.

Treatment	Regression equation	P	R^2	Standard deviation of: intercept	b1	b2	b3
300 cm3/min 1 drinker	$Y1 = -5.88 - 0.188X1 + 0.379X2 - 0.0032X2^2$	0.065	66.3%	7.956	0.548	0.005	0.366
	$Y2 = -7.35 - 0.231X1 + 0.534X2 - 0.0048X2^2$	0.017	83.3%	7.562	0.521	0.005	0.348
300 cm3/min 2 drinkers	$Y1 = -0.60 + 0.111X1 - 0.019X2 - 0.00055X2^2$	0.029	77.7%	3.601	0.313	0.003	0.269
	$Y2 = -1.88 + 0.044X1 + 0.123X2 -0.00053X2^2$	0.006	90.2%	3.806	0.331	0.003	0.248
900 cm3/min 1 drinker	$Y1 = -21.6 - 0.101X1 + 1.13X2 - 0.0113X2^2$	0.023	80.1%	7.517	0.484	0.005	0.289
	$Y2 = -21.4 - 0.105X1 + 1.16X2 - 0.0114X2^2$	0.011	86.7%	7.514	0.484	0.005	0.289
900 cm3/min 2 drinkers	$Y1 = -9.57 + 0.548X1 + 0.137X2 - 0.00118X2^2$	0.001	96.2%	5.098	0.336	0.003	0.207
	$Y2 = -10.4 + 0.524X1 + 0232X2 - 0.00183X2^2$	0.001	97.4%	4.984	0.329	0.003	0.203

Where Y1 = Voluntary water use (litres/pig/day)
Y2 = Total water use (litres/pig/day)
X1 = Temperature (degrees C)
X2 = Liveweight (kg)

drinkers per pen had no significant effect on water use.

At the lower delivery rate, the mean water use was slightly greater with one drinker per pen than two, an outcome which is similar to reported results from Simonsson *et al.*,(1977) cited by Olsson, (1983), who suggested that this surprising difference was probably due to less competition in the case of the pen with two drinkers. In contrast at the higher delivery rate slightly more water was used with two drinkers per pen rather than one probably as a result of increased wastage.

It is evident that the pigs had adapted to a certain extent to the lower flow rates by spending a greater amount of time drinking. This is in agreement with Nienaber *et al.*,(1984), who showed that as water flow rate increased the time spent drinking decreased. As there was no difference in water use between one and two drinkers at the different water delivery rates, it is possible to combine the data. When this was done total water use at 900 cm^3/min was greater on average by a factor of 1.53 than that at 300 cm^3/min. As water utilisation was maintained at a greater rate, and performance was unaffected it is suggested that there was an increase in wastage rather than consumption. This outcome is supported by the report of Olsson,(1983).

If we consider only the one drinker treatments, total water use at the higher delivery rate was 1.43 times higher than the lower delivery rate. This figure is greater than the value of 1.17 times calculated for the Arato 80 drinker at the same delivery rates from Experiment 6. Comparing Experiments 6 and 7, more water was used in Experiment 6 at 300 cm^3/min and less water was used at 900 cm^3/min accounting for the difference in the high to low delivery rate water use ratio.

To determine why this ratio is significantly different, the individual regression lines at the two delivery rates for both experiments have been tested for significant differences.

For 300 cm^3/min:
Experiment 6: $Y = 1.07 + 0.0686\ X$
Experiment 7: $Y = -1.06 + 0.105\ X$
t-ratio intercept = -3.05 $P<0.05$
t-ratio gradient = 2.42 $P>0.05$

For 900 cm3/min:
Experiment 6: $Y = 1.7 + 0.0707\ X$
Experiment 7: $Y = 1.27 + 0.0889\ X$
t-ratio intercept = -0.31 $P>0.05$
t-ratio gradient = 0.6 $P>0.05$

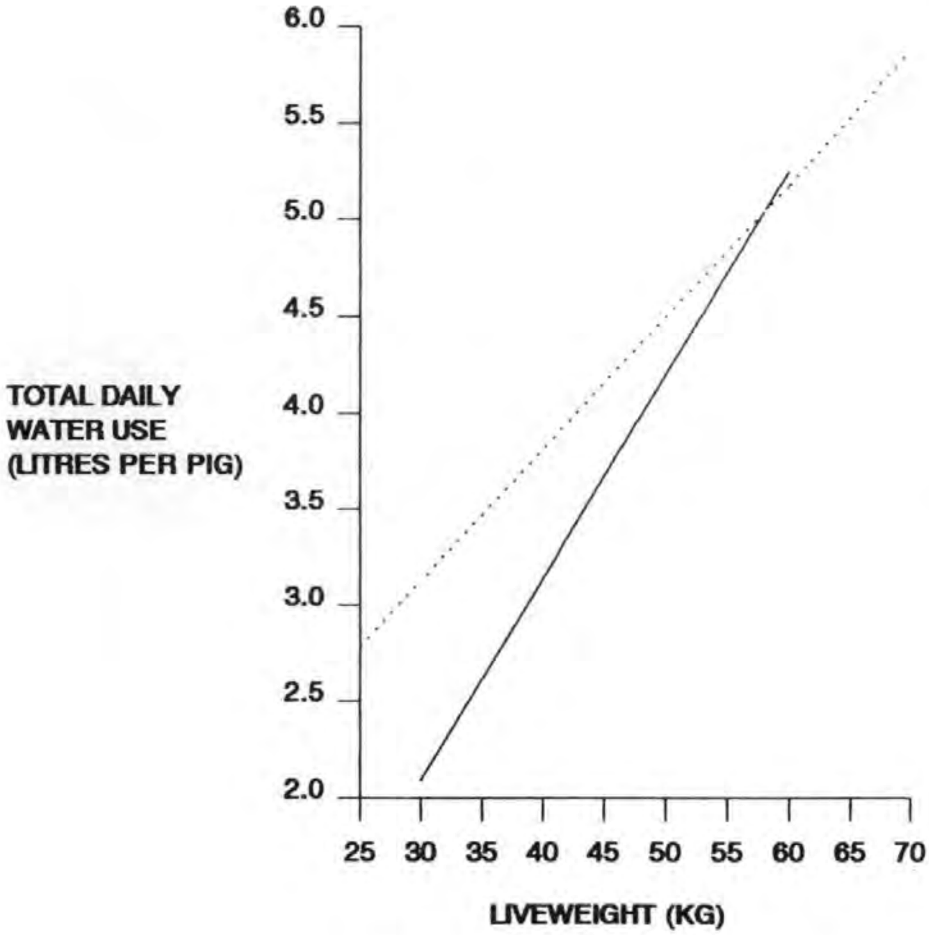
Where Y = total water use (litres/pig/day)
X = liveweight (kg)

Figure 11.4 compares the linear regression lines of total water use against liveweight for equations developed from Experiments 6 and 7 at 300 cm^3/min. The gradients of the linear regression lines are not significantly different, however the intercepts are significantly different ($P<0.05$). This means that the rate of increase in total water use with increasing body liveweight is not significantly different but the absolute volumes are significantly different.

Figure 11.5 compares the linear regression lines of total water use against liveweight for equations developed from the two experiments at the higher water delivery rate of 900 cm^3/min. Neither the intercepts nor the gradients of the lines are significantly different. Therefore the difference in the high to low delivery rate water use ratio described above is due mainly to the differences in total water use at the low water delivery rate.

The differences observed between the two experiments, in particular the significant differences at the lower delivery rate may be due to

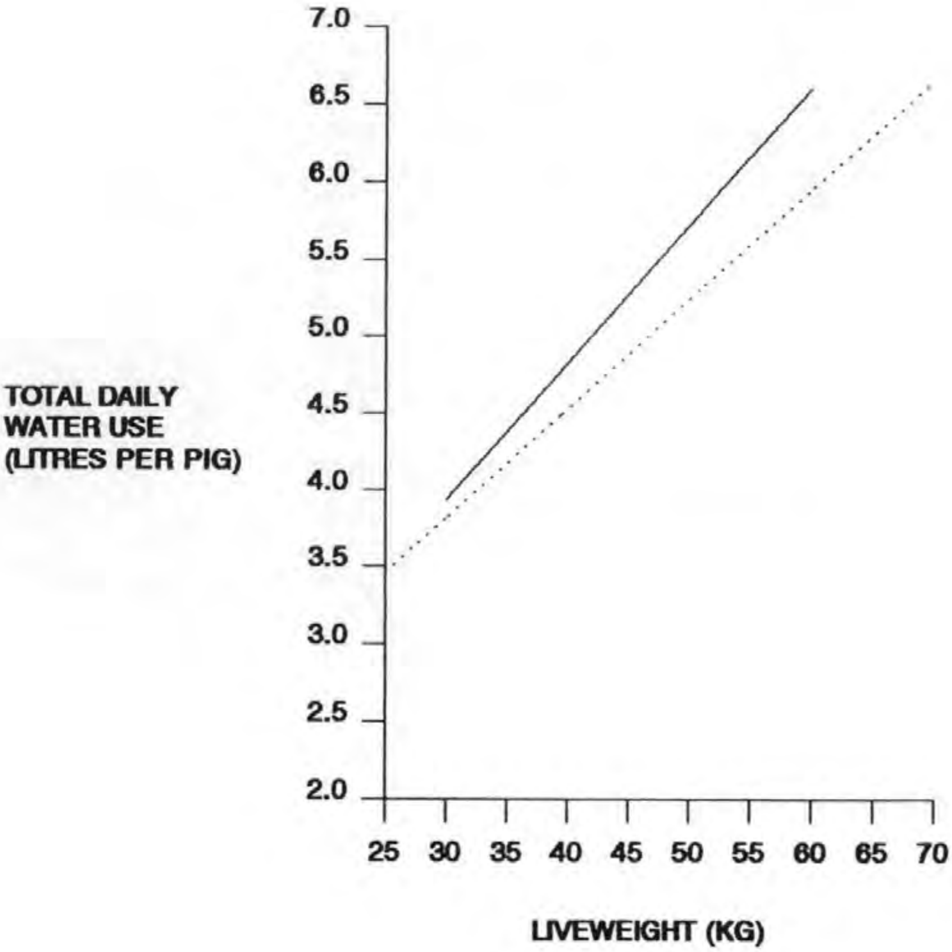
Figure 11.4 A comparison between the linear regression lines of total water use against live weight obtained for the Arato 80 at 300 cm^3/min from Experiment 6 and the same from Experiment 7 (one drinker 300 cm^3/min).



(.....) Y = 1.07 + 0.0686 X
Regression line produced from Experiment 6.

(——) Y = -1.06 + 0.105 X
Regression line produced from Experiment 7.

Figure 11.5 A comparison between the linear regression lines of total water use against live weight obtained for the Arato 80 at 900 cm^3/min from Experiment 6 and the same from Experiment 7 (one drinker 300 cm^3/min).



(.....) Y = 1.7 + 0.0707 X
Regression line produced from Experiment 6.

(——) Y = 1.27 + 0.0889 X
Regression line produced from Experiment 7.

several factors:

(1) Significantly more water was used at 300 cm^3/min in Experiment 6 than in Experiment 7. This may be directly related to the fact that the animals in Experiment 6 were on a higher plane of nutrition, (110 g/kg $W^{0.75}$ compared with 100 g/kg $W^{0.75}$) and would therefore involuntarily use more water. It is thought that water intake for most mammals is directly correlated to food intake (Anand,1961) and therefore voluntary water use would be expected to increase as a result. At the higher delivery rate the effect of these factors may be masked by the considerable increase in water use thought to be due mainly to wastage.

The different feed scales used in the two experiments makes the comparison difficult. However if voluntary water use to feed intake ratios of both experiments are calculated at 300 cm^3/min they are found to be similar; Experiment 6, 1.17:1 and Experiment 7, 1.18:1. Until now the ratio of voluntary or total water use to feed ratios have not been used because it does not normally account for differences in wastage due to drinker design or water delivery rate. However when comparing figures collected under similar conditions at precisely the same delivery rate it is valid to compare the ratio. The use of feed intake as a predictor is investigated at the end of this research programme.

(2) The regression line obtained from the data in Experiment 6 was from a greater weight range of pigs than in Experiment 7 (25-70 kg compared with 30-60 kg). This may have caused small differences in the regression lines obtained.

(3) The mean temperature during Experiment 6 was 15.9°C compared with 17.8°C during Experiment 7. This may have accounted for greater total water use at the higher delivery rate in Experiment 6.

The comparison of Experiments 6 and 7, has shown the problems which may occur when one report is compared directly with another. The above experiments were undertaken in the same performance test house under similar conditions and small differences still occurred. Whether these differences were due to biological variation or to the reasons outlined above is unknown. Therefore there seems little point at this stage in making direct comparisons of these results with those of other authors as many of the reference figures such as temperature and water delivery rate needed to make such a comparison are often omitted or ignored.

Having established the significance of water delivery rate as a parameter affecting water use, the subsequent research programme focused on examining the effects of water delivery rate on water use and pig performance over a greater range of delivery rates for both *ad libitum* and ration fed growing pigs.

Experiment 8: A comparison of water use between four water delivery rates by growing pigs fed *ad libitum*.

Introduction

Experiments 6 and 7 showed that reducing the water delivery rate from 900 to 300 cm^3/min resulted in a reduction in voluntary water use without having any detrimental effects on performance. Experiments 6 and 7 considered only two water delivery rates. The aim of this experiment was to investigate the water use of ad libitum fed pigs over a greater range of water delivery rates with the aim of being able to relate water use to delivery rate.

Materials and methods

Experimental design and treatments

The water use and performance of growing pigs supplied with water from single Arato 80 drinkers at four water delivery rates was investigated. The four water delivery treatments were as follows:

1 200 cm^3/min

2 400 cm^3/min

3 700 cm^3/min

4 1100 cm^3/min

A diagram of the Arato 80 drinker used is given in the Figure 1.3.

The treatments were replicated through four groups of animals, four pens and in time according to a 4 X 4 Graeco Latin Square design.

Every ten days the four groups of animals and the four treatment delivery rates were rotated around the four pens according to the design so that at the end of the experiment each group of animals and each treatment would have spent one ten day period in each pen. This design of experiment differs from the standard Latin Square in that the contribution to error made by both the pen effect and the animal group effect are reduced. In the standard Latin Square design only one of the above effects can be reduced in the analysis.

Animals and housing

The pigs were individually weighed at the start of the trial and ear tagged for identification purposes. Four groups of Large White X (Large White X Landrace) pigs consisting of four gilts and four boars (initial mean weight 28.0 ± 1.1 kg) were assigned to the four treatment pens, balancing groups according to weight, in a performance test house. The pigs were housed in the test house for four days prior to the start of the trial in order to accustom them to the environment and the feeding regime.

Water was available *ad libitum* to each pen from a single drinker, mounted on variable height brackets. The height was initially set at 0.5 m from the ground as specified by the manufacturer, drinker height being increased by an equal amount in each pen to maintain the recommended drinking attitude as the pigs grew. The drinkers were aligned at a 15° decline from the ground.

The different water delivery rates supplied by the drinkers were

Table 12.1 Proximate and mineral analyses of the feed used in Experiment 8

Dry matter (%)	85.2
Digestible energy (MJ/kg DM)	14.8
Crude protein (g/kg DM)	21.8
Crude fibre (g/kg DM)	35.0
Neutral detergent fibre (g/kg DM)	130
Oil (Acid hydrolysis) (g/kg DM)	38.0
Total ash (g/kg DM)	92.0
Calcium (g/kg DM)	20.2
Phosphorous (g/kg DM)	7.2
Magnesium (g/kg DM)	1.9
Sodium (g/kg DM)	2.2
Potassium (g/kg DM)	8.3
Chloride (g/kg DM)	2.9

achieved by varying the internally fitted plastic restricter apertures in the drinkers. The delivery rates selected were checked weekly and remained within 5% of the nominal values. The water was supplied from the mains supply, via an anti back-siphon device and metered through previously calibrated Kent PSM-L water meters. The pressure head of water was maintained at 10 m by the use of a pressure regulator.

The pigs were fed *ad libitum* in groups using troughs with hopper reserves of feed. The feed was formulated from wheat, barley and soya to meet A.R.C. (1981) nutrient requirements for growing pigs and was fed in meal form. Proximate and mineral analysis of the feed is given in Table 12.1. As the feed was fed *ad libitum*, no water was mixed with the feed and consequently total water used represents voluntary water use.

The temperature of the test house was recorded using two previously calibrated Thermographs positioned as close to the pigs as possible whilst remaining out of their reach.

Experimental procedures

The pigs were weighed at the start of the experiment and then every five days.

Water use was recorded daily at 0845 hrs. The troughs were refilled daily maintaining the feed as fresh as possible. Every five days the troughs were emptied and cleaned weighing the uneaten feed.

Results

The health of all experimental animals was good, with no deaths nor incidence of scour. The mean daily temperature varied from 13.3°C to 14.°C during the trial period. This range of temperature was lower than that recorded in Experiments 5,6 and 7 because the experiment was undertaken during January when the outside temperature is at its lowest.

Pig performance and water use data is presented in Table 12.2. Analysis of variance of the data showed that mean liveweight gain and feed intake were not significantly affected by the different water delivery rates examined (P>0.05). For the delivery rates of 200,700 and 1100 cm^3/min there was no significant difference in feed conversion ratio (P>0.05). However the mean F.C.R. at 400 cm^3/min was significantly higher than the other three treatments (P<0.05). The reason for this is not easily explained. It may have been possible that the feed trough used, developed a leak during the experimental period, which went unnoticed.

In this experiment, total water use consisted only of voluntary water use as the feed was fed without additional water. Analysis of variance showed that water use at 1100 cm^3/min was significantly higher than any of the other delivery rates (P<0.05). There was no significant difference between 400 and 700 cm^3/min (P>0.05) or between 400 and 200 cm^3/min. There was a significant difference in water use between the treatment delivery rates of 200 and 700 cm^3/min (P<0.05).

Time spent drinking declined as delivery rate increased. Pigs provided

Table 12.2 Water use, feed intake and performance of growing pigs offered water at one of four delivery rates.

Water delivery rate (cm^3/min)	200	400	700	1100	$S.E._D$	P
Total water use (litres/pig/day)	3.09^a	3.42^{ab}	3.95^b	4.71^c	0.21	0.01
Mean live weight gain (kg/day)	0.793	0.661	0.724	0.750	0.062	N.S.
Mean F.C.R.	3.14^a	3.77^b	3.27^a	3.39^a	0.09	0.02
Mean feed intake (kg/pig/day)	2.52	2.49	2.51	2.46	0.08	N.S.
Mean weight (kg)	41.35	41.55	41.71	41.71	3.24	N.S.
Apparent time spent drinking (S/pig/day)	927^a	512^b	338^{bc}	256^c	75.2	0.01

a,b,c means bearing the same superscript are not significantly different (P>0.05).

with water at 200 cm^3/min spent more time drinking than pigs on any of the other treatments, ($P<0.05$). There was also a significant difference between the 400 and 1100 cm3/min treatments, ($P<0.05$).

Linear regression of the mean water use figures from Table 12.2 against water delivery rate gave the following equation:

$Y = 2.71 + 0.0018\ X \qquad R^2 = 99.9\% \qquad p = 0.001$

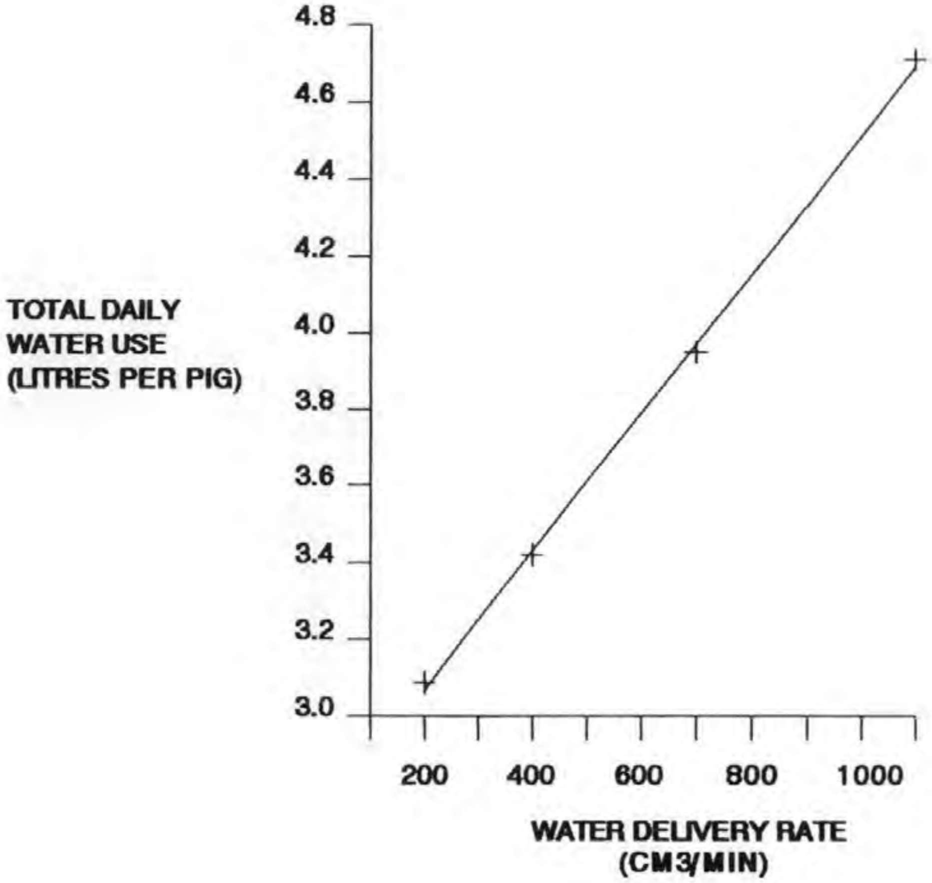
standard deviation intercept = 0.026
gradient = 0.00004

Where Y = water use (litres/pig/day)
X = water delivery rate (cm^3/min)

This relationship is shown in Figure 12.1. The coefficient of determination was very high (99.9%) suggesting that the regression line accounted for all of the variation in water use due to delivery rate. Consequently analysis of variance of the line showed that it was a highly significant representation of the data. It should be noted that the water use data used to calculate this equation were means and the line has only been generated from four means. Confidence limits have not been calculated for the diagram in Figure 5.10 because owing to the design of the experiment, the replicates for each treatment were of significantly different mean weight and therefore water use values for the replicates were different. The confidence limits would mean very little because they would cover water use over the whole of the weight range of the experiment.

Detailed regression analyses have been undertaken to investigate the relationship between total water use and mean liveweight for each water delivery rate studied. The results of these analyses are

Figure 12.1 The relationship between mean total daily water use and water delivery rate.



(——) Linear regression line
$Y = 2.71 + 0.0018 X$

Where Y = water use (litres/pig/day)
X = delivery rate (cm^3/min)

Table 12.3 Regression of mean total water use against mean weight of growing pigs provided with water at delivery rates of 200,400,700 and 1100 cm3/min.

Treatment	Regression equation	P	R^2	Standard deviation of: intercept	b1	b2
200 cm3/min	$Y = 0.571 + 0.0608X$	0.003	75.5%	0.538	0.013	
	$Y = -5.25 + 0.346X - 0.00337 X^2$	0.006	81.7%	3.376	0.164	0.0019
400 cm3/min	$Y = -0.965 + 0.105X$	0.001	95.1%	0.382	0.009	
	$Y = -3.25 + 0.222X - 0.00141X^2$	0.001	95.7%	1.69	0.085	0.0010
700 cm3/min	$Y = 1.03 + 0.0699X$	0.014	60.2%	0.882	0.021	
	$Y = -6.72 + 0.445X - 0.00427X^2$	0.007	81.0%	2.88	0.137	0.0015
1100 cm3/min	$Y = 0.44 + 0.103X$	0.005	71.2%	1.026	0.024	
	$Y = -4.9 + 0.371X - 0.00323X^2$	0.025	68.1%	8.17	0.408	0.0049

Where Y = Total water use (litres/pig/day)
X = Liveweight (kg)

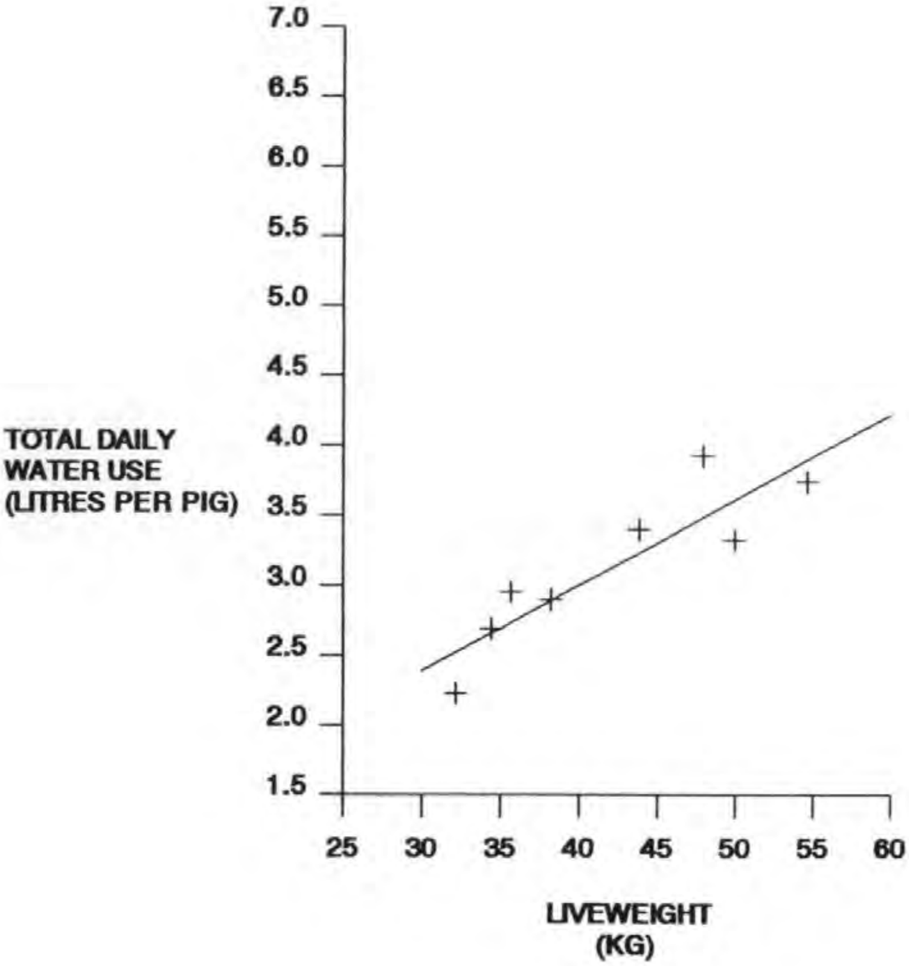
presented in Table 12.3. Comparing linear and quadratic regression for the lower delivery rate the quadratic regression line accounted for agreater amount of variation, indicated by the higher value of the coefficient of determination, but the line itself was a less significant representation of the data. At 400 cm^3/min both the linear and quadratic lines accounted for a high proportion of the measured variation and were significant representations of the data. At 700 cm^3/min the quadratic regression line gave a much increased coefficient of determination and more significant representation of the data than the linear regression line. However at 1100 cm^3/min a lower proportion of the variation was accounted for by the quadratic regression line equation and was therefore a less significant representation of the data.

The relationships between mean total water use and mean liveweight at each treatment delivery rate are illustrated by Figures 12.2, 12.3, 12.4 and 12.5. The linear regression lines have been plotted on these diagrams rather than the quadratic regression lines for the following reasons:

(1) For the four treatment delivery rates the quadratic lines produced do not all give a better fit (as was the case in Experiment 7.)

(2) The small weight range studied casts doubt on the validity of fitting quadratic regressions because according to the fitted quadratic regression equations the points of maximum average daily total water use for delivery rates of 200, 700, and 1100 cm^3/min were at live weights of 51.3, 52.1, and 57.4 kg respectively. Experiments

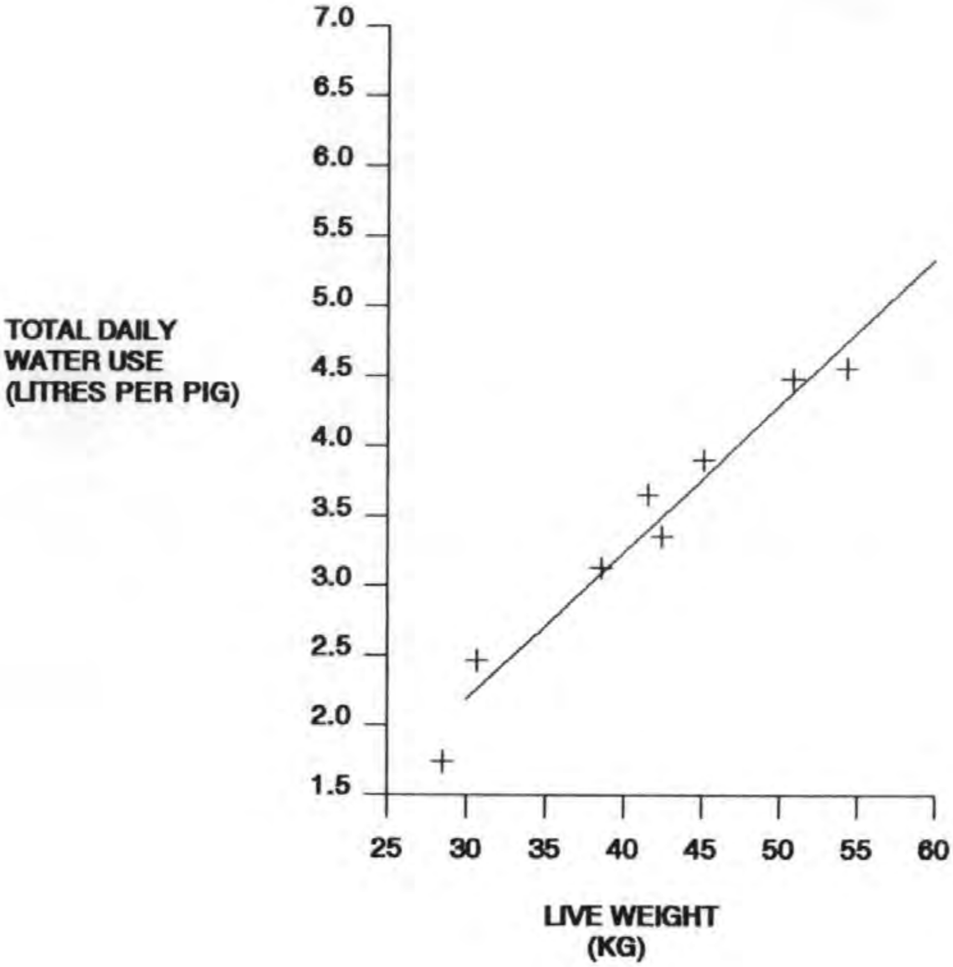
Figure 12.2 The relationship between mean total daily water use and mean live weight at 200 cm^3/min.



(——) Linear regression line
$Y = 0.571 + 0.0608\ X$

Where Y = water use (litres/pig/day)
X = live weight (kg)

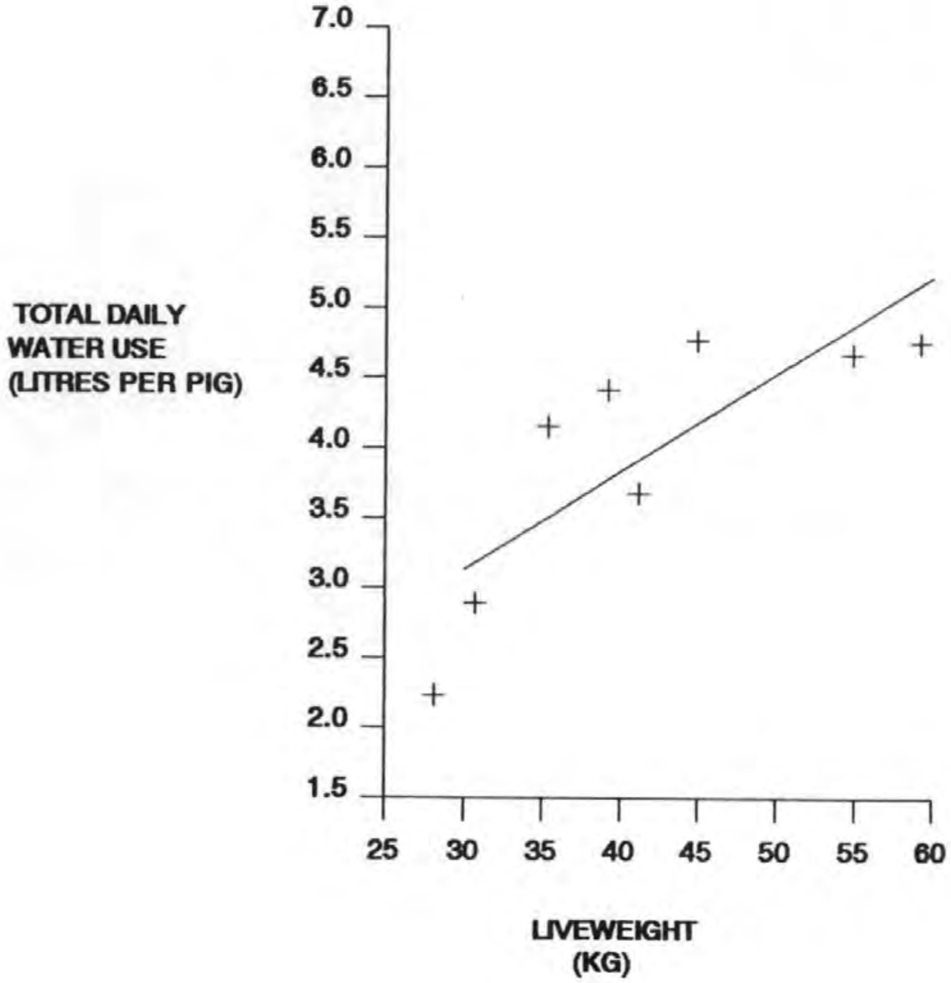
Figure 12.3 The relationship between mean total daily water use and mean live weight at 400 cm^3/min.



(———) Linear regression line
$Y = -0.965 + 0.105 X$

Where Y = water use (litres/pig/day)
X = live weight (kg)

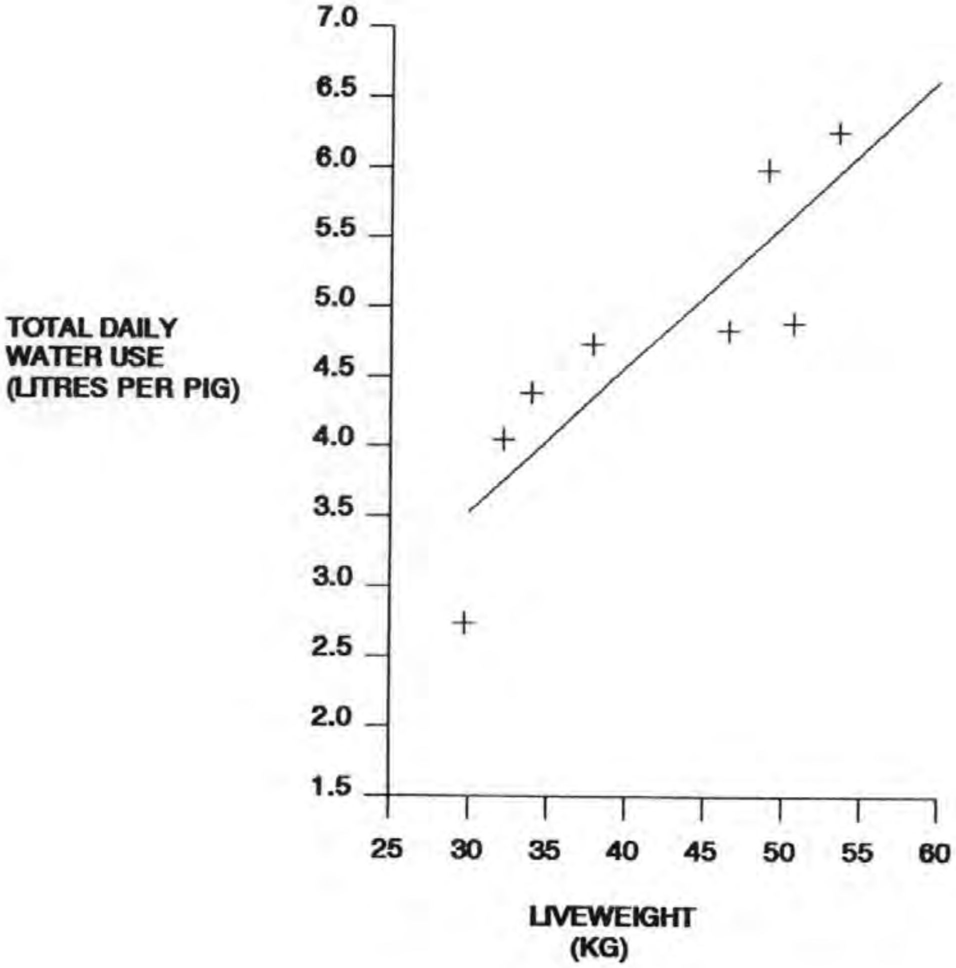
Figure 12.4 The relationship between mean total daily water use and mean live weight at 700 cm^3/min.



(——) Linear regression line
$Y = 1.03 + 0.0699\ X$

Where Y = water use (litres/pig/day)
X = live weight (kg)

Figure 12.5 The relationship between mean total daily water use and mean live weight at 1100 cm^3/min.



(———) Linear regression line
$Y = 0.44 + 1.03\ X$

Where Y = water use (litres/pig/day)
X = live weight (kg)

4, 5, and 6 indicated that the liveweight of maximum water use was considerably higher. The quadratic regression analysis undertaken for this experiment and the previous three is correct for the experiments in question, but when applying the equations in predicting over a greater weight range, the linear regression lines are more realistic.

(3) By chance the animal groups were slightly different in their initial starting weights and consequently, the cross over effects of the experimental design resulted in the mean weight of the groups being different at the beginning of each experimental period. On at least one occasion the cross over effect resulted in a lower period start weight than the previous period end weight. As each group of animals spent 10 days on each treatment there was therefore no significant difference in the treatment mean weight at the end of the experiment as shown in Table 12.2. The difference in mean animal group weight resulted in significant differences in total daily water use, feed intake and liveweight gain between the groups when the analysis of variance was undertaken.

In order that both delivery rate and liveweight can be accounted for a multiple regression of mean total water use against mean liveweight and delivery rate has been under taken. In so doing the problems described above (3), do not occur as this type of regression compares water use at each liveweight and each treatment delivery rate in the same calculation.

$Y = 2.18 + 0.00179\ X + 0.0129\ X2$ $R^2 = 32.5\%$ $p = 0.012$

standard deviation b1 = 1.142
b2 = 0.00064
b3 = 0.02543

where Y = water use (litres/pig/day)
X1 = delivery rate (cm^3/min)
X2 = liveweight (kg)

The relatively low coefficient of determination indicates that the regression equation accounts for only 35.2% of the observed variation.However analysis of variance of the line showed it to be a significant representation of the data ($P<0.05$). Live weight accounted for only 1.2% of the variation whereas delivery rate accounted for 31.3%. The remainder was made up of the error factor. This is an important finding as it means that as predictors of water intake, water delivery rate is by far the more important. It must again be stressed that the experiment was carried out over a relatively small weight range. Figure 12.6 shows values obtained from the multiple regression line above calculated at different weights at each of the different delivery rates. The relatively small gradient of the lines illustrates the relative importance of liveweight as a predictor of water use. The differences between the lines indicates the relative importance of delivery rate as a predictor of water use.

The relationship between apparent time spent drinking and delivery rate is illustrated by Figure 12.7. Linear regression of the mean apparent time spent drinking figures from Table 12.2 against water delivery rate gave the following equation:

$Y = 914 - 0.676\ X \qquad R^2 = 67.8\% \qquad p = 0.114$

standard deviation intercept = 171.2
gradient = 0.2497

Where Y = time spent drinking (s/pig/day)
X = water delivery rate (cm^3/min)

It was found that a curvilinear quadratic regression of the data gave

Figure 12.6 The relationship between mean total daily water use and mean live weight at 200,400,700 and 1100 cm^3/min according to the multiple regression equation:

$$Y = 2.18 + 0.00179\ X1 + 0.0129\ X2$$

where Y = water use (litres/pig/day)
X1 = delivery rate (cm^3/min)
X2 = live weight (kg)

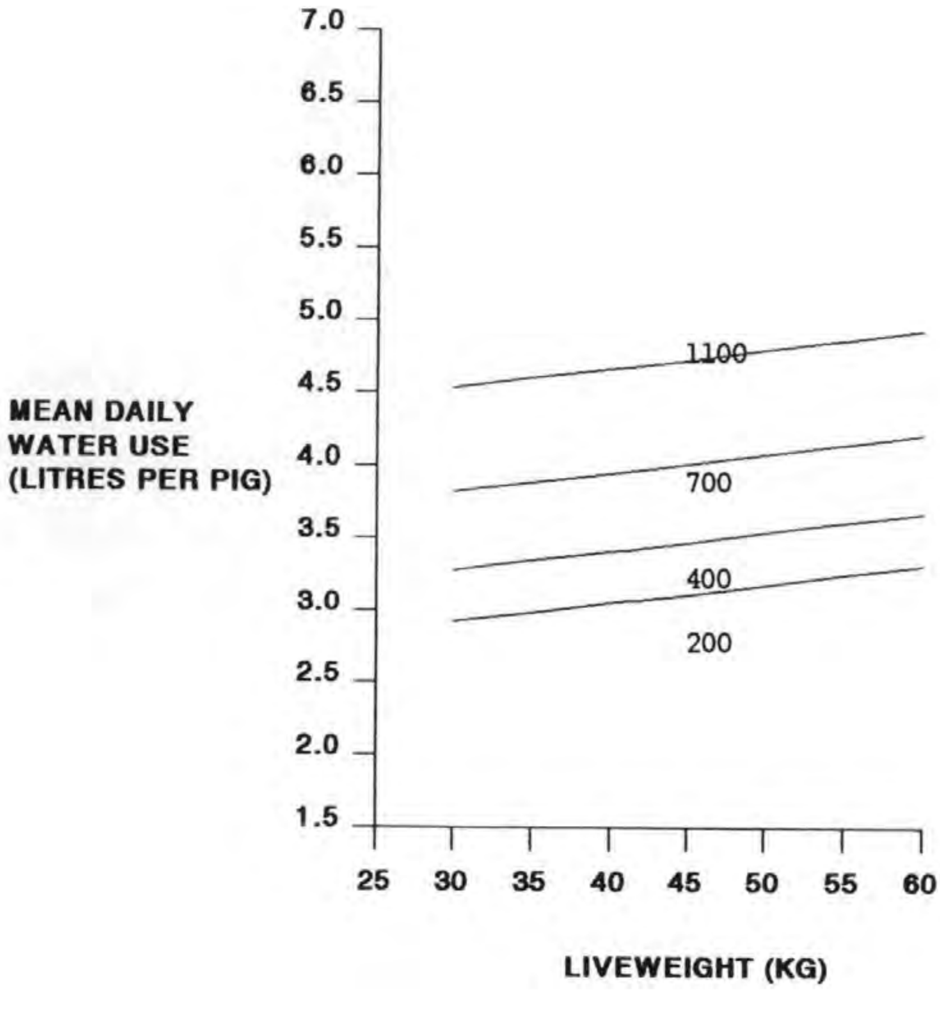
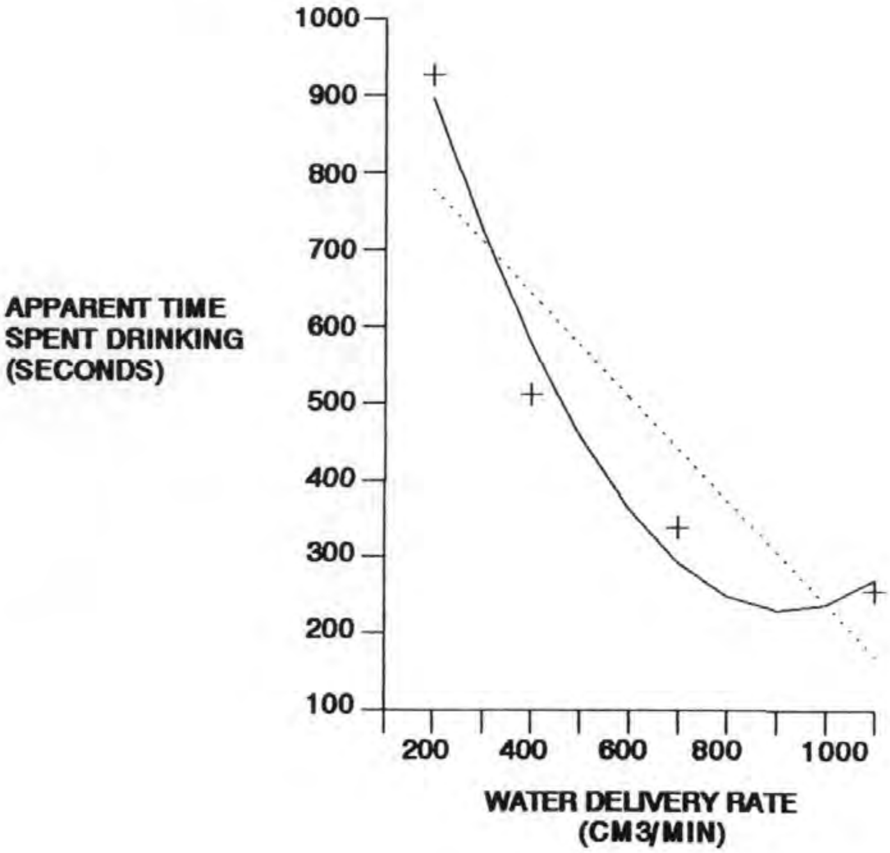


Figure 12.7 The relationship between mean total daily time spent drinking and water delivery rate.



(.....) Linear regression line $Y = 914 - 0.676\ X$

Where Y = Time spent drinking (s/pig/day)

X = delivery rate (cm^3/min)

(——) Quadratic regression line $Y = 1317 - 2.36\ X + 0.00128X^2$

Where Y = time spent drinking (s/pig/day)

X = water delivery rate (cm^3/min)

an increased coefficient of determination but analysis of variance of the line showed that the line was not a significant representation of the data and was less significant than the linear representation.

$Y = 1317 - 2.36\ X + 0.00128\ X^2 \qquad R^2 = 91.5\% \qquad p = 0.168$

standard deviation intercept = 179.8
b1 = 0.0005
b2 = 0.666

The reason for this was that the total degrees of freedom for both regression analyses was 3. Undertaking quadratic regression doubles the regression degrees of freedom and halves the error degrees of freedom.

Regression of apparent time spent drinking against liveweight for each delivery rate has not been undertaken as this will reflect similar results to the regression analysis of water use, owing to the direct relationship between water use, delivery rate and time spent drinking. However a multiple regression analysis of mean time spent drinking against delivery rate and mean liveweight has been undertaken in order that both parameters can be taken account of when predicting the amount of time required for a pig to drink its requirement. The following equation was produced:

$Y = 498 - 0.679\ X1 + 10.1\ X2 \qquad R^2 = 73.5\% \qquad p = 0.001$

standard deviation intercept = 193.7
b2 = 0.1094
b3 = 4.315

Where Y = mean time spent drinking (s)
X1 = delivery rate (cm^3/min)
X2 = live weight (kg)

The high coefficient of determination indicates that the regression equation accounts for a high proportion of the variation. Analysis of variance of the regression proved that it was a highly significant representation of the data (P<0.001). When the regression sums of squares is broken down into the two predictors, it is found that live weight only accounts for 9.5% of the variation. This figure is higher than the similar figure produced in the water use multiple regression analysis suggesting that liveweight is more important in the prediction of time spent drinking than in water use. Delivery rate accounted for 67.4% of the variation, the remainder resulted from error.

A second multiple regression of apparent time spent drinking included an additional parameter of the square of delivery rate.
This produced the following equation:

$$Y = 898 - 2.37\ X1 + 0.00128\ X1^2 + 10.2\ X2 \qquad R^2 = 91.4\% \qquad P=0.001$$

standard deviation intercept = 133.2
b2 = 0.323
b3 = 0.000241
b4 = 2.45

Where Y = mean time spent drinking (s)
X1 = delivery rate (cm^3/min)
X2 = live weight (kg)

Including the square of delivery rate in the equation increased the coefficient of determination by 17.9% making the regression equation account for a higher proportion of the total variation. Analysis of variance of the regression line showed it to be a highly significant representation of the data (P<0.0001). Figure 12.8 shows values obtained from the multiple regression equation above calculated at different weights (over the weight range covered in the experiment) at each of the different delivery rates. Figure 12.9 illustrates the effects of the different water delivery rates on the apparent time spent drinking as liveweight increased.

Figure 12.8 The relationship between mean apparent time spent drinking and water delivery rate at 30,40,50 and 60 kg live weight according to the multiple regression equation:

$$Y = 898 - 2.37\,X1 + 0.00128\,X1^2 + 10.2X2$$

where Y = drinking time (s/pig/day)
X1 = delivery rate (cm^3/min)
X2 = live weight (kg)

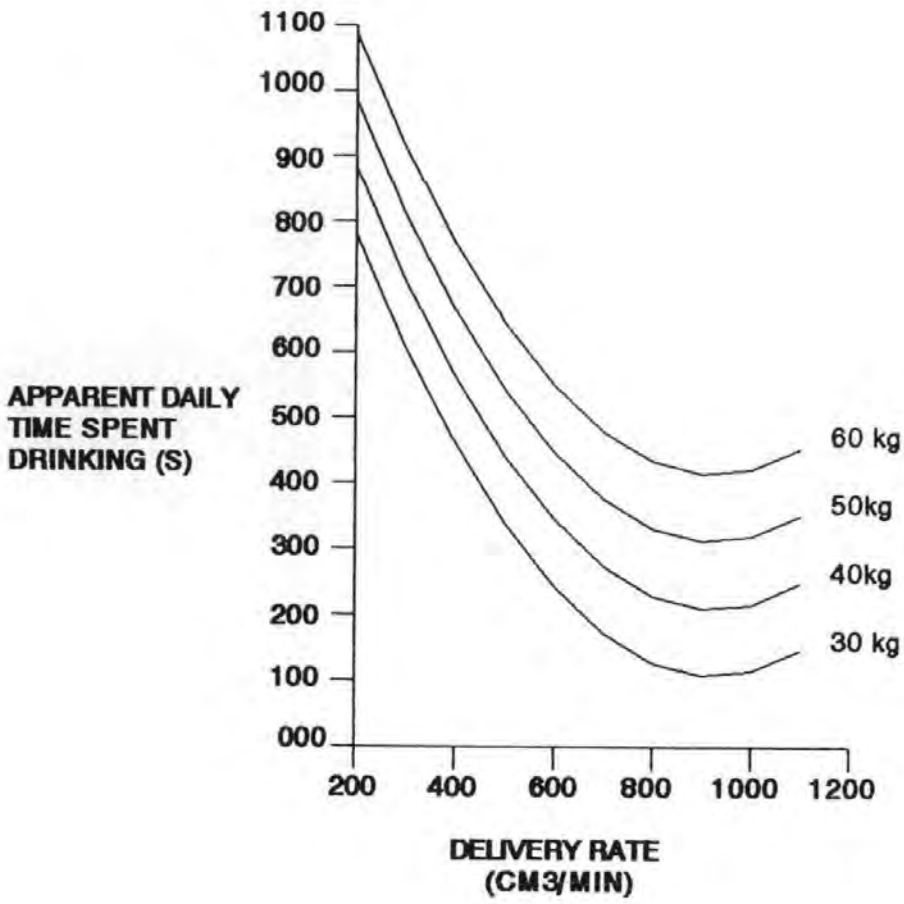


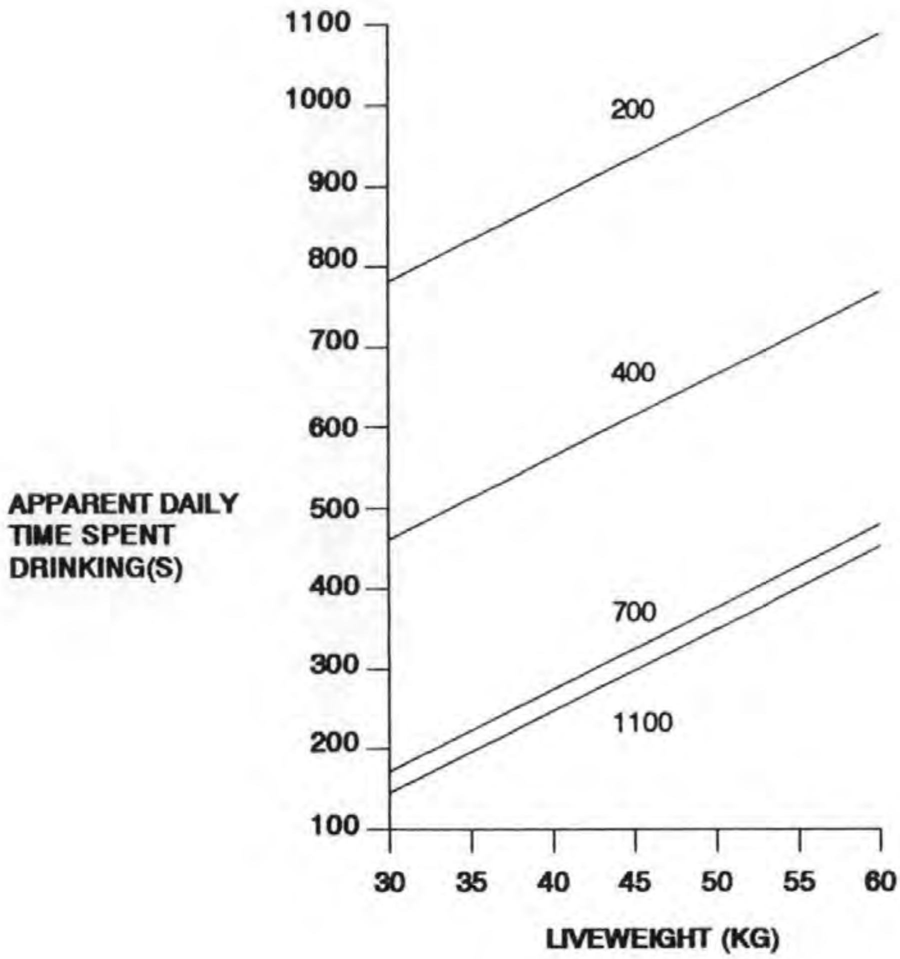
Figure 12.9 The relationship between mean apparent time spent drinking and mean live weight at 200,400,700 and 1100 cm^3/min according to the multiple regression equation:

$$Y = 898 - 2.37\,X1 + 0.00128\,X1^2 + 10.2\,X2$$

where Y = drinking time (s/pig/day)

X1 = delivery rate (cm3/min)

X2 = live weight (kg)



Discussion

The results show that between the delivery rates of 200 and 1100 cm^3/min there is a significant difference in the water used by the pigs, the higher delivery rates supplying more water. This relationship was clearly shown by Figure 12.1. Between these two delivery rates there was no significant difference in performance characteristics. This would tend to suggest that the greater amounts of water dispensed at the higher delivery rates resulted from wastage of water. These conclusions are similar to those reached in Experiments 6 and 7. At a liveweight of 41 kg the increase in delivery rate from 200 to 1100 results in an increase in usage of water of 1.62 litres per pig. Assuming that all of this was wastage and that wastage increases linearly with water delivery rate, for every 100 cm3/min increase in delivery rate there is a corresponding increase in wastage of 0.18 litres. It may be that wastage is not linearly related and that as water use increases so to does water intake. The amount of water wasted at 200 cm^3/min is unknown and the effects of delivery rate on water use below 200 cm^3/min can not be extrapolated from Figure 12.1 as this would suggest a water use of 2.71 litres/pig/day at a delivery rate of 0 cm^3/min. This is obviously incorrect.

The model produced by Gill,(1989) of obligatory water losses and gains, which determine the amount of water required per day by a growing pig to maintain physiological homeostasis, estimates that a 60 kg pig would require between 1.91 and 3.33 litres per day. If the multiple regression equation given in Figure 12.6 is used to calculate the water used by a 60 kg pig at 200 cm3/min it is found to be 3.31 litres/day. This experimental value is in very good agreement with the theoretical value calculated from Gill's model. This would suggest that under the experimental conditions examined, there was little waste water at the water delivery rate of 200 cm^3/min. It is important to point out that this deduction is only appropriate to 200 cm^3/min under the conditions studied. Under a ration feeding system or with a greater number of pigs per drinker, the results may not have been the same.

Water use to feed ratios can be calculated by dividing total daily water use by total daily feed use giving the following results.

water delivery rate (cm3/min)	200	400	700	1100
Water to feed ratio	1.23:1	1.37:1	1.57:1	1.91:1

From the above figures it can be seen that water use to feed intake ratios vary according to delivery rate. Therefore it is quite clear that water use to feed ratio is of no value within the context that researchers and producers currently use it, that is to compare production levels and water intakes for different systems and to make recommendations for water to feed ratios for wet feed systems. Its only use is as a means of estimating the varying amounts of waste from different water supply systems. It is interesting to note that the water to feed ratios calculated above are relatively low compared to the values presented in Table 3.6. They are also lower than the minimum water to feed ratio suggested by Yang et al., (1981), of 1.6 to 1.

The results of this experiment can not be directly applied to the ration fed situation. A second experiment was to have run along side this experiment examining the effects of the same delivery rates on the water use of ration fed pigs. Unfortunately this experiment had to be abandoned because a slime mould entered the water system and slowly restricted pipes, meters and drinkers confounding the treatment delivery rate effects. Time did not allow a repeat of this exact experiment.

It is known that the drinking patterns of pigs is conditioned by the feeding regime (Albar *et al.*, 1985). Ration fed pigs have peak demand periods which occur immediately after the feeds and are higher than those of *ad libitum* fed pigs. The pattern of water use of *ad libitum* fed pigs is more diffuse, characterised by only small peaks. When the delivery rate is reduced for ration fed pigs competition for the drinkers would be greater than for *ad libitum* fed pigs owing to the greater demand peaks. Therefore for *ad libitum* fed pigs it may be possible to reduce the delivery rate to a lower level than for ration fed pigs with out any detrimental effects on pig performance.

In order to be able to predict water use accurately over the water delivery rate range studied here for the ration fed system it is necessary to compare with:

(1) an experiment under taken by Gill,(1989) directly comparing the water use of growing pigs from different drinkers fed either *ad libitum* or ration fed.

(2) Experiments 6 and 7 which examine the water use of growing pigs at two different delivery rates in which the pigs were ration fed.

In an experiment comparing water use from different drinker types for *ad libitum* and ration fed pigs Gill,(1989) showed that water use was higher for *ad libitum* than for scale-fed pigs for three bite drinker types, but from the Mono-flo drinker a greater volume was used when the pigs were fed on a scale relating to metabolic liveweight. Considering only the Arato 80 drinker in Gill's experiment, water use for the *ad libitum* fed pigs was 5.63 litres/pig/day and for the ration fed pigs was 5.00 litres/pig/day at a water delivery rate of 670 cm^3/min. The mean weights for the groups of pigs under the two feeding systems were slightly different and when water use per kg live weight was calculated it was found that for both systems the water use:live weight ratio was 0.11. This shows that water use per kg live weight was similar for *ad libitum* and ration fed pigs. For the two other bite drinkers studied the results were similar. This would suggest that water use is similar for both ration and *ad libitum* fed pigs.

Using the regression equation in Figure 12.6, the predicted water use of a 51.18 kg live weight pig at 670 cm^3/min is 4.04 litres/pig/day compared to Gill's value of 5.63 litres/pig/day. Gill has omitted to specify the house temperature during the course of his experiment. Consequently a comparison of this nature cannot really be made. However the difference between the two values may be a reflection of temperature. In this context, the most useful conclusion from Gill's experiment is that per kg liveweight, the water use of *ad libitum* fed pigs is similar to that of ration fed pigs. Therefore information gathered from *ad libitum* experiments may be used for predicting the water use of ration fed pigs providing that other parameters remain the same.

In order to compare the results of this experiment with those of experiments 6 and 7 it is again necessary to use the multiple regression equation relating water use, delivery rate and liveweight used in Figure 12.6 to predict the water use of 45 kg pigs at 300 and 900 cm3/min. A comparison of results is given in Table 12.4 below.

Table 12.4 A comparison of the results obtained in Experiments 6,7 and 8

	Delivery rate (cm3/min)		
	300	900	Temperature range(°C)
Experiment 6:	4.18	4.88	14.0-17.6
Experiment 7:	3.70	5.3	15.1-19.7
Experiment 8:	3.29	4.38	13.3-14.0

(values given are litres/pig/day)

It appears that the predictions from Experiment 8 are lower than the measured means from Experiments 6 and 7. These differences are most likely due to the lower temperatures recorded in Experiment 8.

This experiment has shown that at the lower delivery rates the growing pig has been prepared to spend significantly longer amount of time drinking in order to achieve its intake without effecting growth. The results may not be the same when total pen drinking time is increased from a single drinker by increasing the number of pigs in the pen, or when the peak requirements are increased by ration feeding.

Experiment 8A: A comparison of water use between two water delivery rates by growing pigs kept under near commercial conditions fed initially ad libitum and later according to a scale based on metabolic live weight.

Introduction

The Codes of Recommendations for the Welfare of Livestock: Pigs (1990) state that one drinker should be provided per 10-12 pigs and at least two drinkers per pen. Two drinkers per pen are recommended in the event that should a fault or blockage occur in one of them the remaining one would continue to function. These recommendations are still not being universally adopted.

Experiments 6,7 and 8 were conducted with relatively small groups of pigs, namely eight. In the commercial situation, pigs are kept in greater numbers, groups of greater than 15 being more common. The aim of this experiment was to investigate the effects of delivery rate on production parameters and water use under near commercial conditions.

Materials and methods

Experimental design and treatments

The water use and performance of growing pigs supplied with water from single Arato 80 drinkers at two water delivery rates was investigated. The two treatment delivery rates were as follows:

1 300 cm^3/min

2 900 cm^3/min

A diagram of the Arato 80 drinker is given in Figure 1.3. The experiment was conducted over a period of 8 weeks. During the first 5 weeks the two treatment pig groups were fed *ad libitum*. For the latter period the pigs were ration-fed. Replication was not possible as space and time was limited, and therefore the results and statistical analysis of this experiment have limitations.

Animals and housing

Thirty-two Large White x (Large White x Landrace) consisting of an equal number of gilts and boars pigs were individually weighed at the start of the trial (initial mean weight 31.36 ±1.46 kg), period and 16 were randomly assigned to the two treatment pens. The pigs were housed in the test house for a period of four days prior to the start of the trial in order to accustom them to the environment and the feeding regime.

Water was available *ad libitum* to each pen from a single drinker, mounted on variable height brackets. The height was initially set at 0.5 m from the ground as specified by the manufacturer, drinker height being increased by an equal amount in each pen to maintain the recommended drinking attitude as the pigs grew. The drinkers were aligned at a 15° decline from the ground.

Different water delivery rates in the drinkers were achieved by varying the internally fitted plastic apertures in the drinkers. The delivery rates selected were checked weekly and remained within 5% of the nominal values. The water was supplied from the mains supply, via an anti back-siphon device and metered through previously calibrated

Table 13.1 Proximate and mineral analyses of the feed used in Experiment 8A

Dry matter (%)	85.2
Digestible energy (MJ/kg DM)	15.4
Crude protein (g/kg DM)	20.8
Crude fibre (g/kg DM)	29.0
Neutral detergent fibre (g/kg DM)	129
Oil (Acid hydrolysis) (g/kg DM)	25.0
Total ash (g/kg DM)	71.0
Calcium (g/kg DM)	15.0
Phosphorous (g/kg DM)	10.3
Magnesium (g/kg DM)	1.5
Sodium (g/kg DM)	2.6
Potassium (g/kg DM)	5.5
Chloride (g/kg DM)	3.1

Kent PSM-L water meters. The pressure head of water was maintained at 10 m by the use of a pressure regulator.

For the first part of the experiment the pigs were fed *ad libitum* in groups using troughs with hopper reserves of feed. The hoppers where kept topped up without allowing any of the feed to become stale. The feed was formulated from wheat, barley and soya to meet A.R.C. (1981) nutrient requirements for growing pigs and was presented in meal form. Proximate and mineral analysis of the feed is given in Table 13.1. As the feed was fed *ad libitum*, no water was mixed with the feed and consequently total water used represents voluntary water use. For the second part of the experiment the pigs were individually fed ration fed on a metabolic weight scale of 100 g/kg $W^{0.75}$ based on the average weight of the pigs. The feed was of the same specification of that fed in the first part of the experiment. In order to make the feed more palatable in the ration-fed situation an equal volume of water was added. Therefore total water use in this period was made up from voluntary water use and water-in-feed.

The temperature of the test house was recorded using two previously calibrated Thermographs positioned as close to the pigs as possible but remaining out of their reach.

Results

The health of all experimental animals was good, with no deaths nor incidence of scour. The daily mean temperature varied from 16.1°C to 18.5°C. This range of temperature was higher than that recorded in

Experiment 8 because it was conducted during mid summer as opposed to winter.

Pig performance and water use data is presented in Table 13.2. Owing to the nature of the measurements and the fact the investigation was not intended to be a complete one a full statistical analysis was not possible. Two sample t-tests showed there to be no significant difference in weekly mean live weight between the two delivery rates, for both of the feeding regimes. There was a significant difference in water use between 300 cm^3/min and 900 cm^3/min for the ad *Libitum* fed pigs. For the ration fed pigs the two sample t-test showed that there was no significant difference in water use between the high and low water delivery rate (P=0.077). This non significant result was probably effected by the small populations compared (n=3).

Regression analyses have been undertaken to investigate the relationship between total water use and mean live weight for the two water delivery rates studied under both feeding regimes. The results of these analyses are presented in Table 13.3. For the *ad libitum* feeding system, the regression equations obtained account for a relatively high proportion of the variation indicated by the high values for the coefficients of determination. The equations are significant representations of the experimental data, ($P<0.05$).

For the ration-fed pigs the linear regression equations produced also account for a high proportion of the variation indicated by the relatively high values for the coefficients of determination. However the equations were not significant representations of the data, ($P>0.05$). This is probably due to the small size of the populations

Table 13.2 Water use, feed intake and performance of growing pigs offered water at one of two delivery rates under two feeding regimes.

	Ad Lib. Period		Ration fed period	
Water delivery rate (cm^3/min)	300	900	300	900
Total water use (litres/pig/day)	3.30	4.44	4.71	5.31
Voluntary water use (litres/pig/day)	3.30	4.44	2.54	3.25
Mean live weight (kg)	41.18	38.49	60.38	56.35
Mean feed intake (kg/pig/day)	1.84	1.77	2.17	2.06
Mean weight gain (kg/day)	0.526	0.488	0.517	0.508
Mean F.C.R.	3.49	3.62	4.19	4.05
Apparent time spent drinking (s/pig/day)	660	296	508	216

This table of results has been presented for completeness. Due to the design of the investigation, analysis of variance was not possible.

Table 13.3 Regression of mean total water use against mean weight of growing pigs provided with water at delivery rates of 300and 900 cm3/min under two feeding regimes.

Treatment	Regression equation	P	R^2	Standard deviation of: intercept	b1
<u>Ad Libitum</u>					
300 cm3/min	$Y = -0.299 + 0.0874X$	0.005	92.9%	0.499	0.0119
900 cm3/min	$Y = 0.29 + 0.108X$	0.034	76.4%	1.128	0.0289
<u>Ration Feed</u>					
300 cm3/min	$Y = 1.7 + 0.0499X$	0.192	82.4%	0.937	0.0154
900cm3/min	$Y = 2.62 + 0.0477X$	0.222	76.6	0.979	0.0173

Where Y = Total water use (litres/pig/day)
X = Liveweight (kg)

measured.

Analysis has been undertaken in order to establish whether the regression lines differ significantly from one another according to water delivery rate or whether they differ at similar water delivery rates but different feeding regimes.

Comparing the two water delivery rates ad *libitum*:

t-ratio of intercept = -1.18 $(P>0.05)$
t-ratio of gradient = -1.73 $(P>0.05)$

Comparing the two water delivery rates ration fed:

t-ratio of intercept = -0.98 $(P>0.05)$
t-ratio of gradient = 0.14 $(P>0.05)$

Comparing the two feeding regimes at 300 cm^3/min:

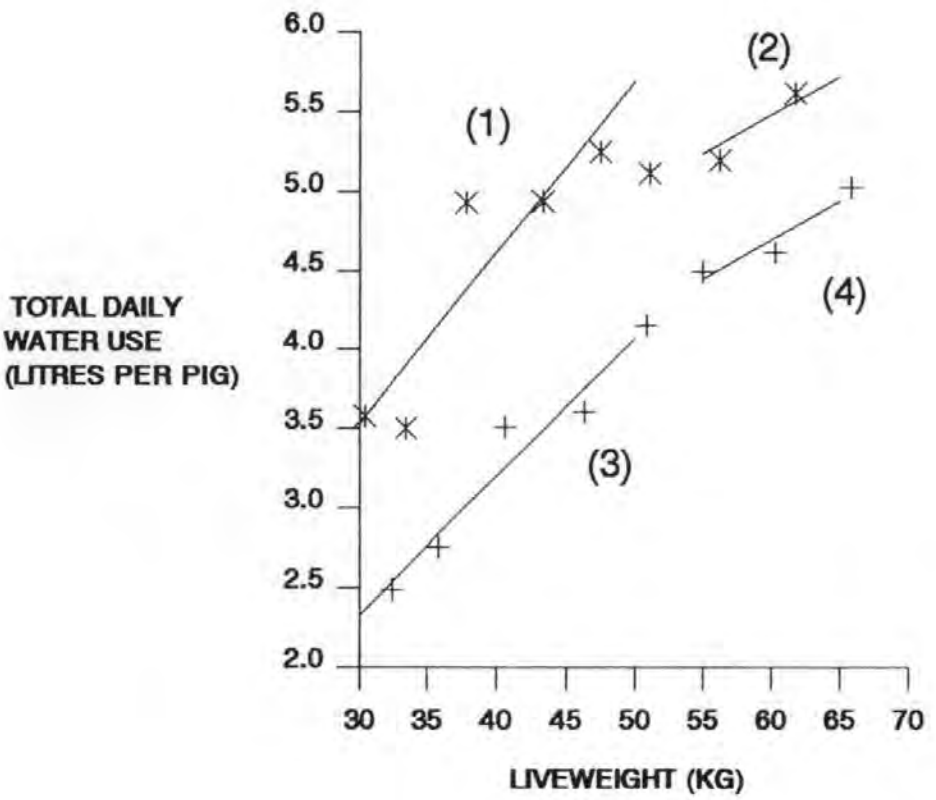
t-ratio of intercept = -4.0 $(P<0.05)$
t-ratio of gradient = 3.15 $(P<0.05)$

Comparing the two feeding regimes at 900 cm^3/min:

t-ratio of intercept = -2.06 $(P>0.05)$
t-ratio of gradient = 2.08 $(P>0.05)$

These comparisons of linear regression equations have been summarised in Figure 13.1. During the ad libitum period there was no significant difference between the two regression lines (delivery rates) for the intercept nor the gradient. This implies that there was no significant differences in the rate of increase in water use for the two water delivery rates. During the ration-fed period there was also no significant difference between the two regression lines for the intercept nor the gradient $(P>0.05)$. This implies that there was no significant difference in the rate of increase in water use for the two delivery rates.

Figure 13.1 The relationships between mean total daily water use and mean live weight at 300 and 900 cm^3/min fed ad *libitum* and rationed.



(1) 900 cm^3/min, ad *libitum*
Y = 0.29 + 0.108 X
(2) 900 cm^3/min, ration fed
Y = 2.62 + 0.0477 X
(3) 300 cm^3/min, ad *libitum*
Y = -0.299 + 0.0874 X
(4) 300 cm^3/min, ration fed
Y = 1.7 + 0.0499 X300 cm^3/min.

Where Y = Total water use (litres/pig/day)
X = Live weight (kg)

Comparing the two feeding regimes, at 300 cm^3/min there was a significant difference between the two lines in both the intercept and the gradient. This shows that there is a significant difference in the rate of increase in water use and therefore that the pattern of water use for *ad libitum* fed pigs may be different from ration fed pigs atComparing the two feeding regimes at 900 cm^3/min there was no significant difference between the two regression lines for the intercept or the gradient. This implies that there was no significant difference in the rate of increase of water use and therefore in contrast to the above, the pattern of water use was unaffected by the feeding regime.

Discussion

Using the regression equations given in Table 13.3 the predicted water use of a pig of a given weight can be calculated for the two delivery rates studied and under the two different feeding regimes in order that the results from this experiment can be compared to those of experiments 6,7, and 8. A comparison of results is given in Table 13.4 for a 45 kg pig.

Experiments 6,7, and 8A have examined the same water delivery rates and therefore an analysis of variance between the linear regression lines of total water use against live weight can be undertaken:

Comparing Experiment 8A with Experiment 6:

(300 cm^3/min)

$Y = 1.07 + 0.0686\ X$	t-ratio of intercept = 0.67	N.S.
	t-ratio of gradient = 1.21	N.S.

Table 13.4 A comparison of water use data obtained in Experiments 6,7,8 and 8A

	Delivery rate (cm^3/min) 300	900	Temperature range(°C)
Experiment 6: (Ration fed)	4.18	4.88	14.0-17.6
Experiment 7: (Ration fed)	3.70	5.3	15.1-19.7
Experiment 8: (*Ad libitum*)	3.29	4.38	13.3-14.0
Experiment 8A:			
(*Ad libitum*)	3.63	5.15	16.5-18.5
(Ration fed)	3.94	4.76	16.5-18.5

(values are given as litres/pig/day for a 45 kg pig).

(900 cm^3/min)
Y = -1.99 + 0.070 X   t-ratio of intercept = 4.7   ($P<0.01$)
t-ratio of gradient = -1.45   N.S.

Where Y = total water use (litres/pig/day)
X = live weight (kg)

At the lower delivery rate there is no significant difference between the two experiment regression lines in either the intercept coefficient nor the gradient. This is shown by the relatively small difference in the values computed for a 45 kg pig presented above. At the higher delivery rate there is a significant difference in the intercept coefficients. This can be explained by the fact that water use was studied over different ranges in the two experiments. There was no significant difference in the gradients of the two regression lines showing that there was no significant difference in the rate of increase in water use with weight.

Comparing Experiment 8A with Experiment 7:

(300 cm^3/min)
Y = 1.06 + 0.105 X   t-ratio of intercept = 2.94   ($P<0.05$)
t-ratio of gradient = -3.57   ($P<0.05$)

(900 cm^3/min)
Y = 1.27 + 0.0889 X   t-ratio of intercept = 1.38   N.S.
t-ratio of gradient = -2.69   ($P<0.05$)

Where Y = total water use (litres/pig/day)
X = live weight (kg)

At 300 cm^3/min there was significant difference between the intercepts of the two lines and the gradients. At the higher delivery rate there was no significant difference between the intercepts of the two lines, however there was a difference between the gradients of the two lines. These differences may have been due to the difference in the numbers of pigs in the groups or the limited weight range studied in

Experiment 8A.

In summarising the results of this investigation, it appears that pig performance under conditions which would equate closely to normal commercial practice was not affected by the low delivery rate despite there only being one drinker per pen for 16 pigs.

Experiment 9: A comparison of water use between four delivery rates by early weaned pigs from 3 to 6 weeks of age.

Introduction

Water is commonly supplied to the weaned piglets either from bowls or from drinkers. With the exception of water bowls with a large reservoir capacity, the availability of water to the pig depends upon the water delivery rate from the drinker. Despite this fact few manufacturers of piglet drinking utensils recommend an optimum water delivery rate for their product. The objective of this experiment was to investigate the water use of piglets over a range of delivery rate.

Materials and methods

Experimental design and treatments

The performance and water use of early weaned pigs supplied with water from drinkers at four water delivery rates was investigated.The four treatment delivery rates were as follows:

1 175 cm^3/min

2 350 cm^3/min

3 450 cm^3/min

4 700 cm^3/min

The treatment delivery rates were replicated through four pens (replicates) and in time according to a Latin Square design.

Consequently at the end of the experiment each treatment would have occurred once in each pen and once in each time period.

Animals and housing

Sixteen groups consisting of 5 entire male and 5 female Large white x (Large White x Landrace) were selected. The piglets weaned at 21 ± 2 days, were ear tagged for identification and weighed. The average weaning weight was 5.84 ± 0.3 kg. As far as possible the groups were balanced for litter and weaning weight. At the beginning of each time period 4 groups were randomly allocated to one of the four treatment pens in a flat-deck early weaner house. The house was maintained at a near constant temperature (nominally 27°C throughout the period of the trial).

Each pen, measuring 1.45 x 1.25 m, was supplied with water from a low pressure water system via two Arato 76 tube drinkers (Figure 1.6) mounted 0.25 m above the wire mesh floors, allowing ad *libitum* access to the water. The pressure head of water was 1.3 m. The drinkers were aligned at a 15° decline from the ground. Different water delivery rates in the drinkers were achieved by varying the size of the internally fitted plastic apertures in the drinkers. The delivery rates selected were checked weekly and remained within 5% of the nominal values.

The piglets were fed in troughs measuring 1.43 m x 0.2 m. The proximate and mineral analysis of the treatment feeds are presented in Table 14.1. The piglets were fed on proprietary diets. For the first two weeks post weaning, they were fed D20M, (J. Bibby ltd.). This was

Table 14.1 Proximate and mineral analyses of the feeds used in Experiment 9

	D20M	D10P
Dry matter (%)	93.0	90.8
Digestible energy (MJ/kg DM)	19.9	18.6
Crude protein (g/kg DM)	22.7	27.3
Crude fibre (g/kg DM)	9.0	22.0
Neutral detergent fibre (g/kg DM)	51.0	66.0
Oil (Acid hydrolysis) (g/kg DM)	212	127
Total ash (g/kg DM)	63.0	64.0
Calcium (g/kg DM)	9.4	9.7
Phosphorous (g/kg DM)	6.9	6.6
Magnesium (g/kg DM)	1.1	1.5
Sodium (g/kg DM)	3.3	2.8
Potassium (g/kg DM)	10.5	10.7
Chloride (g/kg DM)	6.6	3.7

then changed to D10P, (J. Bibby Ltd.) for the third week.

Experimental procedures

In order to maintain a supply of fresh feed, additions were made at 0830 hours and 1630 hours each day. All feed inputs were recorded and soiled feed was removed and weighed when necessary. Water use was metered using previously calibrated Kent PSM-L waters and was recorded daily at 0830 hours. Piglets were individually weighed weekly using a calibrated spring balance. The piglets remained on the trial for 3 weeks. The temperature of the flat deck house was monitored using a previously calibrated Thermograph positioned 1 m above the pens.

Results

The health of all experimental animals was good, with no deaths nor incidence of scour. Mean daily temperature in the building varied between 25.5 °C and 27.5 °C.

Water use, feed intake and performance data for each treatment delivery rate are presented in Table 14.2. Analysis of variance of the data showed that there was a highly significant difference in voluntary water use between the treatment delivery rates ($P<0.001$), each one being significantly different from each other one. A highly significant difference was found in mean daily feed intake ($P<0.001$) between the treatment delivery rates of 175, 350 and 450 cm^3/min. There was no significant difference in mean daily feed intake between 450

Table 14.2 Water use, feed intake and performance of early weaned piglets from 3 to 6 weeks supplied with water at four water delivery rates.

	Treatment delivey rate cm^3/min					
	175	350	450	700	$S.E._D$	P
Water use (litres/piglet/day)	0.78^a	1.02^b	1.32^c	1.63^d	0.10	0.001
Mean feed intake (kg/day)	0.303^a	0.323^b	0.341^c	0.347^c	0.0053	0.001
Mean live weight gain (kg/day)	0.210^a	0.235^b	0.250^c	0.247^c	0.0057	0.001
Mean F.C.R.	1.48	1.39	1.37	1.42	0.045	N.S.
Apparent time spent drinking (s/pig/day)	268.1^a	175.8^b	174.8^b	139.4^b	16.0	0.001

a,b,c,d means bearing the same superscipt are not significantly different (P>0.05) and 700 cm^3/min. However there was a significant difference between 700 cm^3/min and the two lower delivery rates.

Significant differences were found between the three lower delivery rates for mean daily live weight gain but there was no significant difference between 450 and 700 cm^3/min water delivery rates. However daily gain at a delivery rate of 700 cm^3/min was significantly different from 350 and 175 cm^3/min. There was no significant difference between any of the treatments for mean F.C.R.

Analysis of variance of the time spent drinking showed that significantly more time was spent drinking by the pigs at the delivery rate of 175 cm^3/min than at any other of the delivery rates ($P<0.001$). There was no significant difference in time spent drinking between any other of the water delivery rates.

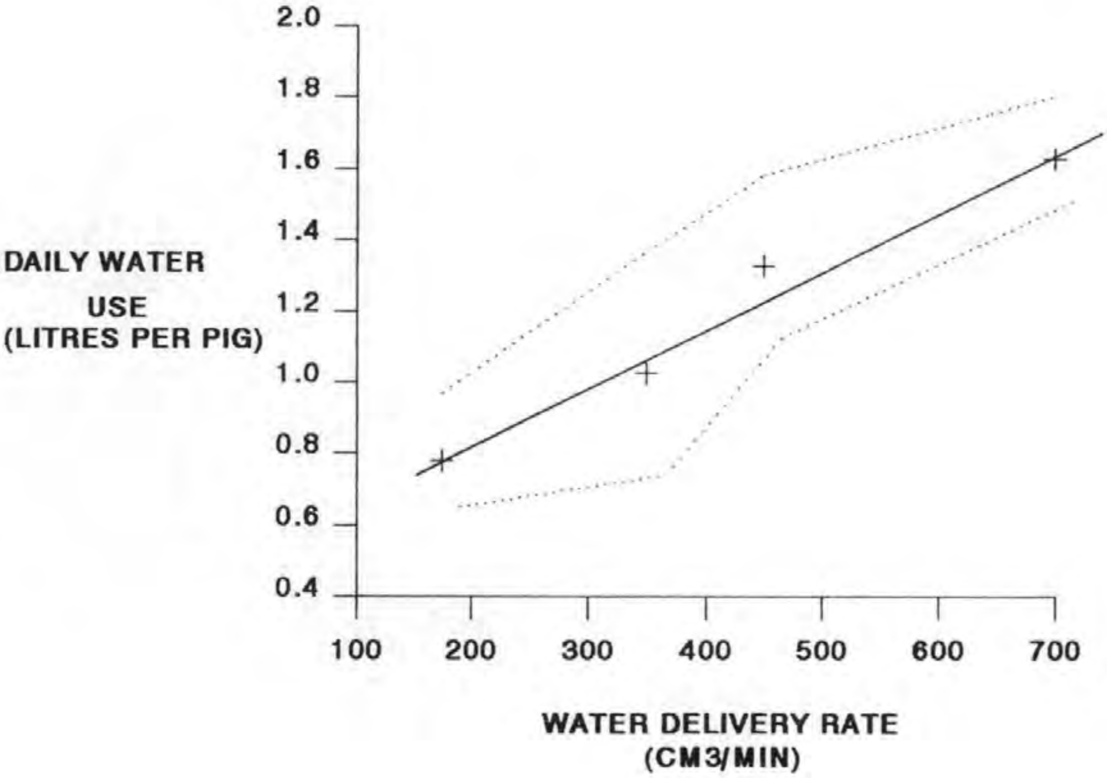
Linear regression of the mean water use against delivery rate gave the following equation:

$Y = 0.499 + 0.00165\,X$ $\quad R^2 = 82.0\%$ $\quad P=0.001$
standard deviation of the intercept = 0.091
gradient = 0.00019
Where Y = water use (litres/pig/day)
X = water delivery rate (cm3/min)

This relationship is shown in Figure 14.1. The coefficient of determination was high (82.0%), showing that the line accounted for a high proportion of the variation in water use due to delivery rate. Analysis of variance of the line showed that it was a highly significant representation of the data ($P<0.001$).

Linear regression of the mean feed intake against delivery rate gave

Figure 14.1 The relationship between mean daily water use and water delivery rate for early weaned pigs.



(——) Linear regression line
$Y = 0.499 + 0.00165\ X$
(.....) 99.9% confidence limits for mean values of water use

Where Y = water use (litres/pig/day)
X = delivery rate (cm^3/min)

the following equation:

$$Y = 0.296 + 0.0000741\,X \qquad R^2 = 52.5\% \qquad P=0.001$$

Standard deviation of the intercept = 0.0082
gradient = 0.000018

Where Y = feed intake (kg/pig/day)
X = water delivery rate (cm^3/min)

The coefficient of determination of this relationship is only 52.5% showing that the regression equation only accounts for half of the variation. However analysis of variance of the line showed that it was a highly significant representation of the data ($P<0.001$).

Quadratic regression of the mean feed intake against delivery rate gave the following equation:

$$Y = 0.264 + 0.000249\,X - 0.000000197\,X^2$$
$$R^2 = 61.9\% \qquad P=0.001$$

Standard deviation of the intercept = 0.016
b1 = 8.39×10^{-5}
b2 = 9.27×10^{-8}

The higher R^2 value for the quadratic relationship indicates that it accounts for a greater proportion of the variation than the linear one and is therefore a better representation of the data. These relationships are illustrated in Figure 14.2.

Linear regression of apparent time spent drinking on delivery rate gave the following equation:

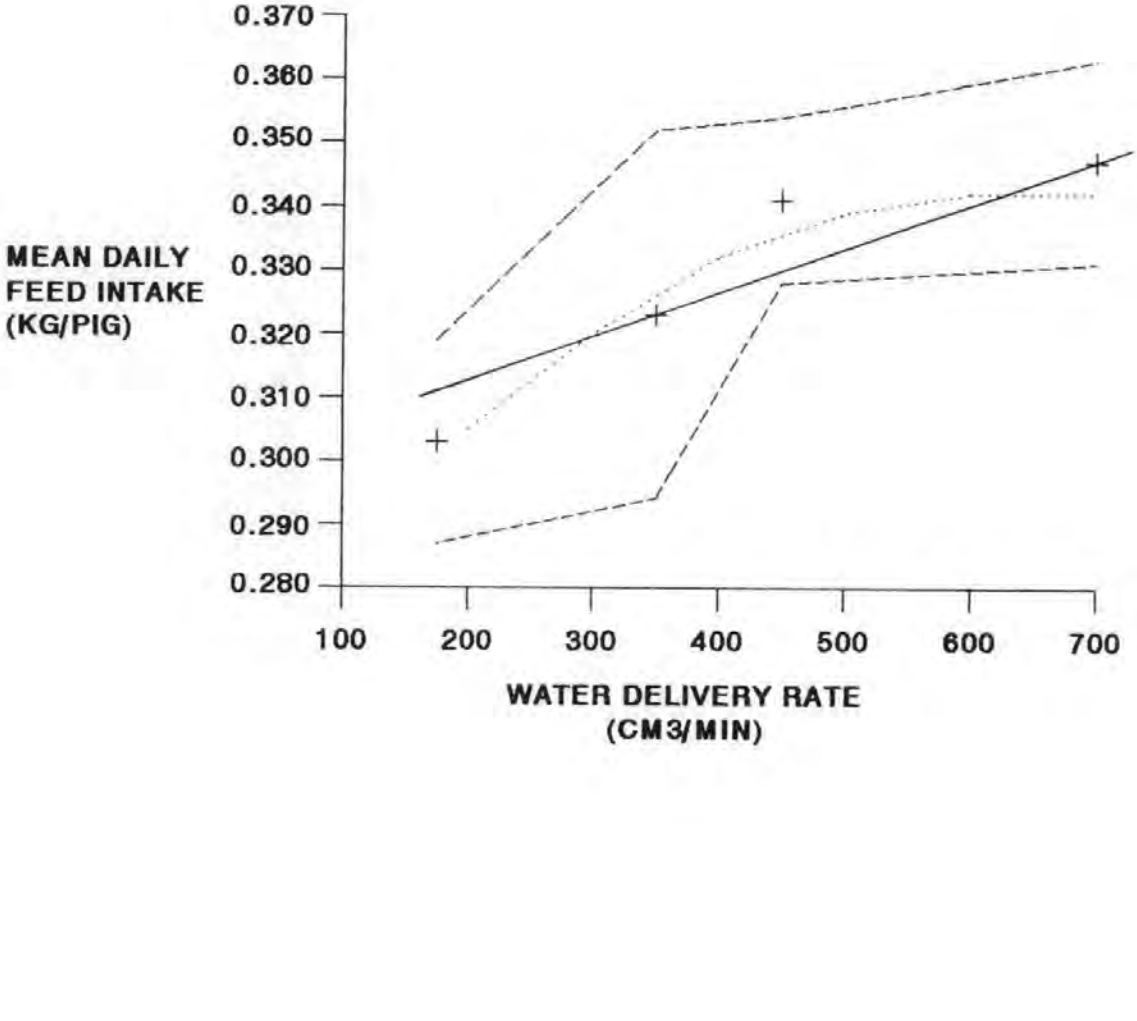
$$Y = 285 - 0.227\,X \qquad R^2 = 62.1\% \qquad P=0.001$$

standard deviation of the intercept = 20.61
gradient = 0.0448

Where Y = time spent drinking (s/pig/day)
X = water delivery rate (cm^3/min)

This equation accounts for 62.1% of the variation measured. Analysis of variance of the line showed that it was a significant representation of the data. Quadratic regression of the apparent time spent drinking on delivery rate again produced a regression equation

Figure 14.2 The relationship between mean daily feed intake and water delivery rate for early weaned pigs.



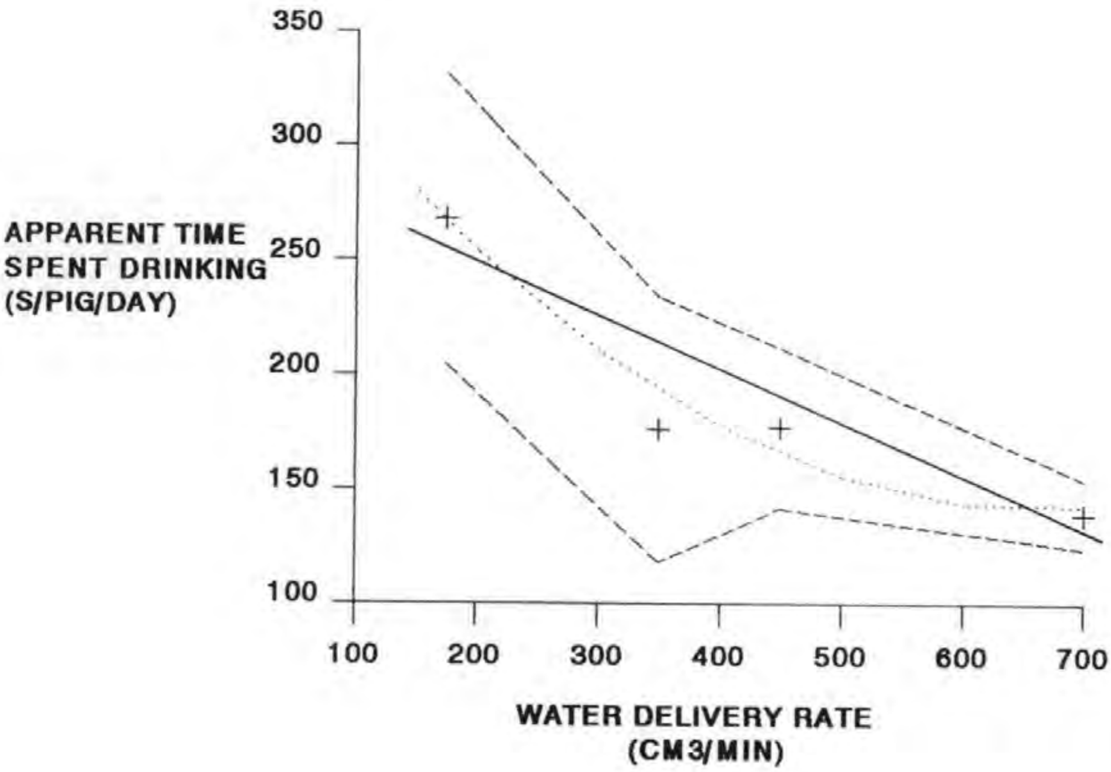
(.....) Quadratic regression line
$Y = 0.264 + 0.000249\ X - 1.97 \times 10^{-7} X^2$

(———) Linear regression line
$Y = 0.296 + 0.0000741\ X$

(-----) 99.9% confidence limits for mean values of feed intake

Where Y = feed intake (kg/pig/day)
X = delivery rate (cm^3/min)

Figure 14.3 The relationship between apparent time spent drinking and water delivery rate for early weaned pigs.



(.....) Quadratic regression line
$Y = 371 - 0.701 X + 0.000533 X^2$

(——) Linear regression line
$Y = 285 - 0.227 X$

(-----) 99.9% confidence limits for mean values of time spent drinking

Where Y = apparent time spent drinking (s)

X = delivery rate (cm^3/min)

with a higher coefficient of determination indicating it to be a better representation of the data:

$$Y = 371 - 0.701\ X + 0.000533\ X^2 \qquad R^2 = 71.3\% \qquad P=0.001$$

Standard deviation of the intercept = 40.86
b1 = 0.2065
b2 = 0.000228

These relationships are illustrated in Figure 14.3

Linear regression of mean daily feed intake on mean daily water use gave the following equation:

$$Y = 0.270 + 0.484\ X \qquad R^2 = 75.5\% \qquad P = 0.001$$

standard deviation of the intercept = 0.00816
gradient = 0.007
Where Y = mean feed intake (kg/pig/day)
X = mean water use (litres/pig/day)

The regression line produced accounts for a high proportion of the variation. Analysis of variance of the line showed that it was a highly significant representation of the data.
Quadratic regression analysis of the of feed intake on water use produced a regression line which accounted for a greater proportion of the variation than linear regression. This was shown by the higher coefficient of determination.

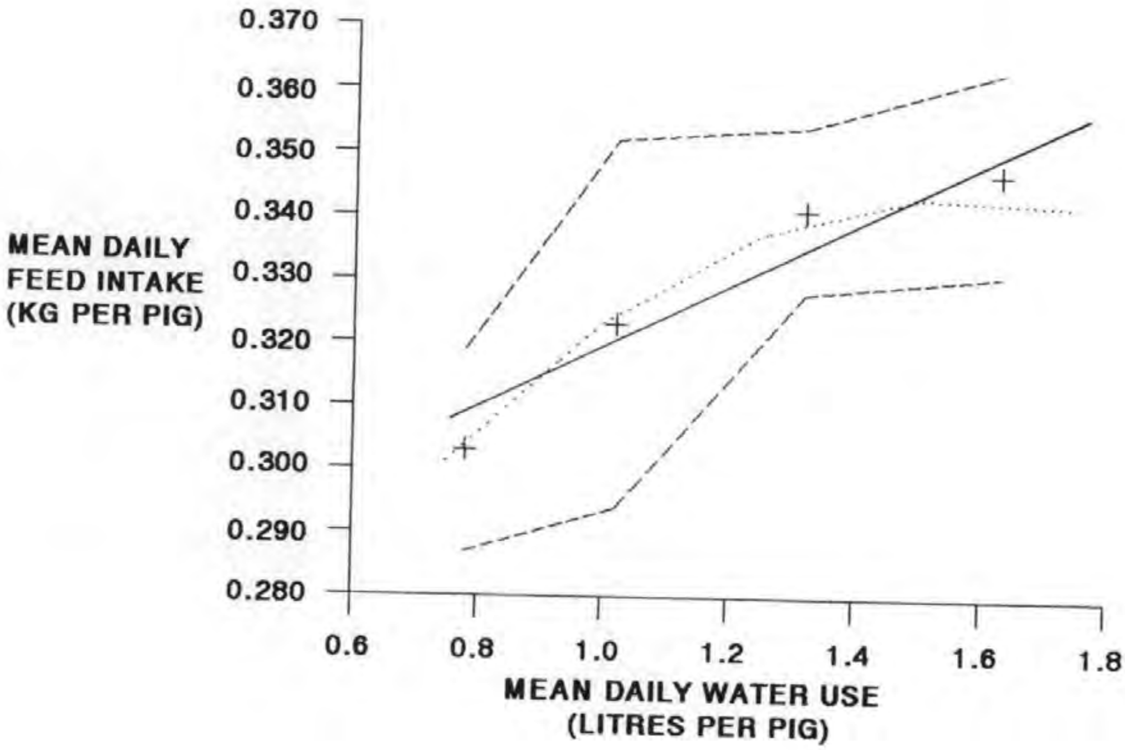
$$Y = 0.189 + 0.196\ X - 0.00619\ X2$$
$$R^2 = 86.0\% \qquad P=0.001$$

standard deviation of the intercept = 0.0249
b1 = 0.0443
b2 = 0.0185

These relationships are illustrated in Figure 14.4.

Detailed regression analyses have been undertaken to investigate the

Figure 14.4 The relationship between mean daily feed intake and mean daily water use for early weaned pigs.



(.....) Quadratic regression line
$Y = 0.189 + 0.196\ X - 0.0619\ X^2$

(——) Linear regression line
$Y = 0.270 + 0.0484\ X$

(-----) 99.9% confidence limits for mean values of feed intake

Where Y = feed intake (kg/pig/day)
X = water use (litres/pig/day)

Table 14.3 Regression of mean total water use against mean weight of growing pigs provided with water at delivery rates of 200,400,700 and 1100 cm3/min.

Treatment	Regression equation	P	R^2	Standard deviation of: intercept	b1	b2
175 cm3/min	$Y = 0.0827 + 0.0637X$	0.001	89.2%	0.068	0.0048	
	$Y = 0.379 - 0.0135X + 0.0053X^2$	0.001	98.1%	0.041	0.0086	0.0004
350 cm3/min	$Y = 0.212 + 0.0745X$	0.001	84.8%	0.088	0.0070	
	$Y = 0.659 - 0.0422X + 0.0053X^2$	0.001	98.0%	0.051	0.0107	0.0005
450 cm3/min	$Y = 0.292 + 0.0945X$	0.001	88.2%	0.097	0.0077	
	$Y = 0.766 - 0.0292X + 0.00562X^2$	0.001	97.7%	0.068	0.0144	0.0006
700 cm3/min	$Y = 0.223 + 0.127X$	0.001	92.4%	0.102	0.0081	
	$Y = 0.681 + 0.008X + 0.00543X^2$	0.001	97.5%	0.094	0.0198	0.0009

Where Y = Voluntary water use (litres/pig/day)
X = Days post weaning

relationship between total water use and the number of days post weaning for each delivery rate studied. The results of these analyses are presented in Table 14.3. Comparing linear and quadratic regression at each of the delivery rates, the quadratic regression line accounted for a greater amount of the variation indicated by the higher value of the coefficient of determination. As table 5.16 illustrates all the quadratic regression equations had values of over 97%. The relationships between mean total daily water use and the number of days post weaning at each treatment delivery rate is illustrated by Figures 14.5, 14.6, 14.7 and 14.8.

The regression analyses showed that delivery rate accounted for a high proportion of the variation in daily water use between the treatments and that the number of days post weaning accounted for almost all of the within treatment variation in daily water use. Therefore a multiple regression analysis was undertaken regressing daily water use against water delivery rate and the number of days post weaning. This produced the equation:

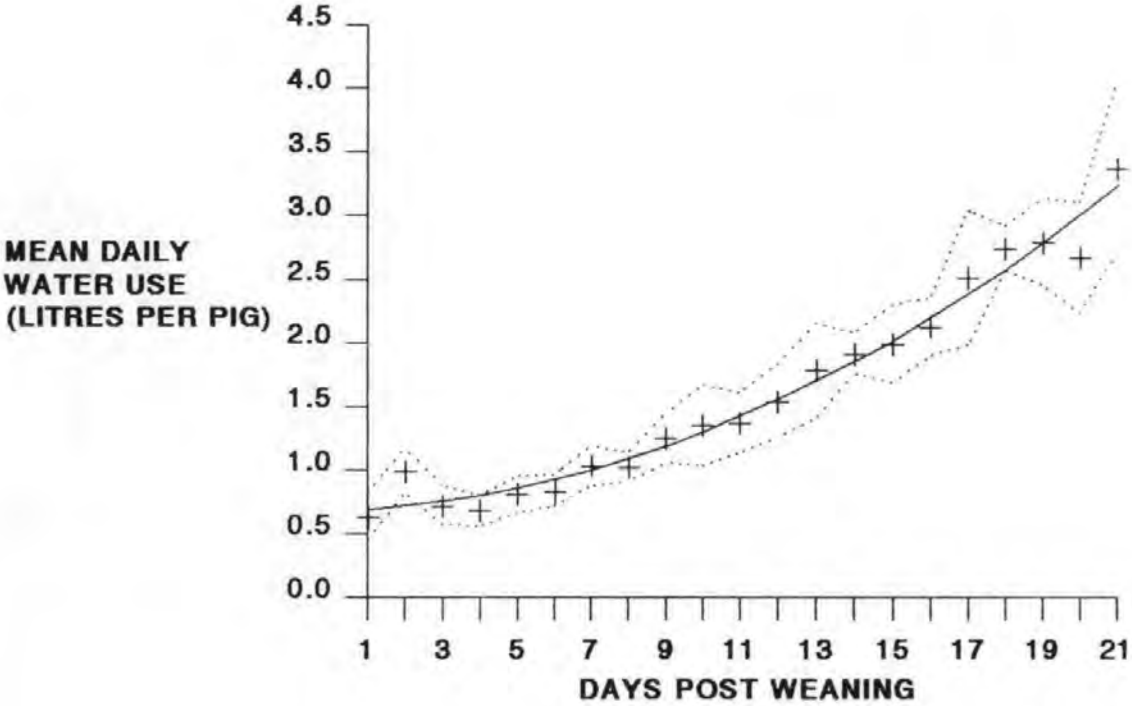
$$Y = -0.478 + 0.00165\,X1 + 0.0895\,X2 \qquad R^2 = 79.1\% \qquad P=0.001$$

standard deviation of intercept = 0.0531
b1 = 0.000092
b2 = 0.00289

Where Y = water use (litres/pig/day)
X1 = delivery rate (cm^3/min)
X2 = number of days post weaning

The high coefficient of determination shows that the equation accounts for a high proportion of the variation. When the regression sums of squares is broken down into the two predictors it is found that the number of days post weaning accounts for 59.4% of the variation and the delivery rate 19.7%. Analysis of variation of the regression equation showed that it was a significant representation of the data

Figure 14.5 The relationship between mean daily water use and the number of days post weaning for early weaned pigs at a delivery rate of 700cm³/min.

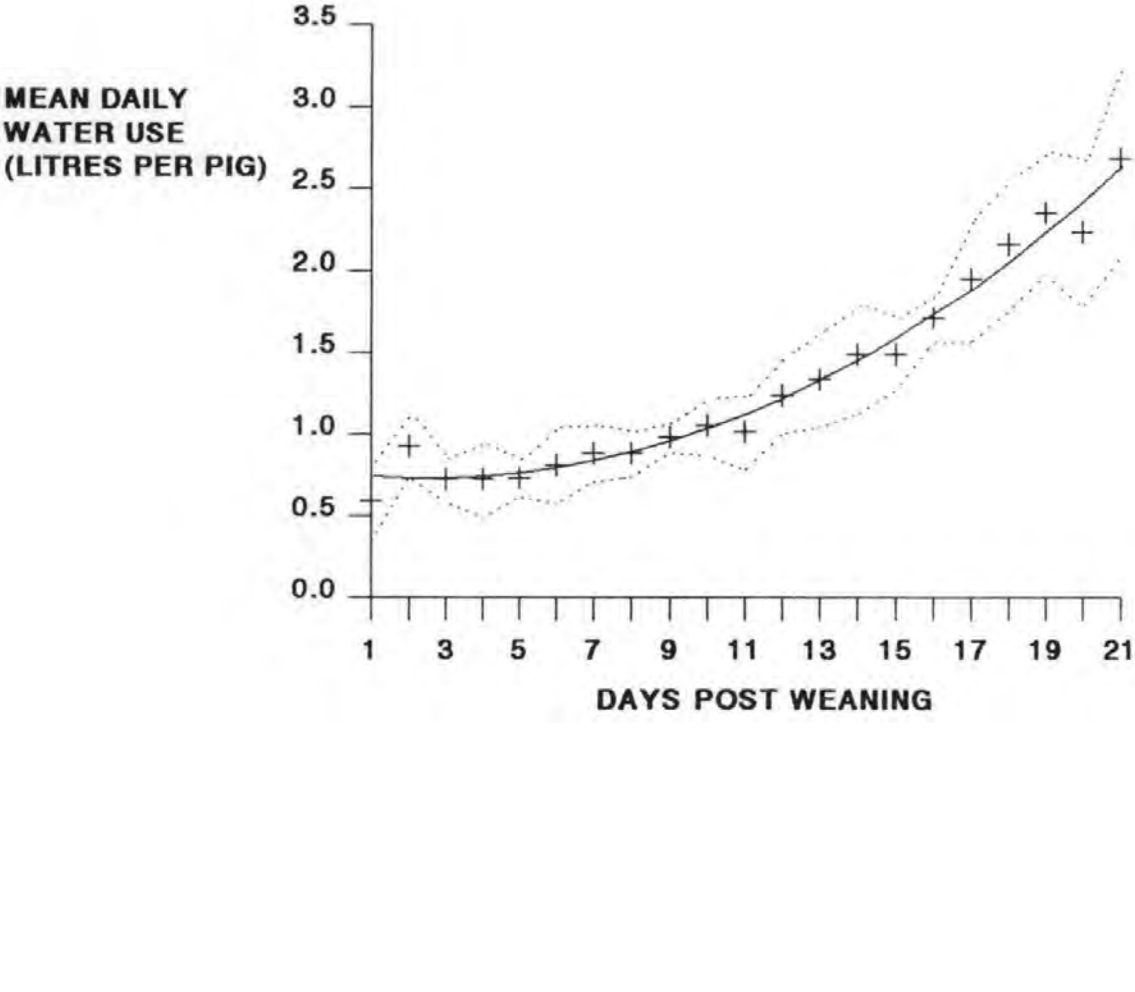


(———) Quadratic regression line $Y = 0.681 + 0.0080\ X - 0.00543\ X^2$

(.....) 99% confidence limits for mean values of water use

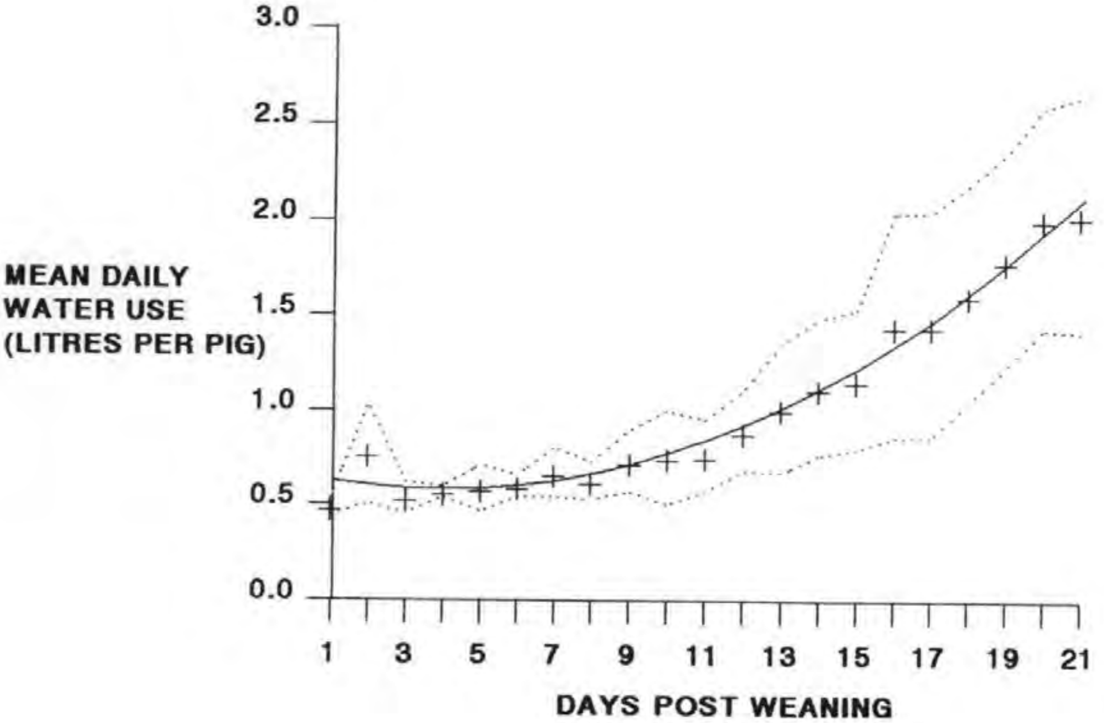
Where Y = Water use (litres/pig/day)
X = number of days

Figure 14.6 The relationship between mean water use and the number of days post weaning for early weaned pigs at a delivery rate of 450 cm^3/min.



(——) Quadratic regression line
$Y = 0.766 - 0.0292\,X + 0.00562\,X^2$ Where Y = water use (litres/pig/day)
(.....) 99% confidence limits for mean values of water use
X = number of days

Figure 14.7 The relationship between mean daily water use and the number of days post weaning for early weaned pigs at a delivery rate of 350 cm^3/min.

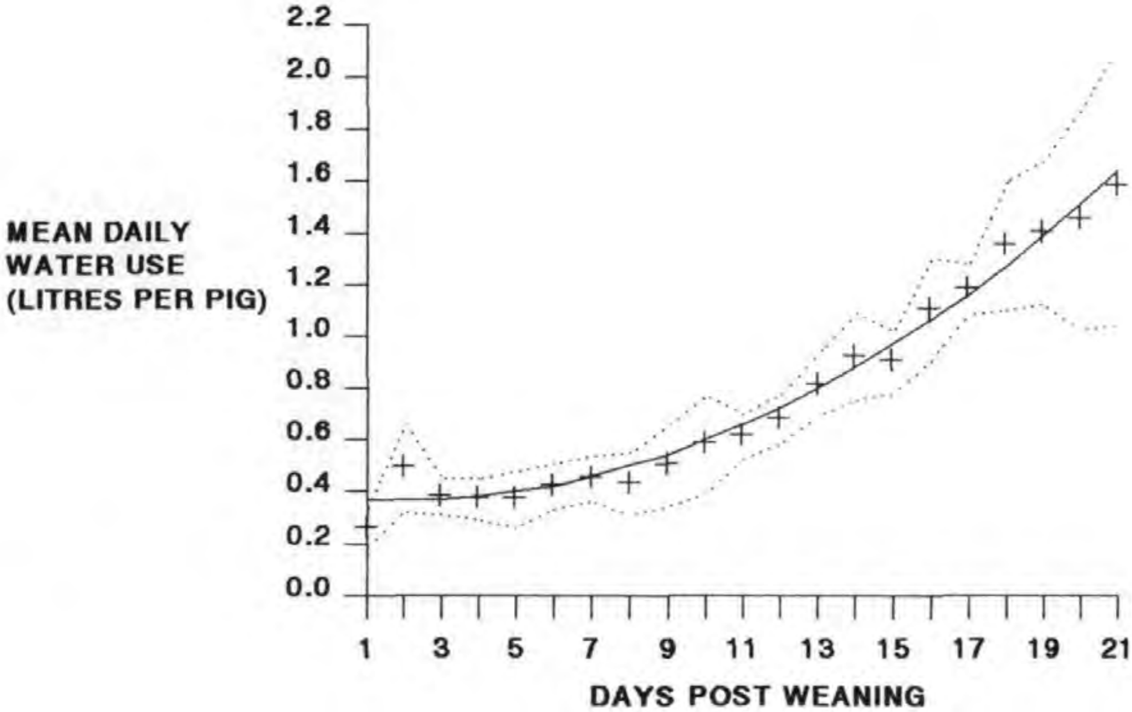


(——) Quadratic regression line
$Y = 0.659 - 0.0422\ X + 0.0053\ X^2$

(.....) 99% confidence limits for mean values of water use

Where Y = water use (litres/pig/day)
X = number of days

Figure 14.8 The relationship between mean daily water use and the number of days post weaning for early weaned pigs at a delivery rate of 175 cm^3/min.



(——) Quadratic regression line
$Y = 0.379 - 0.0135\ X + 0.00351\ X^2$ Where X = water use (litres/pigIday)
(.....) 99% confidence limits for mean values of water use Y = number of days

(P<0.001).

Discussion

The results showed that between the delivery rates of 175 and 450 cm^3/min there was a significant increase in mean daily feed intake and a consequent increase in mean daily live weight gain. Between 450 and 700 cm^3/min there was no significant increase in feed intake or liveweight gain. This suggests that making the attainment of water more difficult during the three week period post weaning, significantly reduced feed intake. The additional water used between 450 and 700 cm^3/min did not result in an increase in feed intake. It is not known whether this extra water used was actually consumed or wasted. In the absence of differences in performance, it is possible that a greater proportion of the extra water used between 450 and 700 cm^3/min than between 350 and 450 cm^3/min was wasted. However a greater quantity may have been consumed without it influencing performance further.

It has been reported that the intake of water by pigs like most mammals is usually correlated with food intake (Anand 1961). That is the greater the feed intake then the greater the water intake. The results from the regression analyses of this experiment have indicated that feed intake is highly correlated with water delivery rate. Water use is also highly correlated with water delivery rate. As a result of the positive correlations between these two pairs of factors it is suggested that in the case of early weaned pigs 3-6 weeks of age, feed intake is positively correlated to water use rather than vice versa.

Therefore in the case of piglets, unlike most mammals, feed intake is dependent on water intake. Water intake is positively correlated to delivery rate or the ease by which the animal attains its water.

According to the fitted quadratic regression equation of mean daily feed intake against mean daily water use, the point of maximum feed intake is achieved when the mean daily water use over the three week period was 1.58 litres per pig. This level of water use results in a mean daily feed intake of 0.344 kg per pig. Although the quadratic regression equation accounted for a higher proportion of the variation than did the linear regression line, owing to the fact that only four treatment levels of water delivery rate have been examined, caution must be taken when interpreting the results.

Using the linear regression equation produced from the regression of water use on water delivery rate the water delivery rate that will result in an apparent water intake of 1.58 litres per pig per day is 655 cm^3/min. The apparent time spent drinking by an animal supplied with water at this rate is 145 seconds (water use of 1.58 litres/pig/day divided by water delivery rate of 655 cm^3/min = 145 s.

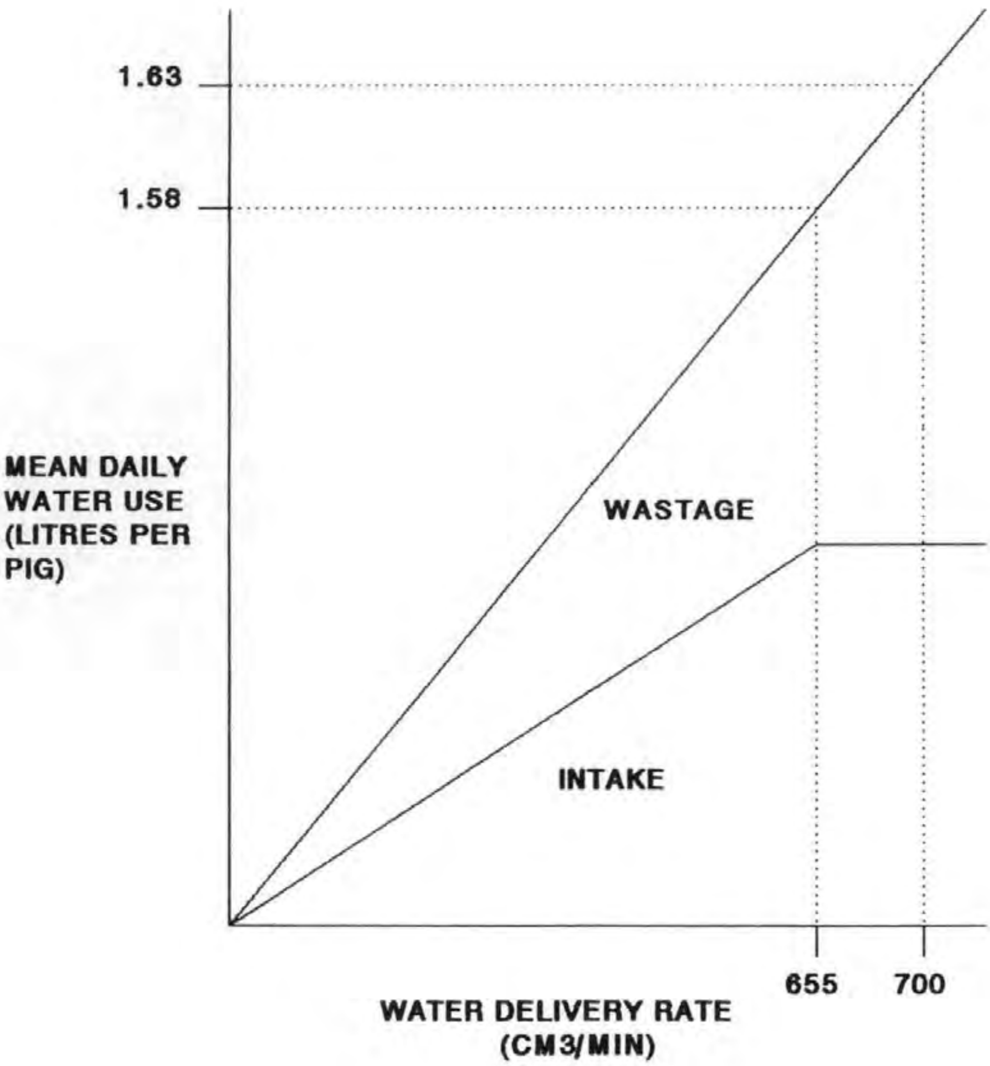
Alternatively drinking time can be estimated using the quadratic equation derived from the regression of time spent drinking. From this equation time spent drinking to obtain an apparent water uptake of 1.58 litres/pig at 655 cm^3 would be 140 seconds.

Increasing the water delivery rate from 655 to 700 cm^3 per minute does not result in a further increase in feed intake. However, as the relationship between water delivery rate and water use is linear there is a corresponding increase in water use from 1.58 litres/day to 1.63 litres/pig/day. This increase in water use could have resulted from either (or both) increased wastage (as there was no increase in performance) or from increased water consumption. The quadratic regression of food intake against water use would suggest that after 1.58 litres/pig/day increases in water use may result in decreased feed intake. This may be due to the fact that the piglets gut volume is relatively constant from day to day and therefore an increase in water intake would result in a decrease in feed intake.

At each delivery rate studied, a proportion of the water used was wasted. This was established from visual observations. However, it is not known what proportion of the water is wasted and whether the proportion of wasted water remains a constant proportion of water delivery rate. Figure 14.9 shows a model has been put forward as an explanation of the relationship between water delivery rate, water intake and wastage, based on the evidence from this experiment. Although unproven it assumes that all the extra water use above a delivery rate of 655 cm^3/min was wastage.

It has been shown that in order for a piglet to use 1.58 at 655 cm^3/min it must spend 145 s per day drinking. At lower delivery rates it has been shown that piglets spent more time drinking to achieve lower levels of water intake. At 450 cm^3/min 175 s was spent drinking resulting in a water use of 1.32 cm^3/pig/day. If the pig was prepared to spend 210 s/day drinking at that delivery rate it would achieve a water use of 1.58 litres/pig. It was seen that at 175 cm^3/min the piglets were prepared to spend only 268 s per day drinking, that is insufficient time to produce a similar intake at a delivery rate of

Figure 14.9 A suggested model of the relationship between water delivery rate, water intake and wastage.



450 cm^3/min as at 655 cm^3/min.

It is not possible to explain this observation from the information available from this experiment. It may be due to one of several factors, such as the differences in water wastage at each delivery rate. It could also be related to the differences due to the delivery rate in the interval between drinking bouts, the length of the drinking bout or the size of the thirst reinforcement of the drinking bout. It is unknown whether the homeostatic mechanism is fully developed at this early stage which may account for the piglets not spending sufficient time drinking to achieve that level of intake which on average maximises feed intake. Also conditioned drinking behaviour resulting from synchronous and cyclical suckling patterns, and social facilitation may have prevented piglets spending longer individual periods drinking on their own. Any single or combination of the above factors may account for the piglets failing to achieve the optimum level of intake of 1.58 litres at the lower delivery rate.

Although the relationships between the number of days post weaning and water use at each delivery rate is highly significant, it does not adequately describe the pattern of water use during the first two days. At each delivery rate, low water use on the first day was followed by a rapid increase in intake on the second day. It is possible that the piglets may have experienced difficulty in locating the drinkers immediately post weaning, or the trauma of weaning per se may have produced lower than expected water use. It could also be due to an immature homeostatic mechanism. Consequently a negative water balance on the first day post weaning resulted in a greater than expected water use on the second day to restore the water balance.

This phenomenon was similarly measured in Experiment 4 for the four treatment diets. It was also reported by Brooks *et al.*, (1984), and Gill *et al.*(1986).

As Experiment 4 was undertaken under similar conditions, comparison of the two experiments is possible. The water delivery rate in Experiment 4 was 175 cm^3/min. The mean water use over the period 3-5 weeks for Experiment 9 was 0.526 litres/piglet per day. For the same period in experiment 4, the mean water use was 0.604 litres/piglet per day. To test whether these values are significantly different or not, it is necessary to compare regression lines produced from the quadratic regression of water use on days post weaning.

Experiment 4:

$$y = 0.311 + 0.0158\,X + 0.00234\,X^2$$

Experiment 9:

$$y = 0.379 - 0.0135\,X + 0.0053\,X^2$$

Where y = water use (litres/pig/day)
x = number of days post weaning

Calculate T-ratios:

t-ratio of intercept $= \dfrac{0.379-0.311}{0.041} = 1.658$ $\quad P>0.05$

t-ratio of b1 $= \dfrac{-0.0135-0.0158}{0.0086} = -3.406$ $\quad P<0.01$

t-ratio of b2 $= \dfrac{0.0053-0.00239}{0.0004} = 7.27$ $\quad P<0.001$

The results of this comparison show that the intercepts from the two equations are not significantly different (P>0.05). However, the pattern and rate of increase of water use with the number of days post weaning is significantly different ($P<0.01$). The difference is most likely due to the fact that the regression equation in Experiment 4 was derived from the data recorded between three and five weeks, and that for Experiment 9 between three and six weeks. If we consider only the first two weeks data post weaning for Experiment 9 then quadratic regression produces the following equation:

$$Y = 0.417 - 0.00275 X + 0.00441 X^2$$

Standard deviation	intercept	=	0.0539
	b1	=	0.01655
	b2	=	0.001073

Calculation of T-ratios shows this line to be not significantly different from that in Experiment 4.

As the results from Experiment 4 were found to be not significantly different from Experiment 9, and Experiment 4 was compared in depth with other studies, a comparison of the results of Experiment 9 with other studies is not included here.

It has become increasingly apparent that comparison with contemporary work is not easy because of the number of factors affecting water use, and disagreements in data for particular classes of pig are difficult to explain when the main determining parameters of water use are omitted in these studies.

An experiment very similar to this experiment was conducted by Hoppe, Libal and Wahlstrom (1988) to investigate the effect of water flow rate from nipple drinkers on weaned pig performance. Superficially their results appear to be contrary to the results of Experiment 9. Crossbreed pigs weaned at 21-28 days were kept 6 or 12 per pen and allowed drinking water from nipple drinkers with water flow rates 70 or 700 ml/min. They reported that water flow rate or density of housing did not affect pig performance. The pigs allowed the lower water flow rate tended to be at the drinkers more often and drank for longer at each contact. In their study they found that the piglets adjusted their behaviour in order to get adequate water intake and, therefore, had comparable performance to their counterparts on unrestricted water flow, (Table 14.4).

Table 14.4 The effects of water delivery rate on weaned pig performance,(Hoppe et al., 1988).

	Treatments			
	No. Pigs/Pen		Flow rate (cm^3/min)	
	6	12	70	700
Daily gain	381	367	363	386
Daily feed intake	603	567	581	590
FCR	1.59	1.56	1.59	1.53

Although there were found to be no statistically significant differences between the treatments, numerical performance appeared superior in the smaller group and with higher flow rates. If the daily gains and feed intakes in Table 14.4 are compared directly with the results of Experiment 9, it can be seen that the mean performance of the pigs in the American experiment is considerably higher than Experiment 9 (feed intakes are almost double). This may account for the discrepancy in the results. The experiment of Hoppe et al.,(1988) covered the period from 4 to 8 weeks of life whereas Experiment 9 investigated the period of 3-6 weeks of life. It is possible that the significant effect on performance of decreased delivery rate shown in Experiment 9 may occur during the earlier weeks of life. After six weeks of age, the piglets are prepared to spend more time drinking at the lower delivery rate in order to achieve that level of water intake which allowed maximum feed intake and performance. Indeed experiments 6, 7, 8 and 8A investigating the effects of water delivery rate on growing-finishing pigs showed that performance was unaffected by delivery rate. The stage of growth studied by Hoppe et al.,(1988) may relate to a period extending sufficiently long after weaning for compensatory growth to occur and hence for the overall performance of the piglets to appear to be not significantly affected by delivery rate.

In another experiment Nienaber and Hahn (1984), investigated the effects of delivery rates of 100, 350, 600 and 850 and 1100 cm^3 min on the water use and performance of pigs weaned at 4-5 weeks, growing over a 4 week period. There was no significant effect of water delivery rate on body weight gain, feed intake or feed conversion. Water use increased as flow rate increased, and time spent drinking at 100 ml/min increased nearly four fold above the average time spent drinking by the other treatments. These results agree with those of Hoppe et al., (1988). The growth period studied is similar to Hoppe et al.,(1988) and again different from that studied in Experiment 9. Nienaber and Hahn (1984), concluded that as water use increased with water delivery rate, while time spent drinking remained constant between 350 and 1100 cm^3/min, water waste, rather than consumption increased with flow rate. This observation is supported by the report of Olsson (1983) that lower water use was related to less water wasted not less water consumed. He found that water use decreased as flow rate decreased; however, feed intake and growth rate remained unaffected. This would appear to support the explanation of the significant increase in water use after 450 cm^3/min without a corresponding increase in performance, in Experiment 9.

Carlson and Peo (1982), found that the growth rate and feed conversion ratio of newly weaned pigs improved with increased water flow rate in one experiment but a low flow rate was adequate in a second experiment. In a similar experiment to Experiment 9, Shurson (1989), reported significant improvements in growth rate during the first and third weeks when pigs received water at 700 versus 70 cm3/min.

It is concluded from this experiment that between the water delivery rates of 175 and 450 cm^3/min there is a significant increase in feed intake and growth rate. This demonstrates the importance of a readily available water source during the period immediately post weaning in the commercial situation.

Experiment 10: A comparison of water use between four water delivery rates of group housed pregnant sows.

Introduction

Experiments 6, 7, 8 and 8A investigated aspects of the effects of water delivery rate on the water use of growing and fattening pigs. In brief, the results from these experiments indicated that significantly less water was used at lower delivery rates without any measured detrimental effects on performance. Conversely, the results from Experiment 9, investigating the use of water by early weaned pigs at different delivery rates, showed that water use was also less at lower delivery rates, but that in this age of pig the lower water consumption resulted in a significant reduction in feed intake and daily live weight gain are significantly reduced.

Information on the water use of gestating sows is minimal. The aim of this experiment was to investigate the effects of four different water delivery rates on the water use of sows at different stages of gestation. If the water use of sows were found to be affected in the same way as that of growing pigs, a reduction in water use achieved by a lower delivery rate, could result in a large reduction in total farm water consumption, due to the relatively large mass of the sow and its consequent water requirement.

Materials and Methods

Experimental Design and Treatments

The water use of group housed gestating sows, supplied with water from four Arato 80 drinkers at four water delivery rates was investigated. The four treatment water delivery rates were as follows:

1 565 cm^3/min

2 925 cm^3/min

3 1325 cm^3/min

4 2650 cm^3/min

A diagram of the Arato drinker used is illustrated in Figure 1.3.

The experiment was conducted over a period of 16 weeks between the period July to November 1988. As the particular housing used is subject to varying environmental temperature and therefore by the climatic trend in temperature between July to November the experimental design was a 4 x 4 Latin Square in order to account for the effects of temperature variation on water use. The treatment delivery rates were replicated four times and in four 4 week periods according to a Latin Square design. Consequently, at the end of the experiment each treatment would have occurred once in each period.

Animals and Housing

The experimental animals consisted of the total number of gestating (Large White x Landrace) sows and one Large White Boar of the Seale-Hayne College Farm herd. The mean parity of the herd was 6.2. The number of animals in the group studied during the 16 week trial period varied from 58 to 71, the mean being 63.5. As there were four Arato 80 Drinkers supplying water to the group this equated to approximately one drinker per 16 animals. It must be noted that although the number of animals remained relatively constant, because the experiment progressed over a large time period (approximately the same as the gestation period of the sow), the individuals making up the population were changing weekly. That is those in the later stages of pregnancy were being removed to farrowing accommodation and recently served animals were being introduced from the service area.

The housing consisted of a covered concrete area divided approximately in half by a dense concrete block wall. One half of the building (the sleeping area) was bedded with straw daily. The other half of the building (the feeding and drinking area) was not bedded and mechanically scraped out daily. The four drinkers were equally spaced along the dividing wall in the feeding and drinking area). The sows were fed from two automatic computerised feed stations, (Porcode Ltd.) which were housed in the same area as the drinkers.

The building was block walled to a height of 2.4 m. Above that poorly maintained cladding helped to protect the animals from the weather. Consequently, the animals were subject to variations in environmental temperature, according to wind speed, wind direction and ambient temperature. The bedded sleeping area was protected from the weather to a much greater degree than the feeding area. The dimensions of the housing are as follows: Bedded area: 24 X 6 m

Feeding area 19 X 6 m

The four Arato 80 drinkers mounted on the dividing wall between the

Table 15.1 Proximate and mineral analyses of the feed used in Experiment 10

Dry matter (%)	89.2
Digestible energy (MJ/kg DM)	13.0
Crude protein (g/kg DM)	19.4
Crude fibre (g/kg DM)	83.0
Neutral detergent fibre (g/kg DM)	288
Oil (Acid hydrolysis) (g/kg DM)	61.0
Total ash (g/kg DM)	92.0
Calcium (g/kg DM)	12.5
Phosphorous (g/kg DM)	8.5
Magnesium (g/kg DM)	3.6
Sodium (g/kg DM)	1.6
Potassium (g/kg DM)	12.7
Chloride (g/kg DM)	2.1

sleeping and feeding areas were aligned at a 15° decline from the horizontal position. Different water delivery rates in the drinkerswere achieved by varying the size of the internally fitted plastic apertures in the drinkers. The delivery rates selected were checked weekly and remained within 5% of the nominal values. The pressure head of water was 10 m.

The sows were identified with transponder collars and were individually ration fed at the two computerised feed stations. The mean feed intake during the trial was 2.34 ± 0.36 kg per sow per day. Individual sows were rationed according to stage of gestation and body condition. A proprietary diet, D62K (J. Bibby and Son Ltd.) was fed throughout the trial. The proximate and mineral analyses of the feed are presented in Table 15.1. The allocated ration of each sow was divided into two daily feeds. The two feeding cycles began at 0700 hrs in the morning and 1900 hrs in the evening. In the event that the sow failed to consume all her feed allowance in the first feed cycle, the allowance was carried over into the second cycle. Underconsumption in one day was not carried forward into the following day.

Experimental Procedures

Water use at the four drinkers was metered using previous calibrated Kent PSM-L meters and was recorded daily at 1000 hrs. Delivery rates were altered according to the experimental design every Monday at 1000 hrs.

The number of animals within the group was recorded daily along with the daily feed consumed, which was available from the feed computer printout. The temperature within the building was continuously monitored using a previously calibrated thermograph positioned in the building.

Results

Water use, apparent time spent drinking and water to feed ratio data for each treatment delivery rate are presented in Table 15.2. Analysis of variance of the data showed that water delivery rate had a significant effect on water use ($P<0.002$). Water use at the highest delivery rate was significantly higher than at any other delivery rate. There was no significant difference in water use between the delivery rates of 925 and 1325 cm^3/min nor between 565 and 925 cm^3/min. However there was a significant difference between the delivery rates of 565 and 1325 cm^3/min.

Water delivery rate had a significant effect on water to feed ratio ($P<0.005$). Water to feed ratio was significantly greater at the highest delivery rate than at any other. There was no significant difference in water to feed ratio between 925 and 1325 nor between 565 and 925 cm^3/min. There was a significant difference between the delivery rates of 565 and 1325 cm^3/min. Table 15.2 also shows data for apparent time spent drinking. This was calculated by dividing the water use by the water delivery rate. The data shows that there was a highly significant decrease in apparent time spent drinking as the delivery rate increase ($P<0.001$). More time was spent drinking at the lower delivery rates.

The mean daily temperature of the building varied between 6.2 and

Table 15.2 Water use and water to feed ratio of ration fed, group housed pregnant sows supplied with water at four water delivery rates.

	Treatment delivey rate cm^3/min					
	565	925	1325	2650	$S.E._D$	P
Water use (litres/sow/day)	9.86^{a}	10.24^{ab}	10.76^{b}	12.28^{c}	0.35	0.002
Water to feed ratio	4.17^{a}	4.34^{ab}	4.67^{b}	5.32^{c}	0.20	0.005
Apparent time spent drinking (s/pig/day)	1047.6^{a}	664.2^{b}	487.2^{c}	227.8^{d}	96.6	0.001

a,b,c, means bearing the same superscipt are not significantly different (P>0.05)

Table 15.3 Mean daily water use and mean daily house temperature for the four periods of the experiment.

	Period (weeks)					
	1-4	5-8	9-12	13-16	$S.E._D$	P
Water use (litres/sow/day)	12.09^{a}	10.43^{b}	10.56^{b}	10.08^{c}	0.35	0.005
Mean daily Temperature (°C)	17.0^{a}	15.11^{b}	11.72^{c}	9.60^{d}	0.85	0.001

a,b,c,d, means bearing the same superscipt are not significantly different (P>0.05)

23.2°C, (Figure 15.1). Mean daily temperature decreased during the course of the experiment.

Table 15.3 presents data for water use and mean daily temperature for the four 4 week periods. Analysis of variance of the data showed that mean daily water use was significantly ($P<0.005$) affected by the period in which the water use was measured. It is likely that the decrease in temperature illustrated in Figure 15.1 is responsible for the significant decrease in water use through the experimental periods. Analysis of variance of the mean daily temperatures for the four periods showed that temperature was significantly different between each of the four periods of the experiment ($P<0.001$).
Linear regression of the daily mean water intake against water delivery rate gave the following equation:

$$Y = 9.2 + 0.00116\,X \qquad R^2 = 30.6\% \qquad P=0.001$$

Standard deviation of the intercept = 0.259
gradient = 0.00016
where Y = water use (litres/pig/day)
X = delivery rate (cm^3/min)

This relationship is shown in Figure 15.2. The coefficient of determination was relatively low 30.6%, indicating that the line only accounted for a small proportion of the variation. Analysis of variance of the line showed that it was a highly significant representation of the data ($P<0.001$).

Multiple regression of the daily mean water intake against water delivery rate and mean house temperature gave the following equation:

$$y = 7.02 + 0.0012\,X1 + 0.159\,X2 \qquad R^2 = 42.0\% \qquad P=0.001$$

standard deviation of intercept = 0.559
b1 = 0.00016
b2 = 0.037
Where y = water use (litres/pig/day)

Figure 15.1 The variation in house temperature during the course of the experiment.

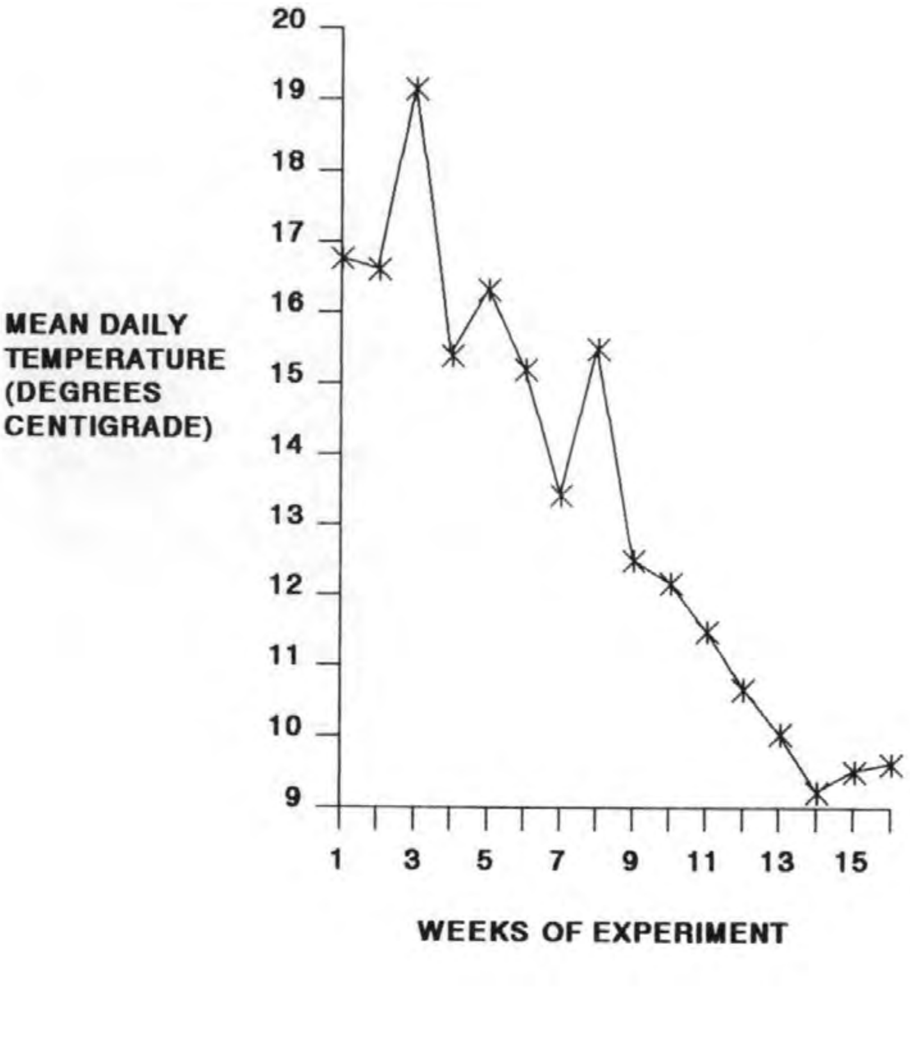
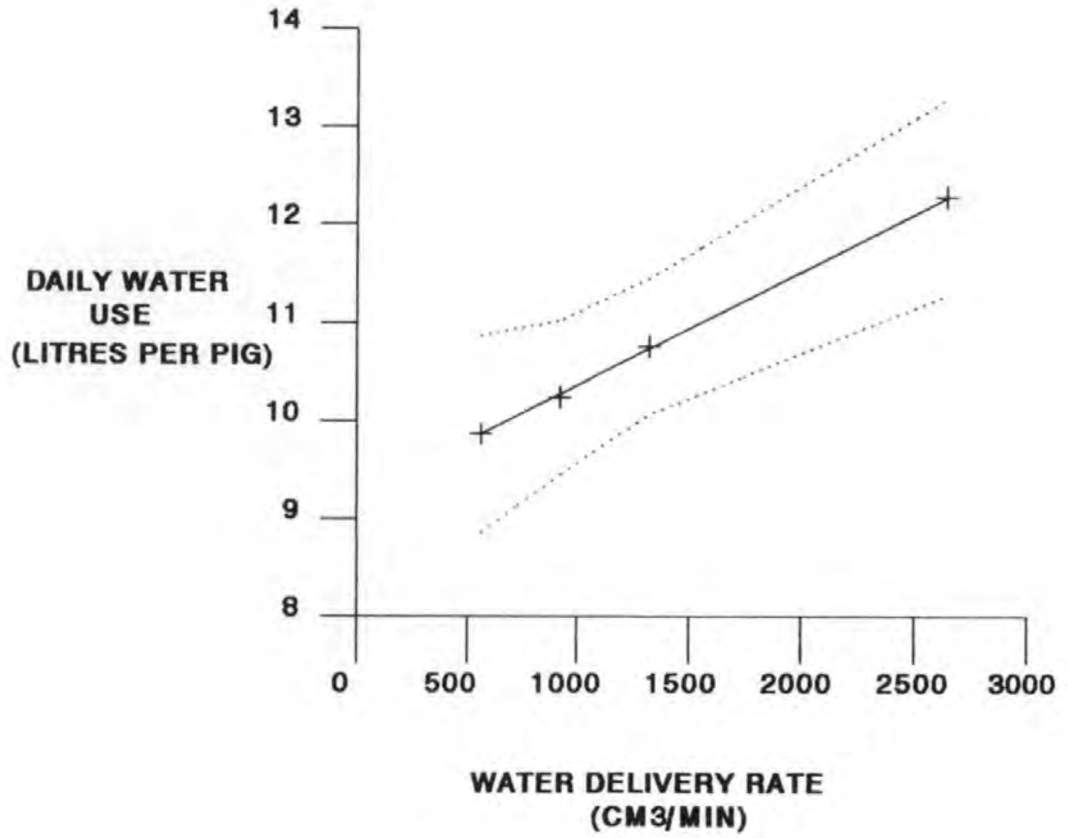


Figure 15.2 The relationship between mean daily water use and water delivery rate for pregnant sows.



(———) Linear regression line $Y = 9.2 + 0.00116\,X$

(.....) 99.9% confidence limits for daily values of water use

Where Y = water use (litres/pig/day)

X = delivery rate (cm^3/min)

X1 = delivery rate (cm^3/min)
X2 = house temperature (°C)

Incorporating temperature in the regression analysis increased the coefficient of variation from 30.6% to 42.0% indicating that temperature had a significant effect on water use. When the regression sums of squares was divided between the two regressors it was found, that of the 42% variation that was accounted for by the line, 10.4% was attributed to variation in temperature. Analysis of variance of the line showed that it was a highly significant representation of the data.

Linear regression of the daily mean apparent time spent drinking against delivery rate gave the following equation:

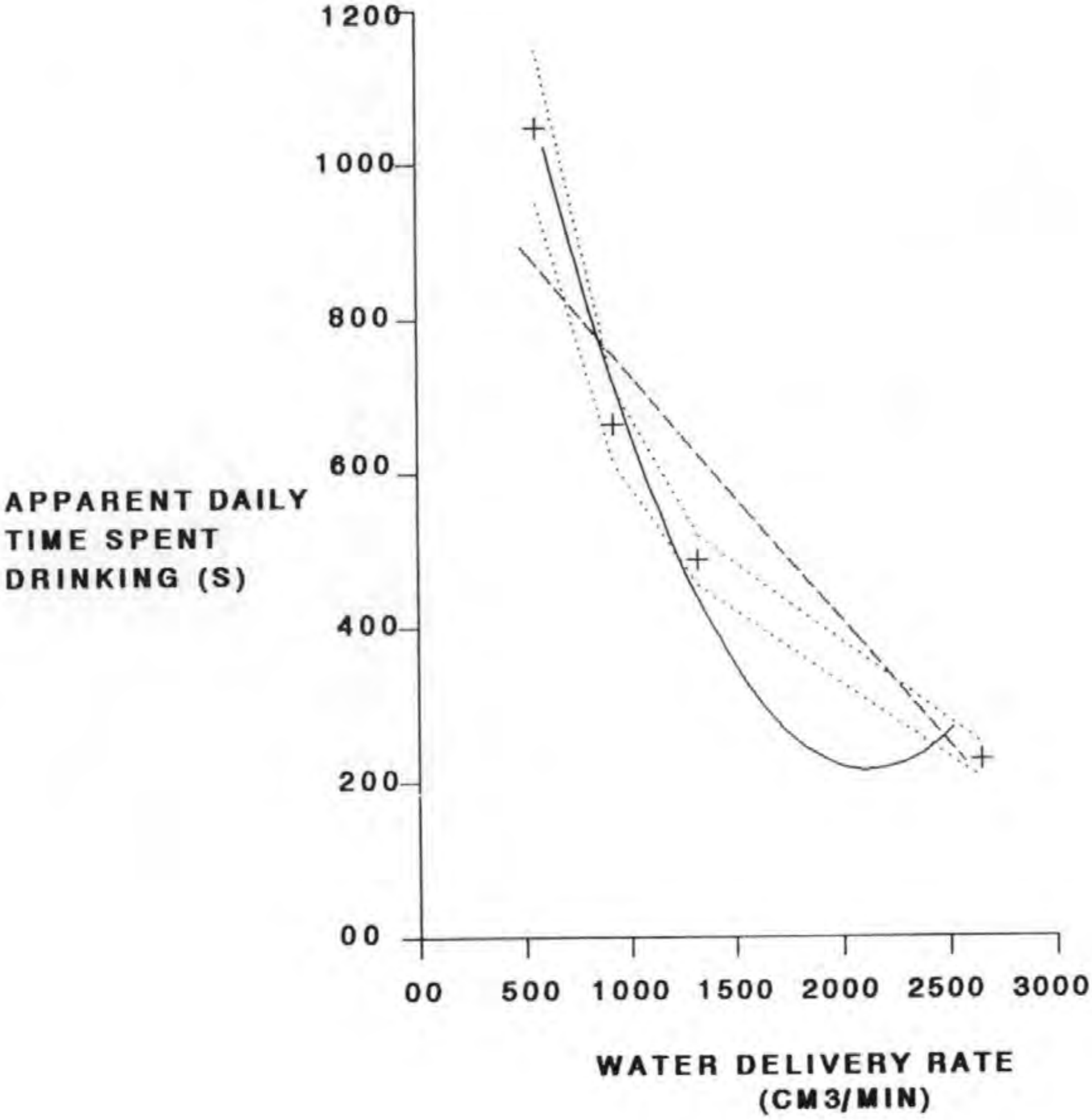
$Y = 1056 - 0.32\ X$ $\quad R^2 = 71.7\%$ $\quad p = 0.001$
Standard deviation of the intercept = 30.02
gradient = 0.019
Where Y = apparent time spent drinking (s/pig/day)
X = delivery rate (cm^3/min)

This relationship is illustrated by Figure 15.3. The coefficient of determination was relatively high indicating that the line accounted for a relatively high proportion of the variation. Analysis of variance of the line showed that it was a highly significant representation of the data.

The coefficient of determination of this regression is considerably higher than that of the linear regression of water use against delivery rate, (71.7% compared with 30.6%). This would suggest that the amount of time spent drinking was more dependent on delivery rate than was water use.

Quadratic regression of time spent drinking produced the following equation:

Figure 15.3 The relationship between mean total daily time spent drinking and water delivery rate for pregnant sows.



(-----) Linear regression line
$Y = 1056 - 0.32\ X$

(——) Quadratic regression line
$Y = 1669 - 1.31\ X + 0.000295\ X^2$

(.....) 99.9% confidence limits for daily values of time spent drinking

Where Y = Time spent drinking (s/pig/day)
X = delivery rate (cm^3/min)

$Y = 1669 - 1.31\ X + 0.000295\ X^2$ $R^2 = 88.9\%$ P=0.01

Standard deviation of intercept = 50.35
b1 = 0.0761
b2 = 0.0000225

Where Y = apparent time spent drinking (s/pig/day)
X = delivery rate (cm^3/min)

This relationship is also illustrated in Figure 15.3. The coefficient of determination of this equation was higher than that of the linear regression showing that the quadratic line accounted for a greater proportion of the variation. Analysis of variance of the line showed it to be a highly significant representation of the data. According to the fitted quadratic regression equation of time spent drinking to delivery rate, the point of minimum time spent drinking is found to be at 2220 cm^3/min. The apparent time spent drinking at this delivery rate is 214.6 s/sow/day.

As house temperature has been shown to account for a significant proportion of the variation, it has been included in a multiple regression with delivery rate and delivery rate squared against apparent time spent drinking to give the following equation:

$Y = 1569 = 1.32\ X1 + 0.0003\ X1^2 + 8.2\ X2$ $R^2 = 89.3\%$ P=0.001

Standard deviation of intercept = 63.3
b1 = 0.08
b2 = 0.0000239
b3 = 2.866

Where Y = apparent time spent drinking (s/pig/day)
X1 = delivery rate (cm3/min)
X2 = temperature (°C)

A further regression analysis was undertaken, to investigate the relationship between water use and house temperature at each delivery rate. This analysis is given in Table 15.4.

Table 15.4 Regression of mean daily water use against mean daily temperature for pregnant sows supplied with water at delivery rates of 565,925,1325 and 2650 cm3/min.

Treatment	Regression equation	P	R^2	Standard deviation of: intercept	bl
565 cm3/min	Y = 7.69 + 0.167X	0.080	7.9%	1.221	0.0916
925 cm3/min	Y = 7.85 + 0.164X	0.040	26.4%	0.766	0.0518
1325 cm3/min	Y = 9.41 + 0.111X	0.230	2.3%	1.223	0.0895
2650 cm3/min	Y = 9.77 + 0.19X	0.029	14.9%	1.151	0.0819

Where Y = Water use (litres/pig/day)
X = Mean daily temperature (degrees C)

As water use from the four drinkers was metered separately, it was possible to show whether there was a preference for any particular drinker, that is whether water use from the drinkers was significantly different. The drinkers were numbered 1 to 4 from the east end of the building. The proportion of the daily water dispensed from drinkers 1 to 4 was respectively 35.09, 24.32, 19.67 20.92 ± 1.1, ($P<0.001$)

Drinker number 1 dispensed a significantly greater amount of water than drinker number 2 which dispensed significantly more water than drinkers 3 or 4 ($P<0.001$). There was no significant difference between the water dispensed from drinkers 3 and 4.

This suggests that the position of the drinker in the house significantly affected the amount of use made of it by the housed sows.

Discussion

To summarise, the results showed that as the delivery rate of water to gestating sows was increased, water use increased significantly. It was found that at the lower delivery rates, in order to achieve their required water intake, the sows were prepared to spend significantly more time drinking. Because of the design of the investigation it was not possible to relate drinking behaviour/water consumption to reproductive performance. Consequently, the difference in water use between the high and low delivery rates cannot definitely be attributed to wastage. However, there were no visible effects on behaviour of the sows as a result of reducing the delivery rates. In a pilot study, reducing water delivery rate to 200 cm^3/minute considerably increased the level of aggression within the sow group. This low rate increased the amount of time required for each individual sow to drink its required intake, and therefore increased the competition for the available drinkers. Because of these adverse effects on behaviour it was necessary to cease experimentation at this delivery rate. Therefore, it is likely that there may be differences in the degree of competition and therefore aggression at the drinkers, between the high and low delivery rates.

The results have provided some basic data on the use of water by group housed dry sows supplied with water at four different delivery rates. Figure 15.2 shows that over the range of delivery rate studied, the mean water use of dry sows lies between 9 to 13.5 litres per sow per day with 99.9% confidence. Some of the variation illustrated by Figure 15.2 was related to variation in temperature. Owing to the type of drinker studied, it is likely that a proportion of the measured water use was wastage, and it is possible that this wastage fraction increased with increased delivery rate.

In a study of water consumption and slurry production of dry and lactating sows, Lightfoot et al., (1984), showed mean daily water consumption of dry sows to be 10.0 litres with a range for individual sows being 6.8 to 13.1 through their pregnancies. The above study was slightly different to Experiment 10 in that the water use of individually crated sows was recorded. Also the sows used a nose operated drinker to dispense water into the feed trough so water usage recorded was actual intake with no wastage fraction. Lightfoot et al., (1984), omitted to measure temperature and therefore a closer comparison of data is limited. However Table 15.2 showed the mean water use for the delivery rates 565 and 925 cm^3/min was 9.86 and 10.24 litres/pig/day respectively. There was no significant difference between these means. Pooling the data from these lower delivery rates gives a mean value of 10.05 litres/pig/day. This figure is approximately the same as the mean figure presented by Lightfoot *et al.*, (1984). As the water use figures given by Lightfoot are actual use figures it can be suggested that either little wastage occurred at the two lower delivery rates studied in experiment 10, or that the water requirement of the sows was not satisfied due to an element of wastage. There may also have been different requirements for water related to differences in nutrition. The contribution of water supplied as drinking to the total slurry produced was similar for both experiments. At the higher delivery rates the element of wastage is increased. It is not possible to recommend a particular delivery rate for sows as behaviour/welfare and performance of the experimental animals was only subjectively monitored in this experiment. Both of these issues would have to be studied in detail before producing a recommendation on minimum delivery rate.

The variation illustrated by Figure 15.2 is variation in mean daily water use recordings. No measurement was made of individual variation of water requirement within the group, whereas Lightfoot measured the individual gestational water requirement of sows. The group of experimental animals in Experiment 10 consisted of sows at different stages in gestation. Friend (1971) recorded the water intake of pregnant gilts and sows offered *ad libitum* feed. Over two reproductive cycles it was seen that water and feed intake increased during the first three weeks post conception, but decreased towards the end of pregnancy. This was similarly reported by Madec (1985), who found that the average daily water consumption of pregnant sows decreased significantly from 7.9 to 5.6 litres/sow.day. Therefore there is likely to be large individual variation in the group water use figures measured in Experiment 10.

The results from this experiment have shown that the environmental temperature significantly affected the amount of water used, within the range 6 to 23°C. Mount *et al.*, (1971) investigated the water consumption of pigs between 7 to 33°C and concluded that only at temperatures in excess of 30°C was there a significant increase in water intake. These results were supported by a report by Close *et al.*, (1971). However, Holmes *et al.*, (1967), exposed growing pigs to temperatures of either 9, 20 or 30°C and showed that water requirements per kg body weight increased linearly with increasing temperature.

Part 3: An evaluation of feed intake as a predictor of water use

Experiment 11: The effect of four levels of feed on the water intake of growing pigs.

Introduction

Experiments undertaken in this research programme, like most of the contemporary work have measured water use rather than actual water intake, where water use includes an unknown component of waste. In comparing experimental results suppositions have been made about the existence and the extent of the waste fraction depending upon any measurable differences in performance. It has been commonly assumed that where differences in water use have occurred with no differences in performance, then the extra water consumed was wastage rather than intake. It is unknown whether this assumption is correct. One of the objectives of Experiment 11 was to obtain some definitive information concerning the water intake of growing pigs.

Liquid feeding systems for feeding pigs are becoming increasingly common. Recommendations of water:feed ratio for these systems have been made from experimentation with non wet-fed pigs. That is, water use from drinkers has been measured, together with dry feed consumption, and used to calculate a water to feed ratio for wet-fed pigs. Water to feed ratios calculated in this way may be over estimated as they include an element of waste which does not occur with wet-fed pigs. Also recommendations of this nature make no allowance for the amount of water a pig may choose to consume with its feed.

The second objective of Experiment 11 was to be able to prescribe water intake to feed intake ratios for wet feeding systems and also to investigate how much water pigs choose to consume with their food (at what ratio) and how much water is consumed at times other than feeding times.

The third objective of the experiment was to evaluate the use of feed intake and metabolic live weight as predictors of water intake, and to investigate the effects of different feed levels on the total water intake and water to feed ratio of the pigs.

Materials and Methods

Experimental design and treatments

The water intake of growing pigs fed at four different feed levels according to scales based on metabolic body weight ($W^{0.75}$) was investigated. The four treatment feed levels were as follows:

1. 80 g/kg $W^{0.75}$
2. 90 g/kg $W^{0.75}$
3. 100 g/kg $W^{0.75}$
4. 110 g/kg $W^{0.75}$

The four treatment feed levels were replicated through four groups of animals, four pens and in four time periods according to a 4 x 4 Graeco Latin Square design. Every fourteen days the four groups of animals and the four treatment feed levels were rotated around the four pens according to the design so that at the end of the experiment, each group of animals and each treatment would have spent one fourteen day period in each pen. This design of experiment differs from the classic Latin Square arrangement in that it permits a three-way control in variation of the experimental units as opposed to a two-way control. The contribution to error made by both the pen effect and animal group effect are accounted for.

Animals and housing

The pigs were individually weighed at the start of the trial and ear tagged for identification purposes. Four groups of Large White X (Large White X Landrace) pigs consisting of two gilts and two boars (initial mean weight 27.2 ± 2.3 kg) were assigned to the four treatment pens, balancing groups according to weight, in a performance test house. The pigs were housed in the test house for five days prior to the start of the trial in order to accustom them to the environment and feeding and drinking systems.

The pigs were individually fed in troughs fitted with Arato 74 push button drinkers. The delivery rate from the drinkers was 1500 cm^3/min. Water was available to the pigs *ad libitum* throughout the day from the push button drinkers in the feed troughs. Water was supplied from a closed reservoir water system giving a water pressure head of 4 m. The water use was monitored through previously calibrated Kent PSM-L water meters. The feed used was formulated from wheat, barley and soya to meet A.R.C. (1981) nutrient requirements for growing pigs and was

Table 16.1 Proximate and mineral analyses of the feed used in Experiments 11 and 11A

Dry matter (%)	85.2
Digestible energy (MJ/kg DM)	15.4
Crude protein (g/kg DM)	20.8
Crude fibre (g/kg DM)	29.0
Neutral detergent fibre (g/kg DM)	129
Oil (Acid hydrolysis) (g/kg DM)	25.0
Total ash (g/kg DM)	71.0
Calcium (g/kg DM)	15.0
Phosphorous (g/kg DM)	10.3
Magnesium (g/kg DM)	1.5
Sodium (g/kg DM)	2.6
Potassium (g/kg DM)	5.5
Chloride (g/kg DM)	3.1

presented in meal form. Proximate and mineral analyses of the feed are given in Table 16.1.

The pigs were housed in pens which comprised a kennelled solid floor lying area and an open, slatted, dunging area.
The temperature of the test house was continuously recorded using two previously calibrated Thermographs positioned as close to the pigs as possible but remaining out of their reach.

Experimental procedures

The pigs were weighed at the start of the experiment and then every seven days, using a previously calibrated weigh crate. The water meters were read four times per day before and after each feed. Water remaining in the troughs after 'between feed periods' was measured and recorded. Uneaten feed and water mixtures were weighed and analysed for dry matter allowing the calculation of the proportion of water and feed in the mixture. The pigs were fed twice per day at 0830 hrs and 1600 hrs. The pigs were allowed ad *libitum* water with their feed. The pigs feed allowance was adjusted weekly following weighing.

Results

The health of the experimental animals was good, with no deaths nor incidence of scour. The mean daily temperature varied from 13.4 to 17.6°C during the trial period.

Pig performance and water intake data is presented in Table 16.2.

Table 16.2 Water intake, and performance of growing pigs fed at four different levels of feed, according to metabolic scales.

Feed level g/kg metabolic weight	80	90	100	110	$S.E._D$	P
Total water intake (l/pig/day)	3.29	3.45	3.53	3.60	0.14	N.S.
Ratio of total water to feed	2.65	2.43	2.21	2.08	0.09	N.S.
Water consumed between feeds (l/pig/day)	2.18	2.19	2.15	2.19	0.10	N.S.
Water consumed with feed (litres/pig/day)	1.13	1.26	1.39	1.42	0.05	N.S.
Ratio of water consumed with feed to feed	0.89	0.89	0.88	0.83	0.02	N.S.
Mean live weight gain (kg/day)	0.386^{a}	0.552^{b}	0.566^{b}	0.709^{b}	0.018	0.03
Mean F.C.R.	3.34	2.58	2.80	2.42	0.13	N.S.
Mean weight (kg)	41.50	41.76	41.89	41.97	0.34	N.S.

a,b means bearing the same superscript are not significantly different (P>0.05).

Analysis of variance of the data showed that there were no significant differences between the treatment means for total water intake, total water to feed ratio, water consumed between feeds, water consumed with feed, water consumed with feed to feed ratio, mean feed conversion ratio and live weight during the experimental period. The lack of significant differences of some of the parameters measured may have resulted from the cross over effects of the feed level experiment increasing the size of the variation within a treatment. That is, at the end of a period, the groups of animals on different treatment feed levels would be of different weights. This may have affected water intake as this is related to body weight. A significant difference in live weight gain was found between the lowest feed level and the other three ($P < 0.03$). However, this level of significance was not as high as expected due to the reasons outlined above.

Despite the lack of significant differences, it is possible to identify some trends from the data in Table 16.2. As the feed level increased from 80 to 110 g/kg $W^{0.75}$ so too does the total water intake increased from 3.29 to 3.6 litres/pig/day. When compared with other data it must be stressed that the figures presented in Table 16.2 for water intake, contain no element of waste. It can be seen that the difference in total water use is accounted for by the difference in water consumed with the feed. Table 16.2 shows that the ratio of water consumed with the feed to feed varied from 0.83 to 0.89 for the four feed levels.

The relationship between water intake and the parameters of feed intake, metabolic live weight and treatment feed level have been investigated using linear, quadratic and multiple regression analyses.

Table 16.3 Regression of mean daily water intake against mean daily feed intake, metabolic weight, and treatment level of feed intake.

Regression equation	P	R^2	Standard deviation of: intercept	b1	b2
$Y = 0.44 + 2.03X1$	0.001	54.5%	0.709	0.466	
$Y = 7.85 - 8.28X1 + 3.45X1^2$	0.001	67.3%	2.966	4.062	1.353
$Y = -0.447 + 0.239X2$	0.001	63.2%	0.768	0.0463	
$Y = 6.86 - 0.673X2 + 0.0278X2^2$	0.001	65.1%	5.519	0.685	0.0208
$Y = 2.36 + 2.72\ X1 - 0.031X3$	0.001	66.2%	0.997	0.493	0.0128
$Y = -1.26 + 0.238X2 + 0.0087X3$	0.001	62.1%	1.292	0.0469	0.0111

Where Y = Mean daily water intake (litres/pig/day)
X1 = Mean daily feed intake (kg/pig)
X2 = Metabolic live weight (kg)
X3 = Treatment feed level (g/kg $W^{0.75}$)

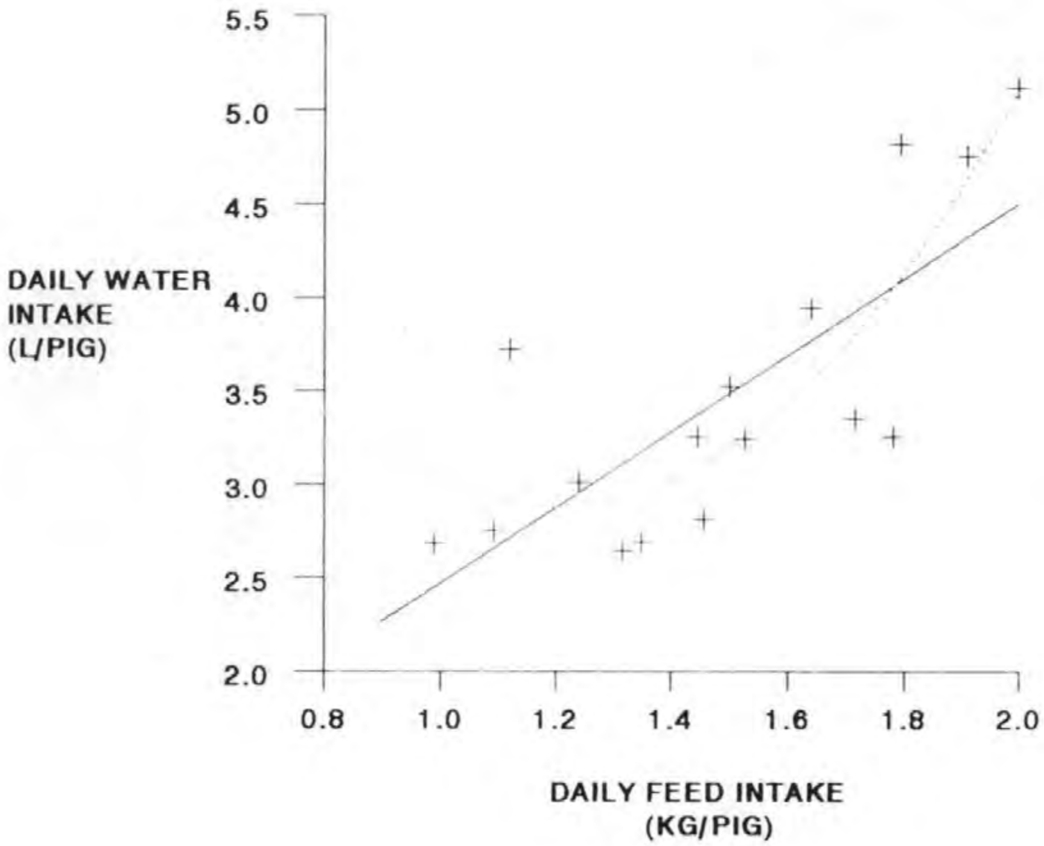
The results of these analyses are presented in Table 16.3

Analyses of variance of the linear regression lines of total water intake against feed intake and metabolic live weight proved both lines to be highly significant representations of the data ($P<0.001$). However, the higher coefficient of determination of the equation, describing the relationship between water intake and metabolic live weight shows that a greater proportion of the measured variation was accounted for by the line. (R^2 of 63.2% compared with 54.5%). When quadratic regression analyses were undertaken, the coefficient of determination increased only slightly for the relationship between water intake and metabolic weight (63.2% to 65.1%), and to a greater degree for the relationship between water intake and feed intake (54.5% to 67.3%). Analysis of variance of the quadratic lines shows that they are highly significant representations of the data and therefore it is suggested that the quadratic relationships describe the data more accurately. These relationships are illustrated by Figures 16.1 and 16.2.

Multiple regression of water intake against feed intake and level of feed, and water intake against metabolic weight and level of feed intake both produced equations which analysis of variance proved to be highly significant representations of the data. The coefficients of determination of these equations showed that a similar proportion of the variation was accounted for as the quadratic regressions (66.2% and 62.1%).

In order to try and improve the precision of the predictive equations, a multiple regression analysis was undertaken for the quadratic of metabolic weight with treatment level of feed intake, and also the

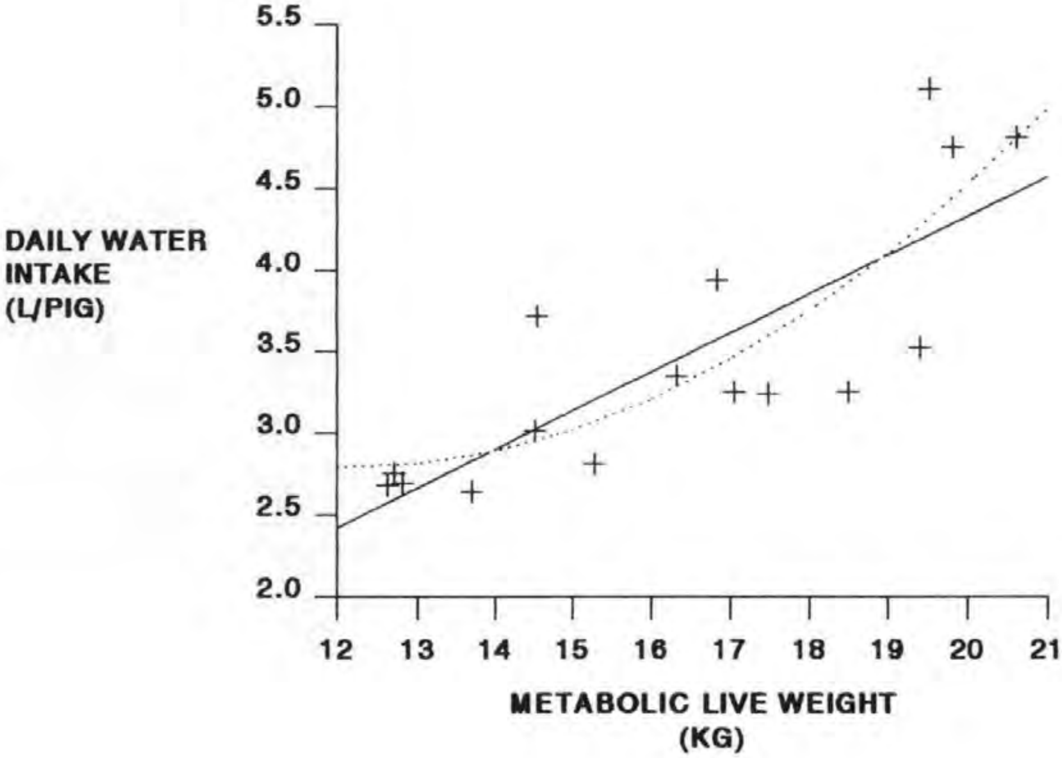
Figure 16.1 The relationship between mean daily water intake and mean daily feed intake of growing pigs 30 to 60 kg.



(.....) Quadratic regression line
$Y = 7.85 - 8.28\ X + 3.45\ X^2$
(——) Linear regression line
$Y = 0.44 + 2.03\ X$

Where Y = water intake (litres/pig/day)
X = feed intake (kg/pig/day)

Figure 16.2 The relationship between mean daily water intake and metabolic live weight of growing pigs 30 to 60 kg.



(.....) Quadratic regression line $Y = 6.86 - 0.673\ X + 0.0278\ X^2$

(——) Linear regression line $Y = -0.447 + 0.239\ X$

Where Y = water intake (litres/pig/day)

X = metabolic live weight (kg)

quadratic of feed intake with treatment level of feed intake. The results are as follows:

1. $Y = 6.95 - 0.826\ X1 + 0.0324\ X1^2 + 0.0120\ X2$
$R^2 = 65.8\%$ $P = 0.001$

Standard deviation of intercept		= 5.468
	b1	= 0.6922
	b2	= 0.02102
	b3	= 0.01071

Where Y = water intake (litres/pig/day)
X1 = metabolic weight (kg)
X2 = treatment level of feed (g)

Analysis of variance of the line proved it to be a highly significant representation of the data. Combining treatment level of feed with the quadratic of metabolic weight only marginally increased the coefficient of determination (65.1% to 65.8%). Ninety per cent of the 65.8% of the variation accounted for by the line came from metabolic weight.

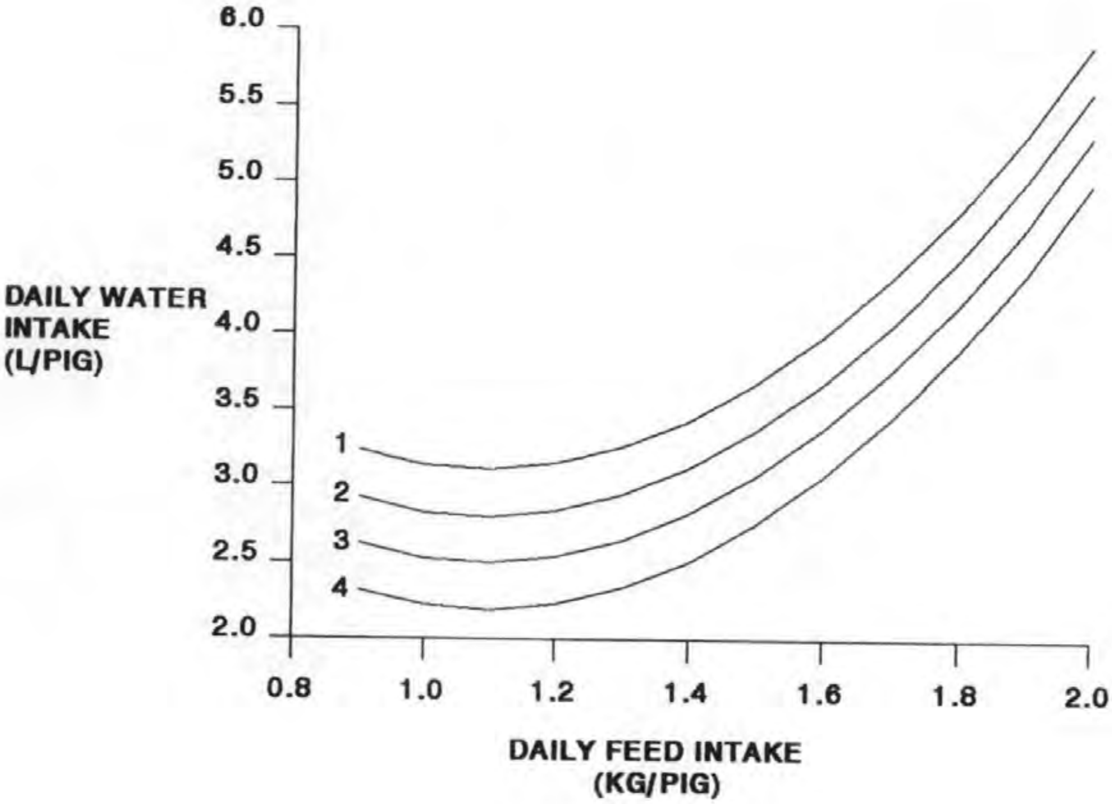
2. $Y = 9.61 - 7.43\ X1 + 3.4\ X1^2 - 0.0305\ X2$
$R^2 = 80.6\%$ $P = 0.0001$

Standard deviation of intercept		= 2.356
	b1	= 3.145
	b2	= 1.044
	b3	= 0.0097

Where Y = water intake (litres/pig/day)
X1 = feed intake (kg/pig/day)
X2 = treatment level of feed (g)

Analysis of variance of the line proved it to be a highly significant representation of the data. Combining treatment feed level with the quadratic of feed intake considerably increased the coefficient of determination (80.6% compared with 67.3%). This multiple regression line therefore gave the most accurate representation of the experimental data. The relationship between mean daily water intake and mean daily feed intake at the four different levels of feeding is illustrated in Figure 16.3.

Figure 16.3 The relationship between mean daily water intake and mean daily feed intake of growing pigs 30 to 60 kg at four different levels of feeding.



$Y = 9.61 - 7.43\ X1 + 3.4\ X1^2 - 0.0305\ X2$

Where Y = water intake (litres/pig/day)
X1 = feed intake (kg/pig/day)
X2 = level of feed (g/kg W0.75)

(1) 80 g/kg W0.75
(2) 90 g/kg W0.75
(3) 100 g/kg W0.75
(4) 110 g/kg W0.75

Linear regression of water to feed ratio against treatment level of feeding produced the following equation:

$Y = 4.2 - 0.0196\ X \quad R^2 = 30.0\%\ P = 0.016$
Standard deviation of intercept = 0.687
gradient = 0.0072

where Y = water to feed ratio
X = treatment level of feeding (g/kg $W^{0.75}$)

The relatively low coefficient of determination shows that the line does not account for much of the variation. This variation was partly attributed to the variation in metabolic live weight. Analysis of variance of the regression line showed it to be a significant representation of the data.

Discussion

The results of the experiment have produced some definitive data describing the water intake of growing pigs. The mean water intake of growing pigs of mean weight 41 kg was found to lie between 3.29 and 3.6 litres/pig/day, depending on the level of feed intake. The increase in water intake resulted from more water being consumed with the food. Water consumed between meals was relatively constant. The extra water consumed may be a result of hunger (that is it may be contributing to gut fill) or from social facilitation. Comparative data concerning the use of water by pigs under different conditions is readily available, however, there is still a paucity of information relating to actual water intake. Experiments have been undertaken such as one by Barber et al.,(1958), where actual water intakes were known because they were predetermined and therefore do not represent actual water requirement. Many other experiments, for example Gill (1989) and

Barber et al.,(1963), have allowed free access to water but from drinking devices which allow wastage.

Total water to feed ratio was found to lie between 2.65:1 and 2.08:1 depending on the treatment level of feed. This is a greater ratio than that recommended by the A.R.C. report (1981), which suggested that the water requirements of growing pigs could be met in wet feeding systems by mixing the feed at the ratio of two to one. Clearly these recommendations do not agree with the water to feed ratios calculated from Experiment 11. Presently there is no data published on the water to feed ratio a pig would select if it were allowed to do so. In this experiment the pigs mixed their own water with food to produce a ratio of 0.83-0.89:1.

In an experiment carried out by Plagge and Leuteren, (1989) comparing three different methods of feeding and watering one of the treatment methods was to feed the pigs dry feed in a hopper with an ad *libitum* nipple drinker mounted inside the trough. It appears that this treatment method was very similar to that used in Experiment 11 and therefore a direct comparison of results is possible. Plagge et al., (1989) measured the water intake of growing/fattening *ad libitum* fed pigs of mean weight 64.5 kg to be 5.0 litres/pig/day. Using the linear and quadratic regression equations produced earlier relating water intake to metabolic live weight, the water intake of a 64.5 kg pig was found to be 4.99 and 5.94 litres/pig/day respectively. These figures are close to the intake measured by Plagge et al.,(1989), bearing in mind that the figures had to be extrapolated from the data of experiment 11. Metabolic live weight has been used as a predictor rather than feed intake because pigs in one of the studies were ration-fed and those in the other were *ad libitum*.

One of the original objectives of the experiment was to determine whether feed intake or live weight (metabolic) was the better predictor of water intake. However, in retrospect it was realised, that because of the design of the experiment, it was not strictly possible to do this because the pigs were ration fed on a scale according to metabolic live weight. The two predictors to be compared were therefore confounded. Had the pigs been fed *ad libitum* then this comparison would have been possible.

Figure 16.1 illustrates the quadratic relationship between daily feed intake and mean daily water intake of growing pigs. According to the fitted quadratic equation the point of minimum water intake was found to be at a feed intake of 1.2 kg/day. The calculated water intake at this feed intake was 2.88 litres/pig. This interpretation is somewhat confounded by the fact that pigs of different live weights may have been receiving the same amount of feed because they were on different treatment feed levels. Therefore, it is difficult to determine whether the higher water intakes at feed intakes less than 1.2 kg/pig/day were a gut filling response or as a result of higher live weight. Figure 16.2 illustrates the relationship between metabolic live weight and daily water intake. The quadratic relationship gives a slightly better representation of the data however the minimum value of water intake does not occur within the weight range studied. Therefore, within the weight range studied water intake increased with increasing metabolic live weight.

The results show that water intake is lower at higher levels of feed making the water to feed ratio lower. Figure 16.3 illustrates the relationship between mean daily water intake and mean daily feed intake of growing pigs according to the four treatment feed levels. Water intake at the same feed intake is different according to the level of feed intake. Within the range 80 to 110 g/kg $W^{0.75}$, an increase in the level of feed intake of 10 g/kg $W^{0.75}$ results in a decrease in water intake of 0.305 litres/pig/day.

Under normal conditions animals show a close and positive correlation between the amount of a particular feed eaten and the amount of water consumed, (Leitch and Thompson, 1944: Chew, 1965). However in an experiment investigating the effects of food on drinking behaviour of growing pigs, Yang *et al.*,(1981), showed that when feed supply is suddenly reduced, water use increases significantly and when feed intake is increased water intake decreases slightly. The water use of pigs of mean body weight of 31.8 kg increased from 2.6 litres/pig/day at a feed intake of 1.5 kg/day to 3.55 litres/pig/day at 0.8 kg feed/day. This drinking behaviour was attributed to abdominal filling by Yang *et al.*,(1981), as growing pigs have large appetites relative to their body size and therefore hungry pigs over-drink water to satisfy gut fill. Kutsher,(1973) suggested that feed deprivation polydipsia is not observed in all animals and is probably of psychological rather than physiological origin.

Yang *et al.*,(1984), showed that pigs whose live weight increase from 27.8 to 68.6 kg over a nine week period fed on a decreasing level of nutrition of 115 to 83 g/kg $W^{0.75}$ decreased their rate of turn over of water. However a second group of pigs whose live weight increased from 30.6 to 59 kg over the same period fed on a scale decreasing from 94 to 60 g/kg $W^{0.75}$ increased their rate of water turnover. They suggested that the extra water intake was not for homeostatic purposes, but was probably caused by hunger. It was concluded that the pigs exhibited polydipsia when the daily feed intake decreased below 73 g/kg $W^{0.75}$.

The results of Experiment 11 are, in principle, in agreement with those of Yang *et al.*,(1984) and Yang *et al.*,(1981,) in that water intake was increased at lower rates of feed. However unlike the report of Yang *et al.*,(1984) Experiment 11 suggests a linear decrease in water intake according to level of feed. This difference may have been due to the fact that Yang *et al.*,(1984) investigated the effect of decreasing level of feed whereas Experiment 11 compared four levels of feed intake. Also Yang *et al.*,(1984) measured water use rather than water intake.

Experiment 11A: The effects of four levels of feed on the water use of growing pigs.

Introduction

This experiment was conducted in parallel with Experiment 11 in the same experimental building at the same time. The main difference between the two experiments was that the way in which the water was supplied. In experiment 11, water was supplied via push button drinkers positioned over the feed trough so that water wastage was negligible and therefore water dispensed was actual water intake. In this experiment water was supplied by bite type drinkers (as in many commercial grower/fattener units) and therefore measured water use consisted of water intake and water wastage.

The objective of running this experiment parallel to Experiment 11 was to be able to make close comparisons between the water intake and water use figures from the two experiments. It was hoped that such a comparison would enable some quantification of wastage from drinkers or an assessment of the efficiency of the drinker type.

Materials and Methods

Experimental design and treatments

The water intake of growing pigs fed at four different feed levels according to scales based on metabolic body weight was investigated.

The four treatment feed levels were as follows:

1. 80 g/kg $W^{0.75}$

2. 90 g/kg $W^{0.75}$

3. 100 g/kg $W^{0.75}$

4. 110 g/kg $W^{0.75}$

The four treatment feed levels were replicated through four groups of animals, four pens and in four time periods according to a 4 x 4 Graeco Latin Square design. Every fourteen days the four groups of animals and the four treatment feed levels were rotated around the four pens according to the design so that at the end of the experiment, each group of animals and each treatment would have spent one fourteen day period in each pen. This design of experiment differs from the classic Latin Square arrangement in that it permits a three-way control in variation of the experimental units as opposed to a two-way control. The contribution to error made by both the pen effect and animal group effect are accounted for.

Animals and housing

The pigs were individually weighed at the start of the trial and ear tagged for identification purposes. Four groups of Large White X (Large White X Landrace) pigs consisting of two gilts and two boars (initial mean weight 24.3 ± 1.6 kg) were assigned to the four treatment pens, balancing groups according to weight, in a performance test house. The pigs were housed in the test house for five days prior to the start of the trial in order to accustom them to the environment and feeding and drinking systems.

The pigs were individually fed in troughs. Water was available *ad libitum* to each pen from a single Arato 80 bite drinker (Figure 1.3), mounted on variable height brackets. The height was initially set at 0.5 m from the ground as specified by the manufacturer, drinker height being increased by an equal amount in each pen to maintain the recommended drinking attitude as the pigs grew. The drinkers were aligned at 15° decline from the ground.

Water was supplied from a closed reservoir water system giving a water pressure head of 4 m. The water delivery rate of the drinkers was set at 600 cm^3/min. The delivery rate was checked weekly and was found to remain within 5% of the nominal value. The water use was monitored through previously calibrated Kent PSM-L water meters. The feed used was formulated from wheat, barley and soya to meet A.R.C. (1981) nutrient requirements for growing pigs and was fed in meal form Proximate and mineral analyses of the feed are given in Table 16.1

The pigs were housed in pens which comprised a kennelled solid floor lying area and an open, slatted, dunging area.

The temperature of the test house was continuously recorded using two previously calibrated thermographs positioned as close to the pigs as possible but remaining out of their reach.

Experimental procedures

The pigs were weighed at the start of the experiment and then every seven days, using a previously calibrated weigh crate. The water meters were read daily at 0830 hours. The pigs were fed twice per day at 0830 hrs and 1600 hrs. The daily meal allowance was mixed with an equivalent weight of water to facilitate consumption. This was necessary for the pigs to consume all of their ration. Uneaten feed and water mixtures were weighed and analysed for dry matter allowing the calculation of the proportion of uneaten feed. The pigs' ration was adjusted weekly according to their weight.

Results

The health of all experimental animals was good, with no deaths nor incidence of scour. The mean daily temperature varied from 13.4 to 17.6°C during the trial period.

Pig performance and water intake data is presented in table 17.1. Analysis of variance of the data showed that there was a significant difference in water use between each of the treatment feed levels ($P<0.001$). That is a higher total water use was recorded at the higher treatment feed level. Voluntary water use was unaffected by the level of feed intake, and therefore the significant difference observed in total water intake was a result of the difference in the amount of water provided involuntarily with the feed and which was directly related to the amount of feed received.

The significant difference between the treatments shown by Table 17.1 in mean daily live weight gain was a direct result of the treatment feed level and was expected. Similarly there was a significant difference in amount of feed intake between the four treatments.

Table 17.1 Water use, and performance of growing pigs fed at four different levels of feed, according to metabolic scales.

Feed level g/kg metabolic weight	80	90	100	110	$S.E._D$	P
Total water use (litres/pig/day)	2.92^a	3.15^b	3.45^c	3.54^d	0.09	0.001
Voluntary water use (litres/pig/day)	1.74	1.77	1.95	1.76	0.02	N.S.
Feed intake (kg/pig/day)	1.15^a	1.33^b	1.44^c	1.69^d	0.013	0.002
Total water to feed ratio	2.63^a	2.47^b	2.38^b	2.09^c	0.03	0.017
Mean liveweight gain (kg/day)	0.372^a	0.517^b	0.534^b	0.661^c	0.017	0.001
Mean F.C.R.	3.27	2.65	2.80	2.67	0.06	N.S.
Mean weight (kg)	36.51	38.21	36.97	41.01	0.34	N.S.

a,b,c,d means bearing the same superscript are not significantly different (P>0.05).

Feed conversion ratio and mean live weight were not significantly effected by treatment feed level.

Water to feed ratio was increased significantly with increasing level of feed ($P<0.05$). There was no significant difference between the treatment feed level rates of 90 and 100 g/kg $W^{0.75}$.

The relationship between water use and the parameters of feed intake, metabolic weight and treatment feed level were investigated using linear, quadratic and multiple regression analyses. The results of these analyses are presented in Table 17.2. Analysis of variance of the linear regression lines of total water use against feed intake and metabolic live weight showed that only the regression analysis between feed intake and water use was a significant representation of the data, ($P<0.05$). Analyses of the quadratic relationships between water use against feed intake and metabolic live weight also showed that only the regression line of water use against metabolic live weight was a significant representation of the data ($P<0.05$). The quadratic regression analysis increased the value for the coefficient of determination from 21.2% to 25.4% suggesting that it accounts for a greater proportion of the variation. The multiple regression analyses of water use against feed intake and level of feeding, and water use against metabolic weight produced no significant regression lines. Similarly multiple regressions including the quadratic of the two parameters produced no significant regression lines.

Table 17.2 Regression of mean daily water use against mean daily feed intake, metabolic weight, and treatment level of feed intake.

Regression equation	P	R^2	Standard deviation of: intercept	b1	b2
$Y = 1.59 + 1.20X1$	0.041	20.7%	0.765	0.541	
$Y = 5.63 - 4.64X1 + 1.87X1^2$	0.050	26.4%	2.889	4.065	1.290
$Y = 1.49 + 0.117X2$	0.121	10.3%	1.093	0.0705	
$Y = 10.6 - 1.103X2 + 0.0389X2^2$	0.157	13.3%	7.596	1.009	0.0328
$Y = 1.54 + 1.18\ X1 - 0.0007X3$	0.142	14.6%	1.471	0.736	0.0199
$Y = 0.02 + 0.103X2 + 0.0176X3$	0.173	11.9%	1.699	0.0709	0.0157

Where Y = Mean daily water use (litres/pig/day)
X1 = Mean daily feed intake (kg/pig)
X2 = Metabolic live weight (kg)
X3 = Treatment feed level (g/kg $W^{0.75}$)

Discussion

The results of this experiment are similar in nature to those of Experiment 11, namely that total water use was significantly increased with increasing level of feed. This increased water use was a result of water imbibed during feeding, non-prandial water use being similar for the four treatment feed levels. There was a significant decrease in total water to feed ratio as level of feed increased. If Tables 16.2 and 17.1 are compared the similarity between the results can be observed.

It was noticed that for this experiment the differences between the treatments, for the parameters mentioned above, were considerably more significant than in Experiment 11. Also when comparing the results of the regression analysis it was noticed that the regression lines produced from the data of Experiment 11 were more significant and better representations of the data than the regressions of this experiment. The reasons for these differences are unknown. In hindsight it was realised that this experiment was less similar to Experiment 11 than had been intended. The fact that the amount of water given with the feed was predetermined meant that pigs were unable to select their preferred water to feed ratio and that in order to consume their allocated ration it was necessary to consume all the water given with the feed. The experiment would have been better had the pigs been allowed to mix their own water with their feed from push button trough drinkers in a similar manner to those in Experiment 11.

The objective of running this experiment alongside Experiment 11 was to try and produce some comparable data of water use and water intake in order that the efficiency of drinkers in supplying water to pigs could be determined and possibly some definitive data could be produced on the proportion of water wasted from drinkers. In order to do this, data must be compared from the two experiments. Table 17.3 presents mean data from the two experiments. A two way analysis of variance has been undertaken to analyse the data using the factors of period and experiment in an additive model.

Table 17.3 shows that there was no significant difference between the two experiments for total water use, feed intake, total water to feed ratio, mean live weight gain or mean feed conversion ratio, ($P>0.05$). The mean live weight of the animals used in Experiment 11 was significantly greater than those of Experiment 11a, ($P<0.001$). The greater live weights of the animals in Experiment 11 are responsible for the numerically higher values for total water use, feed intake and mean live weight gain.

The linear regression lines of total water use against feed intake derived from the two experiments, are compared below:

Experiment 11: $Y = 0.44 + 2.03\ X$

Experiment 11a: $Y = 1.59 + 1.20\ X$

Where Y = Mean daily water use (litres/pig)
X = Mean daily feed intake (kg/pig)

t-ratio of intercept = 1.5 N.S.
t-ratio of gradient = -1.53 N.S.

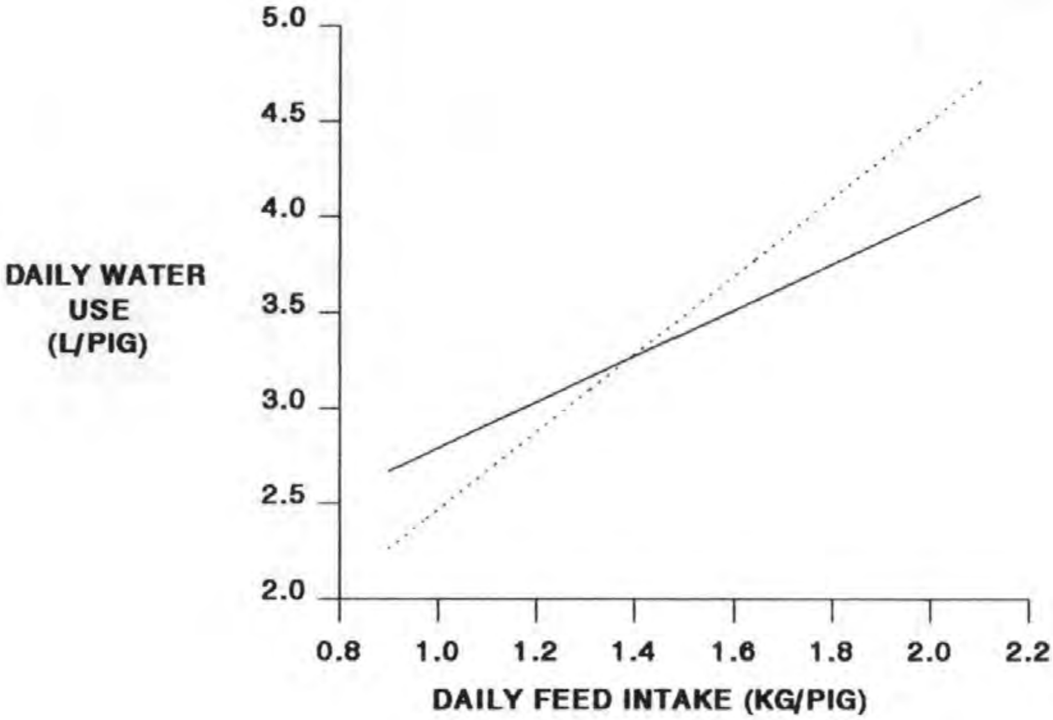
This analysis shows that neither the intercepts nor the gradients of the two lines are significantly different ($P>0.05$). Figure 17.1 illustrates the two regression lines.

It is therefore concluded that there is no significant difference

Table 17.3 A comparison of water use and performance data from Experiment 11 and Experiment 11a.

Mean values	Exp. 11	Exp. 11a	S.E.	P
Total water use (litres/pig/day)	3.47	3.26	0.10	N.S.
Feed intake (kg/pig/day)	1.61	1.40	0.07	N.S.
Total water to feed ratio	2.34	2.39	0.08	N.S.
Mean liveweight gain (kg/day)	0.553	0.521	0.023	N.S.
Mean F.C.R.	2.79	2.84	0.08	N.S.
Mean weight (kg)	41.78	38.18	0.37	0.001

Figure 17.1 A comparison between the linear regression lines of total water use against feed intake obtained from Experiments 11 and 11a.



(.....) Regression line from Experiment 11: $Y = 0.44 + 2.03\ X$

(——) Regression line from Experiment 11a: $Y = 1.59 + 1.2\ X$

Where Y = water intake (litres/pig/day)

X = feed intake (kg)

between the water intake measured in Experiment 11 and the water use measured in Experiment 11a. Also, as feed conversion values for the two experiments were not significantly different it is suggested that the water use figures measured in Experiment 11 were actually water intake figures. Finally it may be concluded that the contribution made to the slurry by the supplied drinking water was similar for both experimental methods and that very little water wastage occurred from the Arato 80 drinker operating at 600 cm^3/min.

Part 4: Determination of the peak water demand periods.

Introduction

When planning water supplies to pig units it is necessary to know the pattern of water demand throughout the day. It is important to know whether peaks in demand occur, how large they are and when they occur. This information is needed when choosing pipe diameters for supplying water to pig units and for evaluating the effects of these high demand periods on rural water supplies. Also when designing low pressure water supply systems, the size of the high demand peaks will dictate the capacity of the water reservoirs used. The predisposing causes of any peaks need to be identified in order that they may be reduced or their effects on the rural network can be minimised.

Experiments 12 and 12A are the results of the monitoring of the pattern of water use of two systems which were primarily running for other reasons and were therefore not experiments initiated for the sole purpose of monitoring water demand. It had only been intended to obtain some basic data to describe the pattern of water use and therefore experimental details and statistical analysis are brief.

Experiment 12: The circadian pattern of water use by lactating sows.

Materials and Methods

Experimental design

The pattern of water use in a commercial farrowing house was monitored over a period of twenty one days.

Animals and housing

The building contained 14 Large White X Landrace sows at different stages of lactation, housed mainly in farrowing crates. The animals were of different parities and had varying numbers of piglets in their litters, (6-14).

The sows were ration fed according to stage of lactation and the numbers of piglets in the litters. The ration was split into two feeds given at 0700 hrs and 1600 hrs.

Water was available to the sows from Arato 74 push button drinkers fitted in the feed troughs of the farrowing crates. The delivery rate from the drinkers (immaterial to this experiment) was 1000 cm^3/min. A water was also available to the piglets, but through a different pipe system from the sows.

Experimental procedures

A calibrated Kent PSM-L water meter was fitted to the water supply pipe of the farrowing accommodation to record the volume of water supplied to the building. Close to the water meter, a video camera was mounted and focused on the water meter display.

A constant time-lapse video recording was made of the water meter using a video recorder over the 21 day period. The meter had to be illuminated in order to allow the camera to function correctly.

The video tape was played back and stopped every hour to note down the meter reading. The percentage of total daily water used in each hour was then determined.

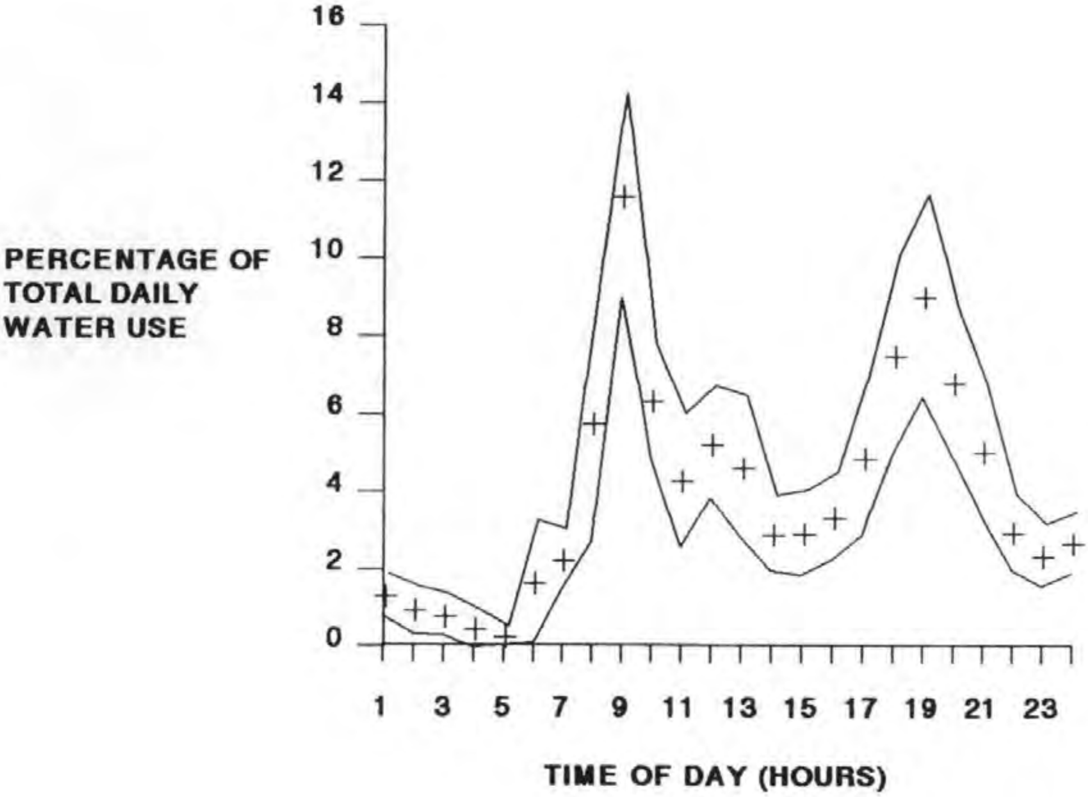
Results

The results are presented in Table 18.1. The results show that water use by lactating sows during the day is not constant and two peaks in consumption occur. These peaks occur during the ninth and nineteenth hours of the day. The results are illustrated in Figure 18.1. It can be seen that although the demand for water is not constant, some water is consumed in every hour of the day. Relatively small quantities are consumed during the first six hours of the day. It can be calculated that approximately 50 % of the total daily water use occurs in six hours of the day.

Table 18.1 The proportion of total daily water used in each hour of the day.

Hour	%	$S.E._M$
1	1.49	0.26
2	1.11	0.29
3	0.98	0.26
4	0.63	0.25
5	0.43	0.14
6	1.82	0.67
7	2.41	0.35
8	5.92	1.24
9	11.79	1.07
10	6.50	0.63
11	4.44	0.73
12	5.42	0.62
13	4.80	0.76
14	3.08	0.43
15	3.09	0.48
16	3.51	0.50
17	5.04	0.84
18	7.68	1.04
19	9.20	1.07
20	6.98	0.81
21	5.20	0.71
22	3.12	0.43
23	2.52	0.37
24	2.85	0.36

Figure 18.1 The circadian pattern of water use by lactating sows fed twice daily according to stage of lactation and body condition



(+) Mean % values of daily water use
(——) 99% confidence limits of individual % values of daily water use

Experiment 12A: The circadian pattern of water use by growing pigs.

Materials and Methods

Experimental Design

The pattern of water use of the experimental growing pigs of Experiment 11 was monitored over the course of the experiment (8 weeks).

Animals and Housing

For details of housing and animal husbandry refer to the methodology of Experiment 11.

Experimental procedures

A calibrated Kent PSM-L water meter was fitted to the water supply pipe of the experimental test building to record the volume of water supplied to the building. Close to the water meter, a video camera was mounted and focused on the water meter display. A constant time-lapse video recording was made of the water meter using a video recorder over the 8 week period. The meter had to be illuminated in order to allow the camera to function correctly. The video tape was played back and stopped every hour to note down the meter reading. The percentage of total daily water used in each hour was then determined.

Table 19.1 The proportion of total daily water used in each hour of the day for growing pigs

Hour	%	S.E.M
1	0.45	0.09
2	0.25	0.05
3	0.12	0.04
4	0.07	0.03
5	0.06	0.04
6	0.12	0.04
7	0.07	0.03
8	0.49	0.19
9	3.40	0.60
10	11.23	0.66
11	9.34	0.64
12	5.85	0.41
13	6.51	0.47
14	6.31	0.31
15	7.32	0.54
16	12.66	0.98
17	17.66	0.98
18	10.06	0.98
19	2.49	0.37
20	1.02	0.12
21	1.42	0.17
22	0.98	0.11
23	1.46	0.18
24	0.68	0.10

Results

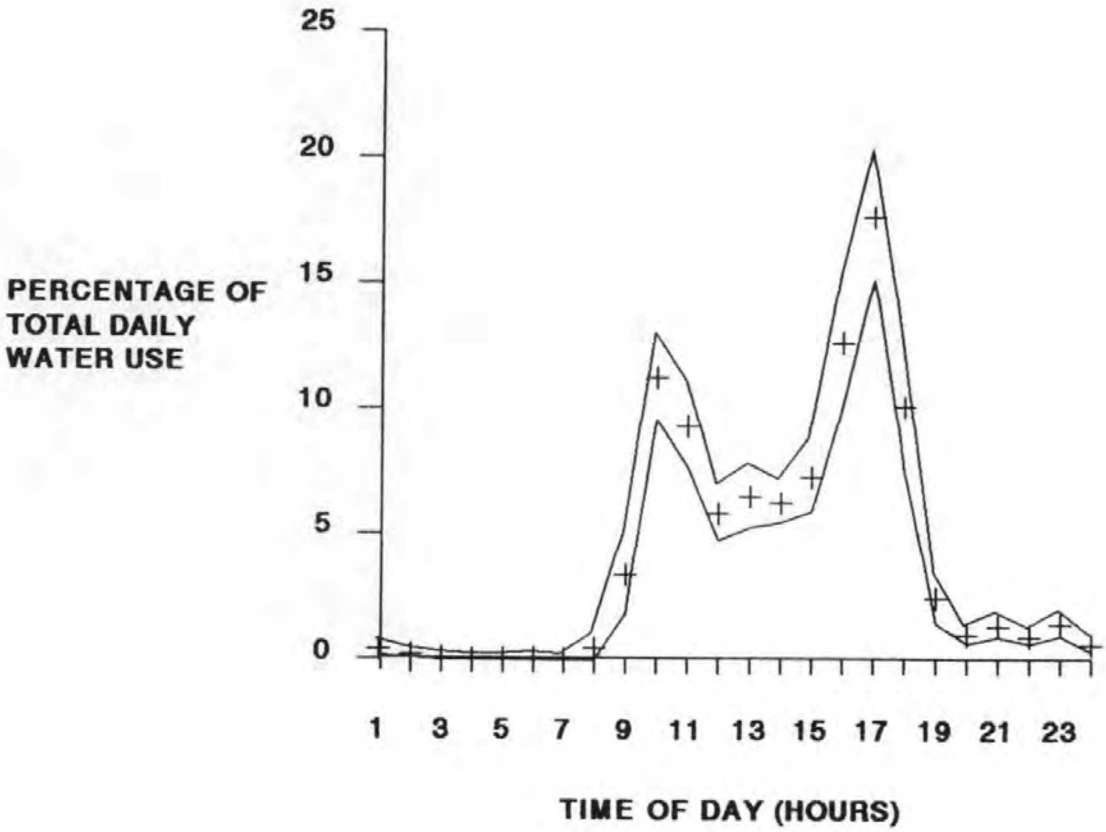
The results are presented in Table 19.1. It can be seen that the water use of growing pigs during the 24 hour period is not constant and two significant peaks in water use occur. These peaks occur in the tenth and seventeenth hours of the day. This is illustrated by Figure 19.1. Only very small quantities are consumed during the first seven and the last 5 hours of the day. It can be seen that although the demand for water is not constant, some water is used in every hour of the day. From Table 19.1 it can be calculated that approximately 67% of the pigs water use is used in only six hours of the day.

Discussion of Experiments 12 and 12A

Comparing Tables 18.1 and 19.1 it can be seen that the standard errors for the hourly use of water by the growing pigs were significantly lower than those for the lactating animals indicating that variation in water use between hours was greater for the lactating animals. This may have been due to variations in physiological status, that is the growing pigs would all be of the same status whereas the lactating animals would have been of different stages of lactation and possibly in late gestation.

For growing pigs (Experiment 12A) the peaks in water us shown by Figure 19.1 occur about 1 hour after feed times whereas for lactating sows the peaks did not occur until 2-3 hours after feed times. This may have been a result of an increased level of social facilitation in the feeding and drinking behaviour of the growing pigs due to being kept in groups rather than individually crated as the sows were, (Hsia

Figure 19.1 The circadian pattern of water use by growing pigs fed twice daily according a scale based on metabolic liveweight.



(+) Mean % values of daily water use

(——) 99% confidence limits of individual % values of daily water use et al.,1984).

The data from Experiment 12, (Figure 18.1) indicated that the peak in water use for lactating sows following the first meal was greater than that following the second meal. This is in agreement with the data presented by Albar et al.,(1985), on the hourly consumption of lactating sows. Conversely, the data in Experiment 12A (Figure 19.1), showed that the morning peak in water use for growing pigs was less than the peak observed following the second meal. Hepherd et al.,(1983), in an experiment measuring the water use of two herds of bacon pigs showed that water use was at a low level from about midnight to the time at which the first feed was delivered at about 0700 hours, the amount during this period being about 10% of the total daily use. Demand rose sharply after the first feed, increased sharply to a maximum just after the second feed was delivered and then fell steeply until midnight. The greater peak following the second meal is similar to the findings of Experiment 12A.

Houpt, Weixler and Troy, (1986), showed that pigs consume a large proportion of their water requirement peri-prandially. Haugse, Dinusson, Erickson, Johnson and Buchanan, (1965), found that 35% of the time, pigs that were presently eating would begin drinking immediately afterwards and also pigs engaged in drinking behaviour would 50% of the time subsequently begin eating.

In an Experiment studying stereotypic behaviour and adjunctive drinking of tethered sows, Rushen (1984), showed that the frequency of drinking was highest after feeding. Less than one percent of the total time spent drinking occurred in the two half-hour periods before food delivery whereas 4-5% of the total time spent drinking occurred in each of the two half-hour periods after feed delivery. Rushen (1984), suggests that stereotypic sequences of behaviour such as post-prandial adjunctive drinking may be a means of reducing the arousal generated by the expectation of food. Although the requirement for water is satisfied in the post-prandial period, Rushen suggests that there was some evidence of polydipsia. However his methodology would suggest there was a difference between drinking behaviour and water consumption; that is drinking behaviour was manipulation of the drinker where as actual drinking was a measurement of the duration of drinking rather than a measure of water use.

Bigelow and Houpt, (1988), investigated the feeding and drinking patterns of pigs 10-130 kg fed ad libitum. They showed that peri-prandial water use as a proportion of total water use decreased as body weight increased. Between 10-40 kg an average of 94% of total water use was peri-prandial whereas at 40-70 kg peri-prandial drinking fell to 75%. Overall 75% of the pigs drinking was associated with eating of which 27% was pre-prandial, 16% post-prandial and 32% intra-prandial leaving 25% drunk apart from eating. These values are somewhat different from those from experiments 12 and 12A because of the different type of feeding. The animals in Experiments 12 and 12A were ration-fed at specific times of the day which resulted in a higher post prandial fraction. Also intra-prandial drinking was not easy to identify and was included in the post-prandial fraction.
Bigelow et al.,(1988), also showed that 68% of water use occurred during the 12 hour light period. In Experiment 12, 70.46% of total water use occurred during the light period and for Experiment 12A the figure was 92.88%.

It was concluded by Bigelow *et al.*,(1988), that the most significant proportion of daily water use is that taken in close association with meals because that water immediately balances the osmotic load that the meal represents and prevents large variations in body fluid osmolarity. The results of Experiments 12 and 12A largely tend to support the work of Bigelow et al.,(1988).

DISCUSSION

5.1 The Theoretical Requirement for Water

At the beginning of the literature review, the factorial models of Gill, (1989) and Brooks *et al.*,(1990), describing the obligatory water losses from and inputs to growing-finishing pigs were discussed. Both authors modelled the water balance in a 60 kg live weight pig fed a compounded diet *ad libitum* in a thermoneutral environment. In order to make a comparison between the theoretical water requirement and the water intake measured in this programme of research, both models have been modified slightly to describe the water losses and gains of a ration fed 60 kg pig under the same conditions. These adaptations of the two models are shown in Tables 20.1 and 20.2.

Adapting the model prepared by Gill,(1989) the water intake is calculated to be between 1.713 and 3.133 litres/pig/day for a 60 kg ration fed pig. Using the model produced by Brooks *et al.*,(1990) the water intake is calculated to be 3.48 litres/pig/day.

From the above two models of the theoretical water requirement of a 60 kg ration fed pig it is suggested that the additional water the animal needs to imbibe to maintain homeostasis lies somewhere between 1.71 and 3.48 litres/pig/day. Brooks *et al.*,(1990) state that the factorial estimation of water requirement is neither a reliable nor practical proposition as it assumes that the pig is in good health and is maintained in a thermoneutral environment. Under these conditions the water demand is probably close to the minimum per unit of food consumed, provided that the pigs are fed *ad libitum* and no water is used for gut fill. The relative contribution of the different inputs and losses to the factorial model are extremely variable, and the interactions between

Table 20.1 Example of the water balance of a 60 kg liveweight pig ration fed at 100 g/kg metabolic weight.

(Adapted from Brooks *et al.*,(1990).

Water used/lost	(ml)	Water consumed/formed	(ml)
Growth(1)	553	Food water(5)	300
Respiration(2)	580	Food oxidation(6)	843
Skin(3)	420		
Faeces(4)	755		
Urine(8)	2315	Water consumed (7)	3480
Total	4623	Total	4623

Assumptions:

1. Growth (826 g/d) assumed to be 67% water. (Whittemore and Elsley, 1979).

2. Respiration loss assumed to be 0.58 litres/day (Holmes & Mount, 1967).

3. Insensible moisture loss from skin assumes 13.4 g/m^2 per h at thermoneutral temperature and 70% RH as obtained by Morison et al., (1967). Surface area = $0.10W^{0.63}$ (Brody, 1964).

4. Ration for a 60 kg pig at 100g $W^{0.75}$ 2.155 kg (1.85 kg DM). DM digestibility assumed to be 82% and faecal DM 35%.

5. Compound diet assumed to be 14% moisture.

6. The diet is assumed to contain per 1000 g fresh weight, Fat 70 g, Carbohydrate 590 g and Protein 180 g. The protein is assumed to have a biological value of 70 therefore 54 g of the protein would not be used in protein growth and would be deaminated. Therefore the yield of metabolic water per kg feed would be

	g/kg	water yield/g	Total
Fat	70	1.10	77
Carbohydrate	590	0.60	354
Protein	54	0.44	24
			455

7. Water intake assumed to be 1.6 kg per kg feed which was the lowest ratio recorded by Yang et al.,(1981) for pigs fed ad libitum.

8. Urine volume derived by difference.

Table 20.2 Example of the water balance of a 60 kg liveweight pig ration fed at 100g/kg metabolic weight.

(Adapted from Gill,(1989).

Water used/lost	(ml)	Water consumed/formed	(ml)
Growth(1)	413	Food water(5)	300
Respiration(2)	580	Food oxidation(6)	445
Skin(3)	420		
Faeces(4)	755		
Urine(8)	290-1710	Water consumed (7)	1713-3133
Total	2458-3878	Total	2458-3878

Assumptions:

1. Growth (826g/d) assumed to be 50% water, estimated from sequential slaughter data (Shields et al.,1983)

2. Respiration loss assumed to be 0.58 litres/day (Holmes & Mount, 1967).

3. Insensible moisture loss from skin assumes 13.4 g/m^2 per h at thermoneutral temperature and 70% RH as obtained by Morison et al., (1967). Surface area = $0.10W^{0.63}$ (Brody, 1964).

4. Ration for a 60 kg pig at 100g $W^{0.75}$ 2.155 kg (1.85 kg DM). DM digestibility assumed to be 82% and faecal DM 35%.

5. Compound diet assumed to be 14% moisture.

6. Metabolic water produced is 7.43 ml/kg W per day.

7. Water intake derived by difference.

8. 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, (Dukes 1984).

them, produced by differences in health status, nutrition and the environment are considerable and complex. However, the animals used in this experimental programme were of good health and housed in a thermoneutral environment, and therefore the factorially estimated theoretical water requirement can be compared with the actual measured water intake.

Of all the experiments in this research, only the results of Experiment 11 can be compared to the factorial estimate as only in this experiment was actual water intake measured. From Table 16.3 of Experiment 11 the relationship between metabolic live weight, feed level and water intake is given by the regression equation:

$Y = -1.26 + 0.238\ X1 + 0.00873\ X2 \qquad P<0.001 \qquad R^2 = 62.1\%$

where Y= Mean daily water intake (litres/pig/day)
X1 = Metabolic live weight (kg)
X2 = Treatment feed level(g/kg $W^{0.75}$)

Using the above equation, the water intake of a 60 kg pig fed at a rate of 100 g/kg $W^{0.75}$ is found to be 4.74 litres/pig/day. This value is significantly greater than the figures computed from the adapted models of Brooks et al.,(1990) and Gill(1989) for the theoretical requirement for water. The mean daily temperature for Experiment 11 varied from 13.4 to 17.6 °C during the trial period which is within the thermoneutral zone for a 60 kg pig. Table 16.1 shows the proximate and mineral analysis of the feed used in Experiment 11, which shows that there were not excessive levels of sodium or potassium in the diet which would have increased the demand for water.

It is not possible to make a further comparison between Experiment 11 and other published work as available data concerning the water intake of ration fed growing pigs is scarce. In an experiment by Plagge et *al.*,(1989) the water intake of *ad libitum* fed pigs of mean weight 64.5 kg W was found to be 5.0 litres/pig/day. Gill (1989), calculated the theoretical requirement of a 60 kg *ad libitum* fed pig to be 1.91 to 3.33 litres/pig/day where as Brooks *et al.*,(1990) calculated the requirement of the same pig to be 4.35 litres/pig/day. Walker, (1990), in an experiment investigating the performance of 10, 20 and 30 pigs per single space feeder, the mean water intake for pigs of mean weight 62.3 kg fed *ad libitum* was found to be 4.13 litres/pig/day. Both the experimental values (5.0 and 4.13 litres/pig/day) for the water intake of a 60 kg pig fed *ad libitum* are significantly greater than the theoretical value calculated by Gill (1989). The value of 4.13 litres/pig/day measured by Walker (1990) is close to the theoretical value suggested by Brooks of 4.35 litres/pig/day, however the mean value reported by Plagge et *al.*,(1989) is higher. The different values are summarised in Table 20.3.

Having compared the theoretical and experimental values of water intake of ration fed and ad libitum fed pigs it would appear that in most cases the predicted theoretical water requirements are considerably less than the experimentally measured values. A possible explanation for this additional water intake which appears to be in excess of requirement, is that the pig is drinking in order to satisfy a requirement for gut fill. Yang et *al.*,(1981) showed that when feed intake is reduced below the level producing physical satiety, the pig increases its water intake. Also when a pig is allowed unrestricted access to food and water it maximises the proportion of food that it consumes within its volumetric limit (gut fill) consistent with consuming adequate water to maintain its homeostatic balance. The pig appears to minimise its demand for water per unit of feed dry matter when it is fed *ad libitum*. Yang *et al.*,(1981) suggests that there may be a daily volumetric limit or a total limit of

Table 20.3 A comparison of the theoretically predicted water requirement and experimentally measured intake of a 60 kg liveweight pig fed *ad libitum* and rationed.

Ration fed:

Source	Value (litres/pig/day)
Adapted from Brooks et *al.*,(1990)	3.48
Adapted from Gill,(1989)	1.71-3.13
Experiment 11	4.74

Ad Libitum fed:

Source	Value (litres/pig/day)
Brooks et *al.*,(1990)	4.35
Gill,(1989)	1.91-3.33
Plagge et *al.*,(1989)	5.0
Walker,(1990)	4.13

total dry solids and water intake which is about 19% of an animals weight. In later studies Yang et al.,(1984) showed that by gradually reducing feed to below 30 g DM/kg live weight polydipsia was induced. However Close et al.,(1975) reported that the mean water intake of growing pigs was decreased during fasting. Yang et al.,(1981) attributed this difference to different strains of pig. It was suggested by Yang et al.,(1981) that polydipsia observed in animals deprived of food is probably of psychological origin rather than physiological. Water may serve as a substitute for food when there is little to eat, apparently meeting the need to fill the stomach.

The combination of the concept of a limited volumetric intake, the suggestion that a pig will minimise its demand for water per unit of dry matter when fed *ad libitum* and the phenomenon of hunger induced polydipsia contradict the findings of Anand (1961). Anand suggested that there was a close positive linear correlation between water and dry matter intake in most mammals. Water to feed ratio varies according to the feed allowance, the higher ratios being observed at the lower feed intakes. This was shown by Experiment 11 where the water to feed ratio decreased from 2.65:1 at 80 g/kg $W^{0.75}$ to 2.08:1 at 110 g/kg $W^{0.75}$. These figures are also in agreement with the results of Yang et al.,(1981) and Yang et al.,(1984), suggesting that there is a limited volumetric intake.

It may be possible that the concept of a limited volumetric intake could be used as an accurate predictor of water intake in pigs.

5.2 Water Intake

From the previous section it is concluded that water intake is made up of two components:

(1) Physiological water requirement which can be calculated theoretically (Brooks *et al.*,(1990) and Gill,(1989)),

(2) Water for gut satiety which is dependent on feed intake, as a limit to volumetric intake is suspected (Yang *et al.*, 1981).

WATER INTAKE = WATER REQUIREMENT + GUT FILL

5.2.1 A constant volumetric intake.

It was described in the literature review how the physiological water requirement may vary according to factors such as environmental temperature and dietary salt content. It may be possible that the gut fill fraction of water intake described above allows for deviations in physiological water requirement from that requirement predicted factorially under thermoneutral conditions, in order that the pig is not physiologically deprived of water. Therefore the way in which water intake is divided into physiological requirement and gut fill is dependent on physiological requirement and the case may occur when the whole of the measured water intake is used to satisfy the physiological requirement. Moreover, if it is postulated that there is a finite volumetric intake, conditions in which the pigs are considerably heat stressed or where dietary salt levels are excessively high, could result in a situation where the animals are physiologically water deprived if feed intake is maintained at the same level, or if further gut extension is not possible. Chew (1965) describing water intake concluded:

"When water is present *ad libitum*, probably considerable water is used to bring about moment-to-moment optimum volumes in the body - figuratively a 'wasteful fine adjustment'."

On a restricted water intake, water balance is still maintained on a long-term basis, but probably not as a satisfactorily from moment-to-moment, (Toates 1979).

Yang et al.,(1981), state that' is common for animals to drink more that their actual water needs, the extra water intake probably acting as a fail safe mechanism for the maintenance of homeostasis'. The water described in the current experimental programme as the gut fill fraction is the same 'extra water' described by Chew (1965), and Yang *et al.*, (1981).

Mount, (1971) showed that water intake was not significantly increased between 7 and 20°C. This could be due to the fact that the gut fill fraction was coping with any additional evaporative loss.

Variations in water:feed ratio of 1.5:1 to 3.75:1 have been shown to have little effect on overall performance (Castle *et al.*, 1957). Therefore if a pig imbibed water equal to 15% of its live weight when fed dry food at 4% of body weight (3.75:1), the animal need not increase water intake until the food intake reached 10% (1.5:1) of its body weight.

Yang *et al.*, (1981) suggested a volumetric limit of 19% for pigs of mean weight 30 kg. In Experiment 11 the water intake was measured for pigs rationed at four different feed levels over a growth period of 30-60 kg. Therefore it is possible to calculate volumetric intakes (as a percentage of body weight) for Experiment 11 for different levels of feed at different live weights. Table 20.4 shows the gut volumetric limit as a percentage of live weight for the water intake and feed intake data obtained from Experiment 11. From Table 20.4 it can be seen that the mean value for volumetric intake as a percentage of body weight is 11.98%. Analysis of variance of the data showed that there was no significant effect of experimental period (body live weight) on volumetric intake nor was there a significant effect of treatment feed level ($P>0.05$). However as the table below indicates, there seems to be a numerical decrease in volumetric limit as the experiment progressed (increase in mean body live weight).

Period	1	2	3	4
Mean volumetric intake (% of live weight)	12.74	12.27	11.12	11.81

From the data of Experiment 11 it is suggested that there is a constant volumetric intake to live weight ratio and for this case is approximately 12%. This concept is in agreement with the hypothesis of Yang *et al.*, (1981) who suggested that pigs had a daily volumetric limit which from their study was found to be 19%.

This difference is relatively large and may be due to one or more of a number of reasons. Yang *et al.*, (1981) studied only a small number of

Table 20.4 Gut volumetric intake: the relationship between daily water intake, daily feed intake and body liveweight for the data from Experiment 11.

Period	Treatment	Feed (g/pig)	Water (l/pig)	Weight (kg)	Gut fill (%)
1	1	0.990	2.68	29.40	12.48
1	2	1.093	2.75	29.67	12.95
1	3	1.317	2.64	32.84	12.05
1	4	1.350	2.69	30.01	13.46
2	1	1.120	3.72	35.53	13.62
2	2	1.240	3.01	35.42	12.00
2	3	1.458	2.81	37.93	11.25
2	4	1.717	3.35	41.42	12.23
3	1	1.447	3.25	48.94	9.59
3	2	1.528	3.24	45.39	10.50
3	3	1.640	3.94	43.13	12.94
3	4	1.785	3.25	43.88	11.47
4	1	1.503	3.52	52.13	9.64
4	2	1.797	4.81	56.57	11.68
4	3	1.910	4.75	53.67	12.41
4	4	1.999	5.11	52.59	13.52
Mean Values		1.49	3.47	41.78	11.98

pigs, for a very short time period and within a narrow weight range (30 kg). It is unclear from the report of Yang *et al.*, (1981) whether the 19% volume includes the wasted fraction of water. The limit to volumetric intake will depend on actual gut size. Gut size depends on the type of feed used, and its development during the use of a particular feed or system of feeding. It may also vary according to breed of pig. Whittemore (1987) relates live weight (W) to empty body weight (We) as W = 1.05 We, but this is only applicable to rationed pigs fed twice daily.

In a system where pigs are fed once daily, the gut has to be large enough to accommodate all the feed in one meal. For *ad libitum* fed pigs, (Henderson, Whittemore, Ellis, Smith, Laird and Phillips, 1982), related live weight (W) to empty body weight (We) as W = 1.18 We. Stranks *et al.*, (1988) cite unpublished data by McCracken who determined the gut fill of 20-30 kg pigs fed ad libitum to be W = 1.10 We. Stranks *et al.*, (1988) conclude that considerable variations occur in practice between different farm and research establishments. Stranks *et al.*, (1988) also conclude that the ratio probably decreases with increasing live weight and will be lower in the later stages of growth particularly if restriction is practised. This is in agreement with the numerical trend observed in Experiment 11 in the relationship between increasing live weight and volumetric intake. When the volumetric intake is expressed as a proportion of empty body weight for Experiment 11, volumetric intake still decreased as empty body weight increased.

The experimental animals used by Yang *et al.*, (1988) were of the Large White breed whereas those used in Experiment 11 were Large White X (Large White X Landrace) progeny. However the difference in volumetric intake was most likely due to the difference in the form of the feed and the feeding regime. In both experiments the feed was rationed, but Yang et *al*, (1981) used a 18% protein pelleted diet which was only fed once per day. Conversely, in Experiment 11 the ration was divided into two feeds and was in a meal form.

In an experiment investigating the effects of water to feed ratios, Barber *et al*., (1963) showed that killing out percentage was significantly higher at a ratio of 1.5:1 compared with a ratio of 3:1. This difference was attributed to a lower gut fill arising from the lower water intake. However comparing ratios of 2.5:1 and 4:1, Braude *et al*., (1967) found no significant difference in killing out percentage.

5.2.2 Further evidence to support a theory of constant volumetric intake from studies using growing pigs

From the evidence presented by Yang *et al*., (1981,1984) and Experiment 11, there appears to be a constant volumetric limit to the intake of a particular type of pig under a specific set of conditions. In the case of Experiment 11 concerning pigs growing between 30 and 60 kg the value for volumetric limit was found to be 11.98%. Other published data with which to make comparisons is scarce as rarely has feed intake and water intake been monitored in the same experiment. Many experiments have measured water use but this is of little use when calculating actual volumetric intake. However, recently the introduction of a new type of feeder, the single space feeder has made more data available describing the water intake and feed intake of growing pigs.

The single space feeder is a hopper feeder containing a push button drinker in the trough, allowing *ad libitum* access to water. The pigs are fed *ad libitum* either a meal or pellet diet and can mix water with the feed as they require it. As all the water dispensed by the drinker falls into the trough, wastage of water is minimal and therefore water use figures recorded in experiments studying the use of single space feeders is very close to water intake. The single space feeding system developed on the continent, is becoming popular because of claims of decreased feed wastage and consequent improvement in feed conversion ratio and decreased water wastage resulting in reduction in slurry production.

Plagge et al., (1989), studied the efficiency of the single space feeder concept for a total of 356 pigs in groups of 12 and found the mean water intake of growing pigs from 24 to 105 kg to be 5.0 litres/pig per day and the mean feed intake to be 2.24 kg/day. The mean volumetric intake as a proportion of weight for this experiment can be calculated by adding the feed intake to the water intake and dividing the mean live weight giving a value of 12.1%. This value, despite being calculated over a much greater weight range is similar to the value obtained in Experiment 11. In an experiment studying the use of single space feeders by groups of 10,20 and 30 pigs, Walker (1990), at a mean live weight of 62.3 kg found mean water intake to be 4.22 litres/pig/day and mean feed intake to 2.28 kg/pig/day. From these figures mean volumetric intake is calculated to be 10.4% of live weight for pigs growing from 34.5 to 89.8 kg.

In order to gain more information concerning the volumetric intake of growing pigs it was decided to undertake a simple experiment measuring the feed and water intake of 8 pigs using a Collinson single space feeder. The pigs grew between 26.71 and 78.79 kg live weight giving a mean live weight of 52.75 kg. Mean water intake was found to be 3.67

litres/pig/day and mean feed intake of 2.1 kg/pig/day. The mean volumetric limit was therefore found to be 10.94 %. Wastage of both feed and water was negligible.

From the evidence presented above, it would seem that the volumetric limit for growing/fattening pigs under normal commercial conditions of production lies between 10 and 12% and not the 19% value suggested by Yang *et al.*, (1981). The term 'normal conditions' needs to be further explained. Normal volumetric limit refers to pigs reared under thermoneutral, homeostatic conditions. It may be that the normal measured volumetric limit is increased by factors which increase polydipsia beyond that of balancing gut fill. Excessively high salt or extremes of temperature, increasing water loss (either renal or evaporative) beyond that catered for by the gut fill fraction described in the earlier section, will increase volumetric intake above that described above as being normal.

5.2.3 Further evidence to support a theory of a constant volumetric intake from studies using early-weaned piglets

Piglets are commonly weaned at 3 weeks of age. Suckling piglets at 3 weeks of age obtain as much as 80% of their water requirements from water in the milk, (Aumaitre, 1964). The process of weaning abruptly separates the piglets' water supply away from its source of nourishment. The intake of drinking water during this period is therefore of great importance and has until recently been ignored as the relative quantities involved are small.

When water is not readily available to the piglets, for example under conditions of inadequate delivery rate performance may be affected. Under extreme conditions, the pigs' welfare may be compromised. Submissive pigs may not satisfy their daily water requirements due to increased competition, and the total time spent drinking may increase. If water intake consistently falls below minimum physiological requirements, then in order to maintain water balance (mineral homeostasis) the pigs will reduce feed intake. Provided the water supply to early weaned piglets is not in any way restricted then the optimum balance between water intake and feed intake will be achieved. If the diet is correctly specified this will in turn result in maximum growth performance.

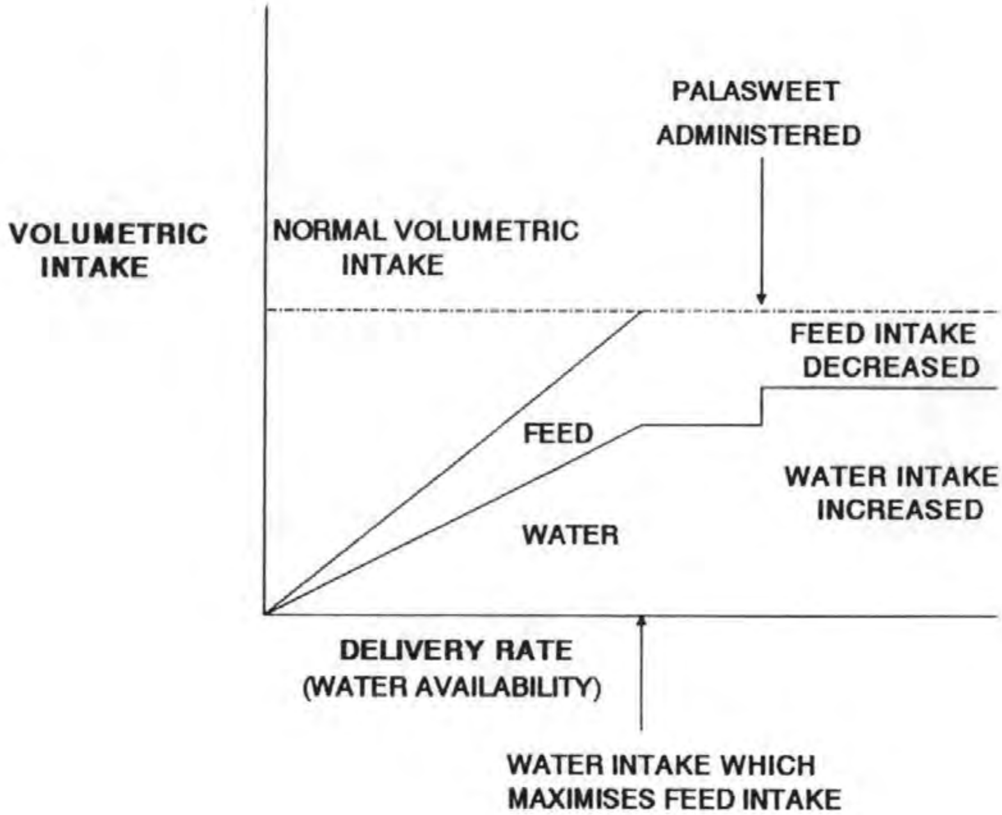
In a situation where water availability is restricted, it is possible that making the water more palatable by the use of a flavouring may result in increased water intake and a consequent increase in feed intake. In a trial conducted at Bicton College of Agriculture (Higginbotham,1987), the water intake of piglets during the first three days post-weaning increased from 0.5 to 0.57 litres/piglet per day when Palasweet was administered in the water. Palasweet is a trade mark of Tate and Lyle Industries Ltd. and is made from thaumatin. Thaumatin is a long chain amino acid and in the dilution used has a very low calorific value, acting merely as a water sweetener. In the same experiment it was noticed that daily gain over the first ten days of the experimental period significantly increased from 126 g/day to 143 g/day when Palasweet was administered to the drinking water.

Experiment 9 investigated the feed intake and water use of early-weaned piglets over a range of water delivery rates, greater than that recommended by the manufacturers. The results showed that between the delivery rates of 175 and 450 cm^3/min, there was a significant increase in mean daily water use and a significant increase in mean daily feed intake. Also mean daily live weight gain increased significantly with increased delivery rate. (See Results Table 13.2, Experiment 9). The results from the regression analyses of experiment 9 indicated that feed intake is correlated with water delivery rate and water use also with water delivery rate. As a result of the positive correlations between the above two pairs of factors, it is suggested that in the case of early weaned pigs 3-6 weeks of age, their feed intake is positively correlated with water intake, and water intake is positively correlated to the ease by which the animal satisfies its thirst.

The evidence presented above would suggest that in young piglets there is not a constant volumetric intake, as increased water intake/use results in increased feed intake. However, in both experiments described above, increases in feed intake were achieved by either making the water more readily available or more palatable.

In the case where delivery rate was optimised maximising feed intake, the addition of Palasweet to the drinking water, increased water intake further during the first three days post-weaning, but at the expense of decreasing the feed intake. (Appendix 1, Trial report to Tate & Lyle, Barber, 1989). Consequently live weight gain for the Palasweet treatment pigs during the first week post-weaning was lower than the control pigs. This data would suggest that early weaned piglets do have a limited volumetric intake, and making the water more palatable in a situation where it is unrestricted results in decreased feed intake due to the limited volumetric intake. No accurate value can be given for volumetric intake, as water use rather than water intake has been monitored, however

Figure 20.1 A tentative model of the relationship between volumetric intake, water intake and feed intake



the value appears to be greater than that observed for growing pigs. Figure 20.1 shows a suggested model of volumetric intake, water intake and feed intake according to the management conditions described above.

Another interesting and probably very significant feature of Experiment 9 was the very short time the piglets were prepared to spend drinking each day. The pigs on the most restricted delivery rate treatment were not prepared to increase their drinking time in order to obtain a greater water intake. This evidence would suggest that in the newly weaned pigs, the mechanisms controlling water balance and thereby influencing water intake are not fully developed. Consequently, the pigs behavioral characteristics and the design and operation of the water delivery system can become limiting to performance. If dietary factors increase the water demand of the pig beyond its ability or willingness to obtain the required water intake, feed intake is depressed and performance suffers.

5.2.4 Environmental temperature and the volumetric intake concept.

It is well documented that feed intake and growth rate of pigs both decrease at high temperatures (Heitman and Hughes, 1949; Heitman, Kelly and Bond, 1958; Seymour, Speer, Hays, Mangold and Jazen, 1964). Sugahara, Baker, Harmon and Jensen (1970) showed that feed intake was reduced in young pigs from 1.33 to 0.91 kg/pig/day at 33°C compared with 23°C. An increase in environmental temperature has also been shown to increase water intake in addition to decreasing feed intake. Increasing ambient temperature from 12-15°C to 30-35°C gave an increase in water consumption per kg live weight of approximately 57% in pigs of 33.5 kg live weight (Mount, Holmes, Close, Morrison and Start, 1971) and of live weight (Mount, Holmes, Close, Morrison and Start, 1971) and of approximately 63% in pigs of 90 kg live weight (Straub, Weniger, Tawfok and Steinhauf, 1976).

Reduction in feed intake results from the lower maintenance energy requirement of the pigs and also acts as a means of avoiding the embarrassment of ridding itself of metabolic heat. The combination of reduced feed intake and increased water intake at high temperatures may be due to the limited volumetric intake. That is the stimulus of thirst may be greater than the stimulus of hunger at high temperatures, the reinforcement obtained from increasing water intake being greater than that from feeding and as a result of a limited volumetric intake feed intake is decreased as a result. There is as yet no evidence to prove that the observed reduction in feed intake is a result of increased water intake. However in an experiment investigating the effects of different temperatures on the feed intake and water use of growing pigs fed *ad libitum* Mount *et al.*, (1971), produced the following results:

Body weight (kg)	Feed intake (kg/pig/day)	Daily water use (litres/pig)	Temperature (°C)
37	2.33	5.07	22
50	1.70	8.40	33

When volumetric intake as a proportion of live weight is calculated it is found to be 20% irrespective of temperature. This evidence suggests that the increase in water use and associated decrease in feed intake may be related to a limited volumetric intake. The figure of 20 % is not strictly volumetric limit because it assumes all water used is imbibed and no water wastage occurs. This is the most probable explanation for the difference between this figure and the value of 12 % for volumetric limit calculated in section 5.2.1.

5.2.5 Suggestions for further research

In the previous section it was demonstrated that feed intake is reduced in young piglets by the addition of a sweetener to the drinking water. Pigs produced for bacon are rationed in their later stages of production in order to prevent them from becoming over fat. Using the concept of a limited volumetric intake it may be possible to increase the water intake of finishing bacon pigs at the expense of feed intake, effectively making the pigs self-rationing. This would have two important consequences:

(1). As feed would be available *ad libitum*, with group aggression would be decreased particularly at feeding times;

(2) As feed would not be rationed, the effects of post-prandial drinking on the water supply network would be reduced.

It may be possible to increase water intake of finishing bacon pigs in several ways. First a sweetener or flavour enhancer could be added to the water supply. The cost of such inclusions may not be economically viable but it would be of scientific value to determine whether stimulated excess water consumption limits feed intake. Secondly during the period in which rationing needs to be imposed, the animals could be kept at higher temperatures. This could be achieved by maintaining high stocking rates and decreasing ventilation. Again the success of this method may depend on the external climate (season) and requires investigating. Thirdly water intake can be increased by manipulating the mineral (for example salt) content of the diet. Obviously this approach necessitates careful investigation as excessive dietary inclusions of salt may result in very serious welfare and production problems. Finally, it has been shown that increasing the fibre in the diet results in increased water intake, in addition to making the diet less energy dense. All the above are possibilities for using the concept of a limited volumetric intake to self ration pigs. However, they need careful evaluation as although the aim is to reduce within group aggression, they have serious welfare implications.

5.2.6 The prediction of water intake of ration fed growing pigs, assuming a limited volumetric intake.

Table 20.4 suggests that the mean volumetric intake for growing pigs is approximately 12%. The water intake for a pig rationed at 100 g/kg $W^{0.75}$ kept under normal thermoneutral and homeostatic conditions is given by $W \times 0.12 - 0.1 \times W^{0.75}$. Therefore the water intake for a 60 kg pig is given by $60 \times 0.12 - 0.1 \times 60^{0.75}$

$= 7.2 - 2.155$

$= 5.05$ litres

The predicted values of water intake for pigs of 20 to 100 kg ration fed at the same level are given in Table 20.5.

5.3 Water use and water wastage.

In the previous section water intake was predicted assuming a limited gut volume, however predicted water intake may differ considerably from actual water use depending on the proportion of waste in supplying the water.

WATER USE = WATER INTAKE + WASTAGE

Table 20.5 The prediction of water intake of ration fed growing pigs, assuming a limited daily volumetric intake of 12%.

Liveweight (kg)	Volumetric limit (kg)	Feed Intake (kg)	Water Intake (litres)
20	2.4	0.945	1.455
30	3.6	1.282	2.318
40	4.8	1.591	3.209
50	6.0	1.880	4.120
60	7.2	2.155	5.045
70	8.4	2.420	5.960
80	9.6	2.675	6.925
90	10.8	2.922	7.878
100	12.0	3.162	8.838

Growing pigs rationed at 100g/kg$W^{0.75}$.

5.3.1 Water supply factors affecting water use.

(i) Drinker type and design.

Gill,(1989) showed that water use was significantly higher (75.6%) from Mono-Flo nose operated drinkers than from Arato 80 bite drinkers. He concluded that as there was no difference in pig performance the difference in water use could be attributed to waste. Similarly Experiment 6 showed voluntary water use to be significantly greater from Mono-flo drinkers than from Arato 80 bite drinkers (35% higher at delivery rate of 900 cm^3/min). However, Experiment 5 comparing four different designs of bite drinker showed there to be no significant difference in water use.

It can be concluded that the type of drinker (ie whether bite type or nose operated) significantly affects water use and wastage however there appears to be no significant difference between different designs of the same type of drinker.

(ii) The prediction of waste from different drinker types

Table 20.6 compares water use by a 60 kg pig from Arato 80 bite drinkers and Mono-flo drinkers measured in Experiment 6, with predicted water intake according to the limited volumetric intake concept and actual water intake interpolated from the data of Experiment 11.

It can be seen that the quantity of water dispensed by both the Arato 80 and the Mono-flo drinkers was higher than and differed considerably from both the predicted water intake and the measured water intake. There was no significant difference in pig performance between the two drinker

Table 20.6 A comparison of predicted water intake and actual water intake with measured water use from two drinker types for pigs of 60kg.

	Feed level (g/kg $W^{0.75}$) 100	110
Predicted water intake (l)		
(from limited volumetric intake concept)	5.05	4.83
	Feed level (g/kg $W^{0.75}$) 100	110
Actual water intake (l) (interpolated from Experiment 11)	4.74	4.83

Feed level: 110 g/kg $W^{0.75}$
Delivery rate: 600 cm^3/min

Drinker type:	Arato 80	Mono-flo
Mean water use (l) (interpolated from Experiment 6)	5.57	6.68

types. From this it can now be concluded that the Mono-flo drinker wastes more water than the Arato 80 bite drinker at a water delivery rate of 600 cm^3/min.

Moreover an estimation can now be made of the waste water from the two drinker types:

Arato 80: 0.74 litres was wasted from a total dispensed of 5.57 litres at a mean delivery rate of 600 cm3/min. This is equivalent to 13 %.

Mono-flo: 1.85 litres was wasted from a total dispensed of 6.68 litres at a mean delivery rate of 600 cm3/min. This is equivalent to 27.7%.

It must be stressed that this is an estimate of water wastage as it is not known whether the pigs actually achieved a water intake of 4.83 litres/day. If the predicted water intake of 4.83 litres/pig/day was not achieved then the proportion of wasted water would be greater.

(iii) Water delivery rate.

In addition to comparing drinker type, Experiment 6 compared the two drinker types at two different delivery rates. The results from Experiment 6 showed that voluntary water use at 900 cm^3/min was significantly greater than at 300 cm^3/min (see below).

Drinker type	Arato	Mono-flo	Arato	Mono-flo
water delivery rate (cm^3/min)	300	300	900	900
Voluntary water use (litres/pig/day)	2.25	2.68	2.97	4.00

Factorial analysis of the data from Experiment 6 showed that both drinker type and water delivery rate were significant factors affecting water use, delivery rate having a more significant effect ($P<0.001$) than drinker type ($P<0.01$).

It can be concluded that delivery rate has a significant affect on water use and water waste.

(iv) The prediction of waste at different delivery rates.

Experiments 6,7, and 8 have investigated aspects of the effects of water delivery rate on the water use of growing pigs and have therefore provided a large amount of data. This data can be compared with:

(a) the water intake predictions from the limited volumetric intake concept (section 5.2 of discussion) and

(b) with actual measured water intake figures from Experiment 11.

This comparison is shown in Table 20.7.

For Experiments 6,7, and 8 there were no significant differences in pig performance between the different treatments. It can be seen that the water use figures for Experiment 6 for both water delivery rates are greater than the predicted water intake and the measured water intake. From this it can be concluded that more water is wasted at the higher delivery rate.

In Experiment 7 more water was used at the higher flow rate than either the predicted water intake or the measured water intake. However less water was used at the lower delivery rate with two drinkers than the predicted intake. This would suggest that the pigs were not achieving the predicted intake according to the limited volumetric intake concept. Water used at the low delivery rate with a single drinker was actually

Table 20.7 A comparison of predicted water intake and actual water intake with measured water use at different delivery rates from different experiments for pigs of 60kg.

		Feed level (g/kg $W^{0.75}$)			
		100	110		
Predicted water intake (litres) (from limited volumetric intake concept)		5.05	4.83		
		Feed level (g/kg $W^{0.75}$)			
		100	110		
Actual water intake (litres) (interpolated from Experiment 11)		4.74	4.83		
Feed level: 110g/kg $W^{0.75}$	Drinker type	Arato	Mono-flo	Arato	Mono-flo
	Delivery rate (cm^3/min)	300	300	900	900
Water use (litres) (interpolated from Experiment 6)		5.19	5.60	5.94	7.75
Feed level: 100g/kg $W^{0.75}$	Drinker number	1	2	1	2
	Delivery rate (cm^3/min)	300	300	900	900
Water use (litres) (interpolated from Experiment 7)		5.24	4.52	6.60	7.92
Feed level: Ad Libitum -	Delivery rate	200	400	700	1100
Water use (litres) (interpolated from Experiment 8)		4.22	5.34	5.22	6.62

Experiments 7 and 8 were undertaken using Arato 80 bite drinkers.

greater than the measured intake of Experiment 11, suggesting that wastage was occurring.

Estimates of water wastage, (as a proportion of total water dispensed)

Delivery rate: (cm3/min)	300	900
Experiment 6:	10.5%	29.3%
Experiment 7:	-3.4%	30.4%

It is interesting to note that although more water was used in Experiment 7 at the higher delivery rate than at the same delivery rate in Experiment 6, when the proportion of waste is estimated from the predicted water intake figures, the figures for both experiments are almost identical. This is because the feed levels are different in the two experiments making the water intakes different. This reinforces the limited volumetric intake concept, that is waste at 900 cm^3/min is constant and where a higher feed level is given to the pigs the water intake is less, the water use is less and the total waste is less.

It can be seen from the results of Experiment 8, that as the water delivery rate increases so does the water use. It is assumed that this increase in water use can be attributed to an increase in waste. It is difficult to draw any further conclusions from this experiment due to the feeding regime. The pigs were fed *ad libitum* in troughs with hoppers. The high FCR values would suggest that the pigs were wasting a high proportion of feed and accurate feed intake figures are not available. Without feed intake figures, water intake cannot be predicted accurately from the limited volumetric intake concept and therefore an accurate prediction of waste cannot be made. (Feed intake figures suggest a level of feed of 150 g/kg $W^{0.75}$).

5.3.2 The affect of pig behaviour on water use

In order to loose heat by evaporation pigs wallow. This behaviour can often be observed in hot weather in intensive pig units when pigs prefer to lie in dunging passages. To facilitate this behaviour pigs have been seen to hold open water drinkers allowing water to fall onto the floor, thus providing a wallow. Vajrabukka et al., (1987) showed that the water use of pigs kept in an environment of 30 °C was reduced from 6.7 to 4.0 litres/pig/day by spraying the pigs with water. However it is unknown whether this reduction in water use is due to increased insensible heat loss from the water spray causing a decreased water requirement for upper respiratory tract loss, or a decreased drinking water use for wallow simulation.

The loss of water due to insensible heat loss obviously forms a variable part of the waste drinking water of the water consumed on pig units. This is a deliberate waste of water supplied for drinking rather than the incidental waste from poorly designed or installed drinkers. This fraction of the water use of pigs may still be a necessary requirement of the pigs and if cooling cannot be attained in another manner then, depriving pigs of this water may be detrimental to their welfare.

WATER USE = WATER INTAKE + WASTAGE + BEHAVIORAL REQUIREMENT

It may be argued whether or not 'behavioral requirement' is the correct term for this need of the pigs as wallowing behaviour is actually behaviour which satisfies a physiological requirement- the regulation of body temperature.

Intensively-housed pigs exhibit a wide range of stereotyped and other unusual behaviours such as bar biting, chain pulling and drinker manipulation (Fraser, 1975). A stereotypic behaviour is an invariant sequence of motor acts repeated frequently and without any apparent purpose (Kiley-Worthington, 1977; Keiper 1969). Stereotyped behaviours are most apparent in confined sows kept in stalls or tethers (Jensen 1980; Vestergaard, 1981). Stereotypic drinker manipulation results in the waste of water. In addition to drinker manipulation, polydipsia has been evident in tethered sows, a result of adjunctive drinking (Rushen, 1984). Rushen, (1984) suggests that the occurrence of adjunctive drinking results from the persistence of feeding motivation, probably due to concentrated feeds failing to provide sufficient stomach distension to reinforce the motivation. This implies that gut fill is not satisfied by the feed alone. Appleby and Lawrance, (1987) investigating the cause of stereotypic behaviour in tethered gilts suggest that stereotypies are hunger induced and are worse below a threshold level of 2 kg/pig/day.

5.4 The prediction of water use for growing finishing herds

In order to supply adequate drinking water to pig housing it is important to be able predict the water use of the pigs on that unit.

In this section a model has been produced to predict the water demand of growing/finishing pigs (20-80 kg) from a 100 sow breeding unit.

Assumptions:
2.25 litters per sow per year
21.4 pigs reared per sow
4.3 farrowings per week
daily gain of growing/finishing herd 0.6 kg
F.C.R. 2.69

(1) Calculate the average number of animals in the feeding herd at any one time:

pigs produced per year = 21.4 X 100 = 2140

pigs weaned/sold per week = 2140/52.25 = 40.76

pigs weaned/sold per day = 40.76/7 = 5.82

time from 20 kg to 80 kg = 60/0.6 = 100 days

number of pigs at any one time = 100 X 5.82 = 582

(2) Calculate daily feed intake:

mean feed intake = F.C.R. X daily gain

= 2.69 X 0.6 = 1.61 kg

(3) Calculate mean live weight of the pigs:

initial weight = 20 kg

slaughter weight = 80 kg

mean weight = $\frac{20 + 80}{2}$ = 50 kg

(4) Calculate daily volumetric limit to intake (12 % of live weight):

50 kg X 12 % = 6 kg

(5) Calculate water intake:

mean daily water intake = volumetric limit - feed intake

= 6 - 1.61 = 4.39 kg (litres) of water per pig

(6) Calculate total herd daily water intake:

582 X 4.39 = 2555 litres per day

According to the limited volumetric intake concept the minimum amount of water needed to be supplied to the pig unit under thermoneutral and mineral homeostatic conditions is 2555 litres per day. This figure is the minimum water intake and does not account for factors increasing water requirement beyond that required for gut fill (such as variations from the norm in diet specification), nor does it allow for any wastage which may occur during the supply of water to the pigs.

The factors influencing intake and water use were reviewed in Chapter 4 and can be broadly divided in to two categories:

1 Factors of a physiological origin, which include:

(a) feed intake

(b) body weight

(c) diet specification

(d) environmental temperature

(e) physiological status

2 Factors of supply origin, which include:

(a) drinker type

(b) water delivery rate

The factors of physiological origin alter the requirement for water and therefore the water intake irrespective of water wastage. The factors of supply origin influence the amount of wastage and may compromise the pigs water intake through malfunction or poor installation.

5.4.1 The affects of factors influencing water requirement on total water intake of the grower herd

(1) Feed intake:

If in the above model, the feed intake increased (mean live weight remaining constant), then water intake for the whole herd would decrease. Conversely, if feed intake were to decrease then water intake would increase.

feed intake = 2.0 kg/pig
water intake per pig = volumetric limit - feed intake
= 6.0 - 2.0 = 4.0 kg (litres)
herd intake = 4 X 582 = 2328 litres/day

feed intake = 1.4 kg/pig
water intake per pig = volumetric limit - feed intake
= 6.0 - 1.4 = 4.6 kg (litres)
herd intake = 4.6 X 582 = 2677 litres/day

(2) Body live weight:

If mean live weight increased (feed intake remaining constant), then water intake would increase. Conversely, if live weight decreased then water intake would also decrease.

mean live weight = 55 kg
water intake per pig = volumetric intake - feed intake
= (0.12 X 55) - 1.61
= 4.99 litres
herd intake = 4.99 X 582 = 2904 litres/day

mean live weight = 45 kg
water intake per pig = volumetric intake - feed intake
= (0.12 X 45) - 1.61
= 3.79 litres
herd intake = 7.79 X 582 = 2206 litres/day

If live weight were to increase along with a corresponding increase in feed intake, for example when pigs grow, then water intake would increase but not to the same extent as if live weight had increased alone.

live weight = 55 kg (10 % increase)
feed intake = 1.77 kg (10 % increase)
water intake = volumetric limit - feed intake
= (0.12 X 55) - 1.77
= 4.83 litres
herd intake = 4.83 X 582 = 2811 litres/day (10%)

(3) Mineral content of diet:

(a) Sodium:

There has been very little work undertaken on the effects of different levels of dietary salt on the water intake of pigs. Hagsten et al.,(1976) showed that increasing the salt inclusion of a diet for growing pigs (17 to 35 kg) from 0.06 % to 0.2 % (an increase of 233 %), caused an increase in water intake from 4.2 to 5.1 litres/pig/day, (an increase of 21 %). Additions above 0.2 % inclusion only resulted in small increases. This may have been due to a decrease in feed intake at 0.27 % resulting in the salt intake remaining the same. The range of salt inclusion studied by Hagsten et al., is lower than normally found in commercial formulations (0.3 to 0.6 %), and therefore the effects of increasing salt inclusion cannot be applied to the model.

(b) Potassium:

Gill (1989), found that an increase in the potassium content of a grower diet from 8 to 17 g/kg (an increase of 112.5 %), resulted in an increase in water use from 4.07 to 5.04 litres/pig/day (an increase of 24 %). Therefore an increase in dietary potassium of 1 g/kg results in an increase in water intake of 2.67 %.

potassium content of diet increased from 8 to 12 g/kg.
this will increase water intake 4 X 2.67 = 10.7 %.
increase in water intake = 2555 X 0.107 = 273 litres per day
herd intake = 2555 + 273 = 2828 litres per day

(4) Environmental temperature.

Gill, (1989) suggests that variations in ambient temperature are unlikely to have any significant effects on water demand of pigs. Experiment 7 studied the effects of one or two drinkers at two delivery rates in a range of temperature varying from 15.1 to 19.7°C. Table 11.4 shows the regression of water use against live weight and ambient temperature for the for treatments. The equation for two drinkers operating at 300 cm^3/min is: $Y = -1.88 + 0.044\ X1 - 0.123\ X2 - 0.00053\ X2^2$ $P = 0.006$ $R^2 = 90.2$

Y = water use (litres/pig/day)
X1 = temperature (°C)
X2 = live weight (kg)

Using the above equation, for a pig of 50 kg live weight a 1°C increase in temperature results in an increase in water intake of 0.044 litres/day. This information can now be applied to the model

assume normal temperature of 15°C increases to 20°C
water intake of each pig will increase by 5 X 0.044 = 0.22 litres/pig/day
increase to herd intake = 582 X 0.22 = 128 litres/day
herd intake = 2683 litres/day

Gill, (1989) and Brooks et al., (1990) in their models describing the obligatory losses and gains of a 60 kg pig assume that the factors creating a demand for water (the losses) are additive. In a similar way the factors of physiological origin described above are also additive. After the normal water intake has been calculated from feed intake and volumetric limit then any extra demand for water must be added on to the calculated normal water intake.

For example:

normal herd intake = 2555 litres/day

increase in water intake caused by an increase in potassium inclusion from 8 to 12 g/kg = 273 litres/day

increase in water intake caused by a 5°C increase in environmental temperature = 128 litres/day

$$\begin{aligned}\text{total herd requirement} &= 2555\\ &+ 273\\ &+ 128\\ \hline &\ \ 2956 \text{ litres per day}\end{aligned}$$

Any factor or combination of factors which create an additional requirement above that which the volumetric limit allows for will result in a decreased feed intake dependent on the magnitude of the additional water requirement.

5.4.2 The affects of factors influencing water wastage on total water use of the grower herd

The two main factors influencing water wastage identified by this research programme are water delivery rate and drinker type. Experiment 6 investigated the effects of two delivery rates and two designs of drinker on the water use of growing pigs. In Table 20.7 interpolated values from regression equations produced from Experiment 6 are compared

Table 20.8 The effects of drinker type and water delivery rate on water wastage

Drinker Type	Delivery rate cm^3/min	Estimated wastage %
Mono-flo	300	13.75
Arato 80	300	7.40
Mono-flo	900	37.6
Arato 80	900	18.6
Arato	Combined 300 + 900	13.2
Mono-flo	Combined 300 + 900	27.6
Combined Mono-flo + Arato	300	10.4
Combined Mono-flo + Arato	900	29.4

(Information calculated from Table 20.7) with predicted water intake values (from limited volumetric intake) in order to assess water wastage. Table 20.8 shows the estimated wastage from the two drinker types and two delivery rates.

The data in Table 20.8 shows that the lowest proportion of waste occurs when water is supplied from the Arato 80 drinker operating at 300 cm^3/min. This data can now be included into the model:

Normal water intake of herd = 2555 litres/day
Using Arato 80 at 300 cm^3/min wastage = 2555 X .074 = 188 litres/day
Total water use = water intake + wastage = 2555 + 188 = 2743 litres/day

According to Table 20.8 the greatest proportion of waste occurs when water is supplied via Mono-flo drinkers operating at 900 cm^3/min.

Normal water intake of herd = 2555 litres/day
Using Mono-flo at 900 cm^3/min wastage = 2555 X 0.376 = 961 litres/day
Total water use = water intake + wastage = 2555 + 961 = 3516 litres/day

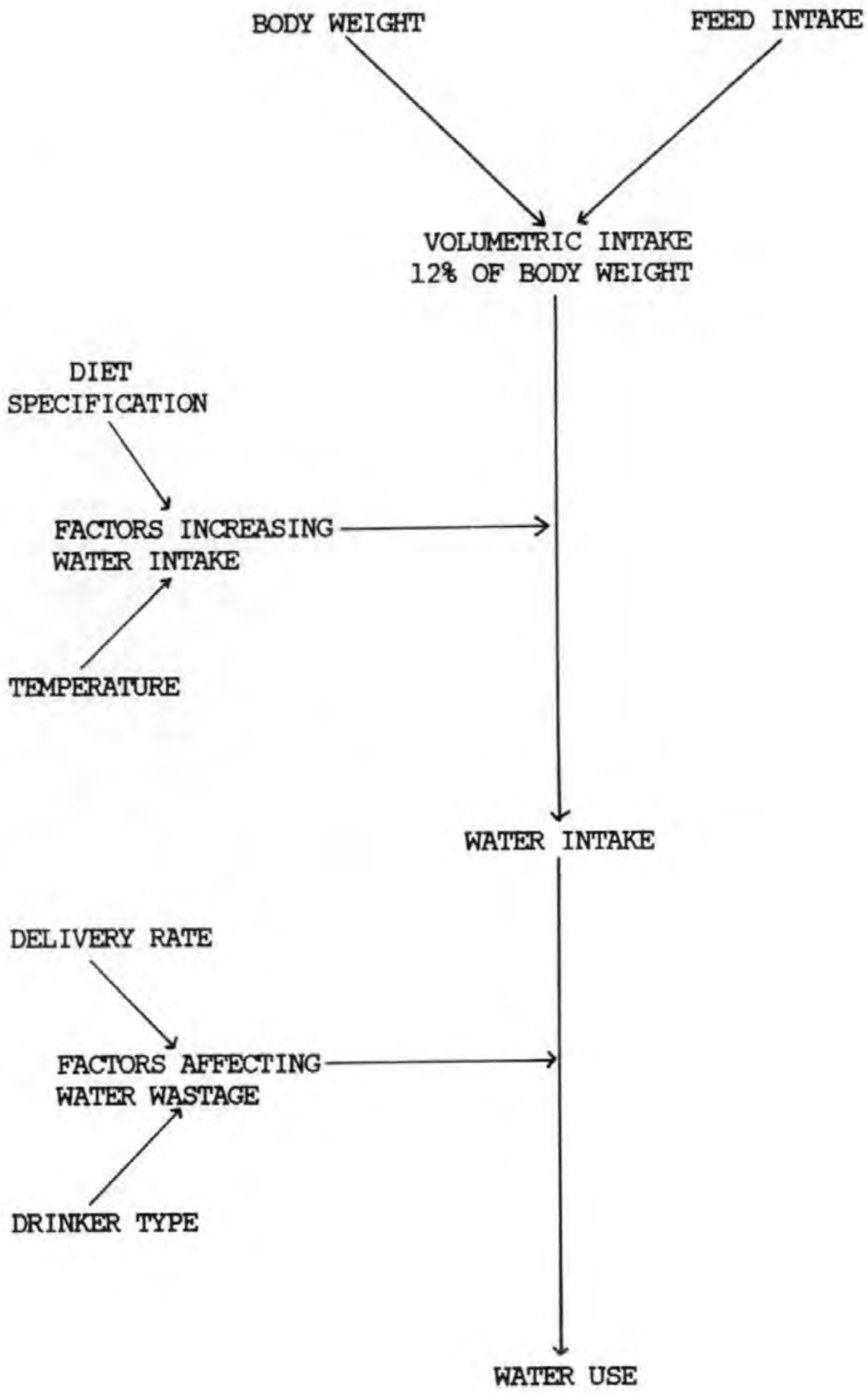
When the values from the two drinker types are combined at each delivery rate it can be seen that a 3 fold increase in delivery rate increases water wastage by 2.83 times (10.4 to 29.4 %). Therefore for every 300 cm^3/min increase in delivery rate, wastage increases by approximately 10 %. This suggests that between the delivery rates of 300 and 900 cm^3/min wastage is approximately linear.

When results from the two delivery rates are combined for each drinker type it can be seen that a change in drinker type from Arato to Mono-flo results in wastage increasing by a factor of 2.09 (13.2 to 27.6 %).

The data in Table 20.8 would suggest that the effects of the interaction between delivery rate and drinker type on total water use is not additive.

Increasing delivery rate from 300 to 900 cm^3/min causes a 2.83 fold increase in wastage and changing drinkers results in a 2.09 fold increase in wastage. Comparing the Arato 80 at 300 cm^3/min and the Mono-flo at 900 cm^3/min wastage increases from 7.4 to 37.6 %, an increase of 5.08 fold.

Figure 20.2 A model describing the water use of growing pigs.



Calculating the interactive affect of delivery rate and drinker type, 2.83 X 2.09 = 5.91, suggests that the two factors are multiplicative.

It is concluded that the factors altering water requirement are additive where as those influencing water wastage are multiplicative. The effect of the combination of factors from each category is multiplicative when total water use of a unit is estimated. Figure 20.2 summarises the model for estimating water use of growing/finishing pig herds.

5.5 Drinking time

5.5.1 The apparent time spent drinking.

In experiments where water use and delivery rate are known, it is possible to calculate the apparent time spent drinking. It is termed apparent because it relates to the total time the drinker valve would have been fully open. It makes no allowances for either the drinker only being partially open or the occasions where the drinker has been accidentally operated without drinking. The apparent times spent drinking for growing pigs, gestating sows and weaned piglets has been calculated for Experiments 6,7,8,9 and 10 and summarised in Table 20.9.

For all of the experiments there is a significant difference in the amount of time the pigs spend drinking according to water delivery rate. The lower the delivery rate the greater the amount of time the pigs must spend drinking. For Experiments 6,7 and 8 concerning growing pigs, there were no significant differences in pig performance. Therefore it is concluded that growing pigs are prepared to spend more time drinking

Table 20.9 A summary of the time spent drinking at different water delivery rates for growing pigs, gestating sows and early weaned piglets

Growing pigs

Experiment 6:

Drinker type	Arato	Mono-flo	Arato	Mono-flo	
Delivery rate (cm^3/min)	300	300	900	900	P
Time spent drinking (s/day)	451^a	536^b	198^c	267^c	0.001

Experiment7:

Drinker Number	1	2	1	2	
Delivery rate (cm^3/min)	300	300	900	900	P
Time spent drinking (s/day)	400^a	340^b	240^c	266^c	0.01

Experiment 8:

Delivery rate (cm^3/min)	200	400	700	1100	P
Time spent drinking (s/day)	927^a	512^b	338^{bc}	256^c	0.01

Early weaned piglets

Experiment 9:

Delivery rate (cm^3/min)	175	350	450	700	P
Time spent drinking (s/day)	268^a	176^b	175^b	139^b	0.001

Gestating sows

Experiment 10:

Delivery rate (cm^3/min)	565	925	1325	2650	P
Time spent drinking (s/day)	1048^a	664^b	487^c	228^d	0.001

A,b,c,d means bearing the same superscript are not significantly different.

to achieve their required intake when the attainment of water is made more difficult by decreasing the water delivery rate. Also it appears that gestating sows are prepared to spend more time drinking to achieve their required intake, however in Experiment 10 no parameters of performance were investigated and the possibility of an effect on reproductive performance can not be ignored. Having established that point, the water use of the gestating sows between the delivery rates of 565-2650 cm^3/min, only varied between 9.86 and 12.28 litres/sow per day. In a preliminary experiment to Experiment 10, it was observed that a delivery rate of 300 cm^3/min resulted in a significant increase in aggression at the drinkers such that this treatment had to be halted.

In contrast to the situation described with growing pigs, Experiment 9 showed that piglet performance decreased significantly as the attainment of water was made more difficult by decreasing the water delivery rate. It appeared that the piglets were not prepared to increase their time spent drinking enough in order to achieve their required intake, (an intake giving maximum growth). The piglets did adapt to a certain extent to the lower delivery rates, however this adaptation was not great enough to prevent a decrease in performance. A similar result has been reported by Nienaber et al.,(1984). They reported that the young pig is adaptable to restrictions in its water supply but there are limits to those adaptations.

Under the conditions studied in Experiments 6,7,8 and 9, the growing pig appears to be more adaptable than the weaned piglet. There is a difference between growing pigs and weaned piglets in their preparedness to spend more time drinking in order to achieve their respective water intakes under less favourable conditions. It is unknown why this difference occurs and at what age/weight the pigs become more adaptable.

It may be that the homeostatic mechanism controlling water balance in the younger piglet is not fully developed and only sufficient water is imbibed initially to maintain survival. It is possible that this ability to adapt to lower delivery rates is affected by the behaviour of the piglets. The reinforcement achieved by drinking may be less than that from other behaviours such as eating, sleeping or being part of a social group (litter).

5.5.2 Social facilitation and its effects on water demand

Hsia and Woodgush,(1984), demonstrated that the pig is a highly social animal and social facilitation plays a large part in the feeding behaviour of growing pigs. In a study of social facilitation and drinking behaviour in ducks Clayton (1976), defined social facilitation as an increase in the frequency or intensity of response when in the presence of others engaged in the same behaviour. Social facilitation has been reported in the suckling piglet, (Petherick, J.C.,1983, Pond et al.,1978) who have described the suckling behaviour of piglets as synchronous. It has also been reported in the feeding behaviour of early weaned pigs, (Csermely et al.,1981).

It could be that social facilitation occurs in the drinking and resting behaviour of early weaned pigs. That is, that the piglets are motivated to drink when their pen mates are engaged in drinking activity. Synchronous resting and suckling behaviour was reported by Barber (1986), in a study of suckling piglet behaviour. This behaviour may be important to the extent that drinking behaviour may only be undertaken by early weaned piglets in periods designated by the piglet group as drinking periods. Such a phenomenon affecting drinking behaviour would be more accurately described as negative social facilitation. That is although there may be a homeostatic requirement for an individual piglet to drink, this may not be satisfied because the piglet group do not share that same momentary requirement. In an experiment investigating the drinking behaviour of early weaned pigs given a sweetener in the water, (Appendix 1), it was observed that individual piglets rarely drank outside the recognised drinking periods. It is likely that where litters are not mixed at weaning, the effects of social facilitation are stronger.

If the above theory is correct, then the piglets leading the weaned group, the dominant ones, would not suffer as a result of the effects of social facilitation. Hsia et *al*.,(1984) showed that dominant pigs benefited more from social facilitation in the feeding behaviour of growing pigs than the less dominant ones. If this also applied to drinking behaviour, the submissive piglets who were unable to achieve their required water intake during the drinking periods would show a reduced performance. The reason for being unable to achieve their water requirement would be due to competition at the drinkers within the drinking periods on the assumption that there is a time-window in which the group must drink and out of which there is little drinking activity. A reduction of delivery rates would increase the drinking time required for the dominant pigs to achieve their requirement. This in turn would decrease the time available to the submissive piglets to achieve their requirement and exacerbate the problem of competition at the drinkers.

In conclusion, there is some evidence to suggest that the reduced ability of early weaned piglets to adapt to reduced water delivery rates is due to the effects of social facilitation. If delivery rates are reduced in order to reduce wastage, the detrimental effects on those pigs failing to achieve their required water intakes could be ameliorated by increasing the number of drinkers in the pen. This would provide the submissive piglets with the opportunity to drink within the prescribed drinking periods. In order to replicate the feeding pattern of the pre-weaning period, one drinker would need to be made available to each piglet in the early stages of weaning. This would simulate the udder and allow synchronous drinking. However unless such a luxury provision is to be available throughout the pig's life, it will still be necessary for the pig to cease operating as a member of a group and function as an independent individual at some stage. The important question that needs to be resolved is whether the transition from functioning as the member of a group, to functioning as an individual is an is an instinctive, time dependent change, or whether it is a learnt behaviour derived from experience. Resolution of this question would enable recommendation to be made regarding the age/time post weaning at which the ratio of drinkers to pigs could safely be reduced.

5.5.3 Water supply and total pen time available for drinking.

Experiments 6,7 and 8 were conducted using groups of eight pigs in pens supplied with only one drinker. Commercially, pigs are kept in larger groups of 15-25 pigs. The Codes of Recommendations of Welfare: Pigs (1990) suggest a minimum of one drinker per 10 pigs and a minimum of two drinkers per pen in the event that one of them should malfunction. For a given water delivery rate and a fixed number of drinkers there is a maximum amount of water that can be dispensed within a twenty four hour period. Obviously it is hoped that this maximum amount of water is greater than the total pen water requirement.

For example, the data from Experiment 6 produced the following regression equation for the Mono-flo drinker operating at 300 cm3/min:-

Water use (litres/pig/day) = 1.55 + 0.0675 live weight (kg)

For a 90 kg pig this gives a water use of 7.625 litres/day. At 300 cm^3/min it would take the pig 25.4 minutes to consume. It would appear that within a pen of eight pigs supplied by one drinker the supply would be sufficient. The drinker would have to be operating for 8 X 25.4 minutes. Similarly in the commercial environment two drinkers could supply sixteen pigs operating for the same length of time.

The supply systems as described above can only be considered adequate if the pigs can achieve their required intakes at the times when they express a desire to drink. Experiment 12A showed that ration fed growing pigs fed twice per day consume 60 % of their water requirements in the two, two hour periods following the feeds. Continuing the above example:

16 pigs require to drink 60 % of their requirement in 4 hours

(7.625 X 0.6) X 16 = 73.2 litres

From one drinker operating at 300 cm^3/min this would take:

$\frac{73.2}{2}$ = 244 minutes = four hours and four minutes.

Therefore in theory one drinker operating act 300 cm^3/min could supply enough water for a group of 16 ninety kg pigs. However, in practice this would not be possible as the calculation has not accounted for the time taken for different pigs to approach and withdraw from the drinker.

The water supply to a building can only be regarded as adequate if it can supply the pigs' water needs within the peak demand periods. Hsia et *al*.,(1984) showed the effects of social facilitation on the feeding behaviour of growing pigs. It was suggested in the last section that this may be responsible for weaned piglets not achieving optimum water intake. Although it has not been investigated nor detected in this study, there may be an effect of social facilitation on the drinking behaviour of other classes of pigs besides early weaned piglets. Therefore the supply of water to pig housing during the peak demand periods is important.

5.6 The effects of peak demand periods on the supply of water to pig housing.

Experiments 12 and 12A showed that both ration fed lactating sows and ration fed growing pigs express certain peak demand periods in their use of drinking water. Experiment 12 showed that 50% of the water use of lactating sows occurs in six hours of the day, immediately after meal times. Similarly Experiment 12 A showed that growing pigs use 67% of their total water use in six hours of the day, again immediately after meal times. Both experiments indicated that only a small proportion of water was used during the night period.

These peak demand periods have serious implications for the design of drinking water supplies to pig housing and on the rural supply network to areas containing large numbers of pigs. Pigs fed ad *Libitum* do not express peak demands in their water requirement to the same extent as ration-fed pigs, however peaks in demand have been identified, (Gill, 1990).

Water is commonly supplied to pig housing through pipes of relatively small internal diameter. These small bore pipes are expected to supply water to buildings of considerable length containing large numbers of individual pens. Often the diameter of the pipes is restricted further by the build up of foreign matter within the pipes. Water pressures are restricted in the United Kingdom owing to the Water Authorities' insistence that :

1. farm supply systems are a Class I risk of contamination to their main lines by the potential through back-siphonage and so
2. every farm building with a supply shall be provided with a 'header (break) tank' to prevent back-siphonage. The provision of such an air break effectively restricts the pressure head available to the height of the header tank.

It is suspected that some of the existing drinking water supply systems to pig houses may be unable to supply enough water at the required delivery rates during the periods of peak demand.

In order to investigate the effects of the peak demands in water use on existing supply systems it is necessary to consider the mechanics of how water flows through closed pipes.

5.7 The flow of water through closed pipes

5.7.1 Water flow

When water is flowing along a passage such as a pipe, it will be subject to a resistance due to friction. If the velocity of flow is very small, the fluid will flow in layers parallel to the sides of the pipe. This type of flow is called laminar flow. If the velocity is large, cross currents called eddies are generated causing greater resistance to the flow. This type of flow is called turbulent flow.

In laminar flow the frictional resistance (loss of energy) is due to viscous drag between the different layers of water within the pipe because they are moving at different speeds. In contrast, most of the energy lost in turbulent flow is due to the generated eddies. In laminar flow, the layer of water in contact with the pipe is at rest. The other layers move with increasing velocities as the distance from the boundary layer of the pipe increases. Therefore there is a velocity gradient across the section of flow, the highest velocity being at the centre of the pipe. In turbulent flow, the creation of eddies means that the velocity of flow is more uniform over the cross section of the pipe.

It can be found by experiment, that the change from laminar to turbulent flow depends on the Reynolds number and occurs at a critical velocity. In round pipes when the Reynolds number (Re) is less than 2000, the flow is laminar and when it is greater than 2500 it is turbulent. Between Re=2000 and Re=2500, the nature of the flow is unstable. The critical velocity depends on the viscosity of the liquid, its density and on the diameter of the pipe.

$$Re = \frac{Vd}{v}$$

Where V = mean velocity (ms^{-1})
d = diameter (m)
v = kinematic viscosity (m^2s^{-1})
Re = Reynolds number, a dimensionless constant

The kinematic viscosity = $\frac{\text{viscosity}}{\text{density}}$

The kinematic viscosity of water = 1.14 $\times 10^{-6}$

With liquids of low viscosity such as water, the critical velocity is relatively low and therefore, for most of the instances considered in this project, the flow is turbulent.

5.7.2 Frictional resistance in pipes

(i) Head loss due to friction

The head loss due to friction in a pipe is given by Darcy's formula:

$$h_f = \frac{4flV^2}{2gd}$$

Where h_f = the head loss due to friction (m)
l = the length of pipe (m)
V = the average velocity of water in the pipe (ms^{-1})
d = the diameter of the pipe (m)
g = the acceleration due to gravity (ms^{-2})
f = the dimensionless friction coefficient.

From Darcy's formula it can be seen that the total frictional resistance to fluid flow (head loss) is directly proportional to the friction coefficient, the length of the pipe and the square of the mean velocity. and is inversely proportional to the diameter. Therefore the smaller the diameter the greater the head loss. Mean velocity can be calculated by dividing the volume flow rate by the area of the pipe.

Thus $$\frac{V}{A} = Q$$

where Q = volume flow rate (m^3s^{-1})
V = mean velocity (ms^{-1})
A = cross sectional area of the pipe (m^2)

As the area of the pipe = r^2, the mean velocity is directly proportional to the volume flow rate and inversely proportional to the square of the radius. Hence the smaller the pipe diameter, the smaller the radius and the greater the mean velocity. Head loss is directly proportional to the mean velocity, however mean velocity is directly proportional to the diameter.

Therefore the diameter of pipes involved in water supply have a significant effect on total head loss as Darcy's formula shows that head loss is inversely proportional to the diameter and directly proportional to the mean velocity, which is also inversely proportional to the diameter.

The Darcy formula may be used for both laminar and turbulent flow. It is important to note that the total head loss due to friction is inversely proportional to the water pressure.

(ii) The friction coefficient

The friction coefficient increases with the roughness of the interior surface of the pipe. For example, a galvanised iron pipe will have a lower friction coefficient than a smooth plastic pipe. As head loss is directly proportional to the friction coefficient, the rougher the surface of the pipe, the greater the friction and the greater the head loss. As the pipe ages and corrodes, the friction coefficient increases.

The friction coefficient is related to the Reynolds number and the relative roughness of the pipe. For turbulent flow $f = \frac{0.079}{(Re)^{0.25}}$

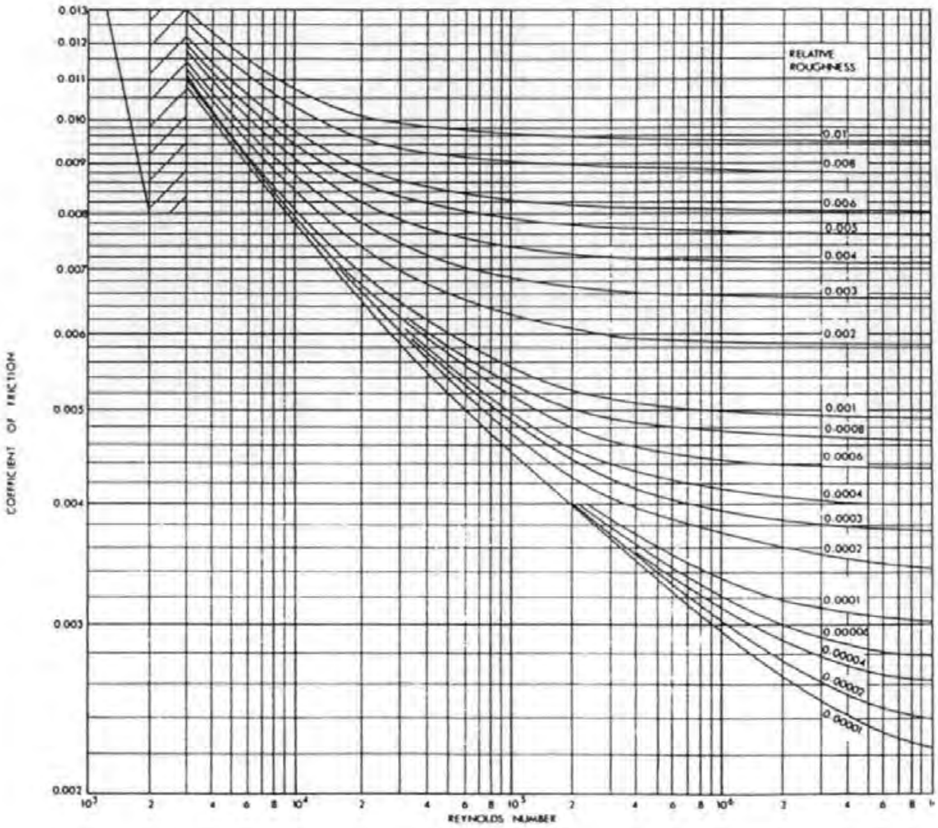
Table 20.10 Values of absolute roughness for pipes and ducts.

Material	k/mm
Non- ferrous drawn piping	0.0015
Plastic piping	0.003
Asbestos cement piping	0.013
Black steel pipng (new)	0.046
Black steel piping (rusted)	2.5

(CIBSE, 1986)

Figure 20.3 The relationship between relative roughness, friction factor and Reynolds number

(CIBSE, 1986)



Pipe roughness can be described in terms of k/D, the relative roughness, where k = the effective mean height in mm of the excrescences on the inside of a pipe of internal diameter D, (Waterhouse, 1982). Table 20.10 shows values of k for pipes made from different materials and of different ages.

As f, the friction factor, is a function of the Reynolds number and of the relative roughness, it may be represented diagrammatically. This was first done by Lewis Moody (1880-1953) and is the best means available for predicting values of f. Moody's diagram is shown Figure 20.3.
When planning water supplies for pig housing, it is necessary to determine the head loss due to friction. Volume flow rate and pipe diameter will be known, from which mean velocity can be calculated.
From this data the Reynolds number may be calculated and a value for f can be taken from Moody's table (Figure 20.3). Massey, (1983) states that Darcy's formula together with Moody's chart provide the best data at present on pipe friction in turbulent flow.

Example

Below is an example of how to calculate the head loss due to friction when planning a water supply for a pig house.

Determine the head loss due to friction in a 10 m long copper pipe of internal diameter 13.6 mm carry water flowing at 10 litres per minute.

[1] Calculate the mean velocity:

$$V = \frac{Q}{A}$$

$Q = 10$ litres/min

$= 0.01\ m^3/min$

$= 167\ X10^{-4}\ m^3\ s^{-1}$

Area $= r^2$

$= (0.0068)^2$

$= 1.45\ X10^{-4}\ m^2$

$$V = \frac{1.67\ X10^{-4}}{1.45\ X10^{-4}}$$

$= 1.15\ ms^{-1}$

[2] Calculate Reynold's number:

$$Re = \frac{Vd}{v}$$

$$= \frac{1.15\ X\ 0.0136}{1.14\ X\ 10^{-4}}$$

$Re = 1.4\ X\ 10^{-4}$

[3] Calculate the relative roughness k/D for plastic piping using Table 20.9:

$$k/D = \frac{0.003}{13.6}$$

$= 2.22\ X\ 10^{-4}$

[4] Look up on Moody's Table to find a value for the frictional factor f at a Reynolds number of $1.4\ X\ 10^{-4}$ and k/D of $2.2\ X\ 10^{-4}$:

$f = 0.007$

[5] Use Darcy's equation to calculate head loss:

$$hf = \frac{4flV^2}{2gd}$$

$$hf = \frac{4\ X\ 0.007\ X\ 10\ X\ 1.15\ X\ 1.15}{2\ X\ 9.84\ X\ 0.0136}$$

$$= \frac{0.370}{0.267}$$

$hf = 1.385$ m

The head loss in the pipe is therefore 1.39 m

5.7.3 Head loss in pig unit supplies

The example described above is not unlike that which would occur in a water supply system for pigs. In fact the relative roughness is likely to be greater in older pig water supply systems, as the degree of corrosion is higher. Also the accumulation of foreign material in the pipe will gradually reduce the effective pipe internal diameter and therefore make the head loss greater.

It can be appreciated now that a considerable amount of head is lost in a 10 m length of pipe. Available head in most pig units is limited by the height of the water in the header tank, which in turn depends on the height of the building. It is rare to find the available height in a pig building to be greater than 3 m. Therefore a head loss of 1.39 m is a high proportion of the available head (almost half). A 20 m length of pipe operating under the same conditions would result in a head loss of 2.78 m which is virtually all the available head.

The head loss due to friction in pipes has been considered mathematically, indicating the extent of the problem of supplying sufficient water at the necessary delivery rates to housed pigs. It is clear that many existing water delivery systems are unable to supply the correct amounts of water during periods of peak demand.

Having implied that many modern day pig unit water supplies are poorly designed for the purpose for which they are intended, it is interesting to note that from very early times man has been aware of friction in pipes (Merriman 1916). Pliny states that in the early clay pipes, a slope of at least 1/4 inch in a hundred feet was necessary to ensure the free flow of water (Merriman 1916).

5.7.4 Other resistances to water flow in pipes

When water is made to flow through a system of pipes, in addition to head loss due to friction, energy is lost due to certain other factors. These include sudden enlargements or contractions of the pipe, sudden changes of direction, as at bends, and by constrictions such as valves and water drinkers, which interfere with the free flow of water (Lea 1924). In order to determine the total loss of head in a delivery system, all the losses identified above are added together (Lewitt, 1970).

The total head of a liquid at any instant is the sum of its datum head, its velocity head and its pressure.

$$\text{Total head} = z + \frac{P}{\rho g} + \frac{V^2}{2g}$$

where z = datum head (m)

$\frac{P}{\rho g}$ = pressure head of water (m)

$\frac{V^2}{2g}$ = velocity head (m)

Bernoulli's theorem states that in any system, provided no frictional head losses are encountered, the total head remains constant.

$$z + \frac{P}{\rho g} + \frac{V^2}{2g} = \text{constant}$$

In the normal situation where frictional head losses do occur,

$$\text{Total head } H \text{ (m)} = z + \frac{P}{\rho g} + \frac{V^2}{2g} - hf$$

Losses of head due to bends and constrictions are expressed as a fraction of the velocity head.

$$h = k \frac{v^2}{2g}$$

where k is a constant dependent on the nature of the bend or constriction. For example the value of k for a right angle bend is 0.9. Therefore the pressure loss due to the bend is equal to:

$$h = 0.9 \frac{v^2}{2g}$$

Different values of k are given in Table 20.11.

Bernoulli's equation can be applied to any water supply system. For example, if the head of water in the header tank is known, the frictional losses can be calculated and therefore the head of water available to the pigs at the drinker can be calculated. Similarly the height of water required in a header tank could be calculated for a required pressure at the drinker.

5.75 Rationalising the supply to housed pigs

Water is commonly supplied to pigs through small diameter pipes which service long rows of up to twenty pens. If the drinkers in all of the pens are operating simultaneously (for example in a post prandial period), then available head in the pens furthest from the supply source would be considerably less than those pens closet to the source. This may result in some pigs wasting large amounts of water (pens closest to the source) and some being deprived resulting in a reduction in pig performance., (pens furthest from source). In this case, the total water supplied to the row of pens may be in agreement with predictions made

Table 20.11 Values of k for friction losses at elbows, bends, tees and junctions, (CIBSE, 1986).

ELBOWS AND BENDS

TYPE	10-25 mm	32-50 mm	65-90 mm	≥100mm
MALLEABLE CAST IRON 90° ELBOW	0.8	0.7	0.6	0.6
MALLEABLE CAST IRON 45° ELBOW	0.6	0.6	0.5	0.5
MALLEABLE CAST IRON BEND	0.7	0.5	0.4	0.4
SCREWED MILD STEEL BEND	0.7	0.5	0.4	0.3
MALLEABLE CAST IRON RETURN BEND	0.9	0.8	0.8	—

TYPE	10-25mm	32-50 mm	65-90mm	≥100mm
FLANGED CAST IRON BEND	0.5	0.5	0.5	0.5
WELDED MILD STEEL ELBOW	0.4	0.4	0.3	0.3
WELDED MILD STEEL BEND	0.4	0.3	0.3	0.2
COPPER PIPE ELBOW	1.0	0.8	0.5	—
PANEL RETURN BEND	0.6	—	—	—

TEES AND JUNCTIONS

(Based on velocity pressure of combined flow. Factors refer to the branch indicated by the subscript, e.g. ζ_2 is for flow to or from branch 2.)

DIVERGING / CONVERGING	ζ_2	ζ_3	DIVERGING / CONVERGING	ζ_2	TONGUE TEE
A_1, A_2, A_3	0.5 + (factor for bend or elbow as appropriate) + (factor for enlargement or reduction where bores differ)	0.2 + (factor for enlargement or reduction where bores differ)	A_1, A_2, A_2	0.5 + (factor for bend or elbow as appropriate) + (factor for enlargement or reduction where bores differ)	$\zeta_2 = 4.5$ $(d < 20mm)$ $\zeta_2 = 3.0$ $(d \geq 20mm)$ $\zeta_3 = 3.0$

REDUCTIONS

(Based on velocity pressure in smaller pipe.)

A_2/A_1	ζ	A_2/A_1	ζ
0.1	0.55	0.4	0.40
0.2	0.50	0.6	0.25
0.3	0.45	0.8	0.05

ENLARGEMENTS

(Based on velocity pressure in smaller pipe.)

A_1/A_2	ζ	A_1/A_2	ζ
0.1	0.80	0.4	0.35
0.2	0.65	0.6	0.15
0.3	0.50	0.8	0.05

from the model of water use described in Section 5.4. However, closer examination of individual pen supply would show that the water delivery rate decreases as the distance away from the source increases.

This problem can be reduced in the following ways:

(1) Darcy's Law shows that headloss is inversely proportional to pipe diameter and directly proportional to the square of velocity, and therefore headloss could be reduced by increasing the diameter of supply pipe. The greatest proportion of headloss occurs in the supply of water to the first pens in the line, where the velocity is greatest. Towards the end of the line, the velocity reduces (as less pens have to be supplied) and the headloss is significantly less. Therefore the diameter of the supply pipe could gradually be reduced along the row of pens as the velocity drops.

(2) Darcy's Law shows that headloss is directly proportional to the length of the supply pipe. If water was supplied to a row of pig pens, either from both ends of from the middle, then the drop in available head would be halved.

(3) The extent of the peak demand periods could be reduced by feeding different pens of pigs at different times. The effects of this practice on pig behaviour would require careful investigation.

The delivery rate in many pig drinkers can be altered by varying the resistance to flow provided by the drinker itself. This is done by increasing or decreasing the size an aperture within the drinker. A problem occurs when governing delivery rates in drinkers in a row of pens: should the delivery rates of individual drinkers be set when no other drinker is operating or should they be set when all of them are operating ? If the former practice is employed, during periods of peak demand, water delivery rate in the first few pens closest to the source would just be about adequate, but towards the end of the line delivery rates towards the end of the line would diminish to almost nothing. During periods of reduced demand, delivery rate would remain at the prescribed rate. If the latter practice is employed, then during periods of peak demand, water delivery rates to all pens would be as prescribed. To achieve this, the apertures in the drinkers would gradually increase in size as the distance from the source increased. During periods of reduced demand the delivery rates in all pens, particularly those at the end of the line would be higher than prescribed leading to increased wastage. This problem could be alleviated to a certain extent in two ways:

(1) The drinkers could be fitted with an aperture which alters diameter according to water pressure. When water pressure is high the aperture would close, decreasing the delivery rate. If thee water pressure dropped, then the aperture would open maintaining a constant delivery rate.

(2) The use of a new type of pipe line developed by Carpenter and Brooks called ZEROH_2O pipe (Barber Brooks and Carpenter, 1989). This equipment includes a high storage, large diameter (90 mm), main supply pipe connected to small diameter laterals which service individual pens. Pressure level and the incoming supply 'break' is catered for by a 'microtank' assembly which can be fitted at a much higher support point, in any building than a conventional 'header' supply tank. Headloss in the main supply is considerably reduced owing to the large diameter of the pipe. Pressure head drops during peak demand periods would result in a similar drop in delivery rate to all drinkers supplied by the system. The

diameter of the drinker apertures would be similar and set to allow nominal delivery rates at low demand periods. The large main storage pipe would result in smaller variations in pressure head than conventional systems and therefore smaller variations in delivery rates. Any reduction in delivery rate would occur equally along the row of pens supplied.
The maintenance of constant delivery rates is of great importance in the supply of water to pigs as reduced delivery rates may result in reduced water intake and depressed performance, and excessively high delivery rates increase water wastage and its consequent cost of storage as effluent.

The water use of a growing/finishing unit can be predicted from the model described in Section 5.4. The peak water demand periods have been identified in Section 5.5.3, which showed that 60 % of the water required is used in 4 hours of the day. With the addition of the information given in Section 5.7, water supply systems for pig housing can be designed. however, supply system design is beyond the scope of this study.

Conclusion

The literature review concluded with a statement from The Codes Of Welfare of Livestock: Pigs (1983), 'It is important for pigs to have sufficient fresh clean water for their daily needs'. This research programme has shown why it is important to have sufficient water and has identified some of the factors altering the daily needs of pigs.

It is important to differentiate between water needs (requirement), water intake and water use. Water requirement is the physiological requirement to maintain homeostasis and body fluid osmoregularity, whereas water intake may include an additional fraction to satisfy gut satiety, which is a physical need as distinct from a physiological requirement.

Water requirement is dependent upon the balance between the various losses and gains which in turn depend on factors such as environmental temperature and diet specification. Water intake is closely related to feed intake, not as a positive correlation, but in relation to total volumetric intake which is mainly dependent on liveweight.

Growing/finishing pigs (25-80 kg) appear to have a total daily volumetric intake equal to 12 % of their body liveweight. Given *ad libitum* access to feed a pig maximises its dry matter intake and only drinks sufficient to fulfil its requirement to maintain body fluid osmoregularity. If water availability is restricted, dry matter intake is reduced to maintain homeostasis and consequently performance suffers.

Where feed intake was restricted, volumetric intake was sustained at 12 % by an increase in water intake beyond that required to maintain osmoregularity. This additional water consumption is primarily to satisfy gut fill but may also provide the pig with a safety margin allowing it to buffer small increases in demand due to variations in diet or temperature.

When water intake is increased beyond what may be regarded as the 'normal' requirement, feed intake may be depressed. Similarly, in the case of newly weaned piglets, when water intake was increased by making the water more attractive with a sweetener, feed intake was decreased.

Therefore water intake cannot be anticipated on the basis of a simple factorial analysis of losses and gains, but is dependent upon feed intake and total daily volumetric intake. Assuming a 12 % volumetric intake in growing pigs, under normal homeostatic conditions, the water intake of pigs can be accurately predicted from a knowledge of feed intake.

Water use is dependent on water intake and the factors affecting water wastage. The two main factors affecting water use are drinker design and water delivery rate. For the range of delivery rates studied for growing pigs, waste appeared to increase linearly. Growing pigs were able to adapt to lower delivery rates and maintain their required intake by spending longer amounts of time drinking. For these pigs, performance was unaffected by lower delivery rates and wastage was reduced. An experiment which investigated the effects of delivery rate for the newly weaned pig showed that the young piglet was not prepared to increase the time spent drinking to achieve optimum water intake. Consequently water intake was reduced and performance suffered.

More attention should be given to supplying water at the correct delivery rate for a particular age of pig. A minimum delivery rate of 500 cm^3/min is recommended for newly weaned pigs. In the case of the growing/finishing pig wastage is reduced at lower delivery rates.

Ration fed pigs tended to consume most of their water post-prandially causing large, relatively short term demands on the water supply networks. Failure to satisfy these short term peak demands may affect both the performance and behaviour and ultimately the welfare of the pig. Careful consideration of the water intake of pigs, the selection of drinkers and the provision of appropriate delivery rates will allow piped water supply systems to be designed and installed in a way which maximises production and welfare, and keeps wastage to an acceptable level. Some wastage seems inevitable if production and welfare are to be maximised.

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Appendix I

TRIAL REPORT

Title: The effect of the addition of Palasweet and Palasweet+ on the water use, drinking behaviour and performance of early weaned pigs from 3-5 weeks of age.

To: Dr. J.D. Higginbotham,
Tate & Lyle Speciality Sweetners,
10-12 Deacon Way,
Reading,
Berkshire.
RG3 6AZ.

From: Mr. J. Barber,
Seale-Hayne College,
Newton Abbot,
Devon.
TQ12 6NQ.

Trial period: 14.4.88 to 21.7.88

Experimental method:

Two hundred and forty Large White x (Large White x Landrace) piglets weaned at 21 +/- 2 days were randomly assigned to one of three treatments. The treatments were: (1) fresh water,(2) fresh water with Palasweet and (3) freshwater with Palasweet+.

During the course of the experiment there were eight replicate groups of control, Palasweet and Palasweet+ piglets. Each replicate group of piglets was made up of five boars and five gilts. The mean weaning weight was 5.95 +/- 0.12kg. The piglets remained on the trial for two weeks when their mean weight was 7.47 +/- 0.43 kg.

The piglets were housed in an Elswick early weaning container. A calibrated Medimix applicator was used to dilute the Palasweet and Palasweet+ at a rate of 1%. Palasweet and Palasweet+ were administered for 3 days immediately after weaning. Ad. lib. drinking water was available from two Arato 76 piglet drinkers mounted 20 cm above the wire mesh floor. As the water delivery rate has proved to be critical in this type of experiment, the water delivery rate at each drinker was set at 450 +/- 20 cm^3/min and checked weekly.

The animals on all three treatments were fed ad. lib. on Bibbys D10P. The creep diet prior to weaning was Bibbys Super Natural (D20M).During the suckling period water had been available from Arato 76 piglet drinkers.

Remote video recordings of three replicates of both the control and Palasweet+ groups were made on the first and second days after weaning by means of a video camera and time-lapse recorder.

Records:

1. Food
The feed troughs were filled daily and for the first week uneaten food was weighed back daily in order to calculate daily intake. The uneaten food was weighed back at the end of the second week. Daily additions to the feed hoppers were recorded.

2. Water use
Water use was metered using previously calibrated Kent PSM-L meters and recorded daily at 10.00 hours.

3. Liveweight records
Pigs were weighed individually at weaning and from then on once per week.

4. Health
Health records were kept throughout the experiment. There was no incidence of scouring.

5. Temperature
A seven day Thermograph chart recorder was used to monitor changes in temperature during the trial period. The average temperature was 26 degrees centigrade but varied from 20 to 28 degrees centigrade.

6. Video recordings
A detailed analysis was made of the 24 hour video recordings which will be given later in this report.

7. pH of drinking water
The mean pH of the control drinking water was 7.6, whereas that of the Palasweet+ drinking water was 3.23.

Results

Table 1. Piglet performance and water use.

(means are given for the 14 day period)

	Control	Palasweet	Palasweet+	
Mean daily water use (l/pig)	0.729	0.799	0.841	N.S.
Mean daily feed intake (g/pig)	265.4	234.4	265.4	N.S.
Mean daily liveweight gain (g/pig)	259.5 a	196.3 b	221.1 ba	* *
F.C.R.	1.03 b	1.21 a	1.09 b	* *
Mean weaning weight (kg)	5.91	5.83	6.07	N.S.

(means bearing the same letter are not significantly different)

Table 1 shows the mean values obtained over the experimental period (14days) for the control, Palasweet and Palasweet+ replicates. There were no significant differences in mean daily water use, mean daily feed intake nor mean weaning weight. The mean daily liveweight gain for the control replicates was significantly higher than that for the Palasweet replicates but not significantly different from the Palasweet+ replicates.

As the Palasweet and Palasweet+ treatments were only effectively administered for three days, it was decided to break up the results into three periods: (1) days 1-3 post weaning, (2) days 4-7 post weaning and days 8-14 post weaning, in order to allow a closer examination of the actual treatment period.As liveweight was recorded weekly it was only possible to break this and further computed data into two periods: (1) days 1-7 and (2) days 8-14 post weaning.

1. water use

Table 2. Total water use broken down into three periods.

(litres per pig)

Period	Control	Palasweet	Palasweet+	S.E.M.	
Days 1-3	1.234 a	1.630 b	1.652 b	0.09	* *
Days 4-7	1.986 a	2.250 ba	2.615 b	0.12	* *
Days 8-14	6.986	7.306	7.507	0.39	N.S.

(means bearing the same letter are not significantly different)

Table 2 summarizes total water use for the three periods. For the first period (days 1-3) the control replicates used significantly less water ($p<0.01$)than the Palasweet and Palasweet+ replicates which did not differ significantly.This is illustrated in Figure 2. For the second period (days 4-7) the controls used significantly less water than the Palasweet+ replicates ($p<0.01$) but not significantly less than the Palasweet replicates. During the third period there were no significant differences between the three treatments.

2 Feed intake

Table 3. Total feed intake broken down into three periods.

(grams per pig)

Period	Control	Palasweet	Palasweet+	S.E.M.	
Days 1-3	414.4 a	314.4 b	283.0 b	21.38	***
Days 4-7	721.9	728.0	690.5	34.22	N.S.
Days 8-14	2579.8	2213.8	2434.4	112.1	N.S.

(means bearing the same letter are not significantly different)

Table 3 shows total feed intake for the three parts of the two week trial period. For the fist period the feed intake of the control groups was significantly greater ($p<0.001$) than the Palasweet and Palasweet+ replicates which were not significantly different. For the second and third periods there were no significant differences in feed intake between the three treatments.

3 Liveweight gain and F.C.R.

Table 4. Total liveweght gain and F.C.R. for the first and second weeks post weaning

Period	Control	Palasweet	Palasweet+	S.E.M.	
	Total liveweght gain (grams per pig)				
Days 1-7	930.3	578.9	816.2	16.2	N.S
Days 8-14	2650.9 a	2181.9 b	2278.5 b	12.9	**
	F.C.R.				
Days 1-7	1.14	1.63	1.26	0.09	N.S.
Days 8-14	0.97	1.03	1.07	0.03	N.S.

(means bearing the same letter are not significantly different)

Table 4 summarises total liveweight gain and F.C.R. for the first and second weeks post weaning. During the fist week after weaning there were no significant differences between the treatments for total liveweight gain and F.C.R. During the second week the liveweight gain for the control groups was significantly greater($p<0.01$) than that of the Palasweet and Palasweet+ groups which were not significantly different. There were no significant differences in F.C.R. between the three treatments during the second week.

Summary of significant results

Water use:
Days 1-3 control < Palasweet = Palasweet+
Days 4-7 control < Palasweet+
control = palasweet
Palasweet = Palasweet+

Feed intake:
Days 1-3 control > Palasweet = Palasweet+

Liveweight gain:
Days 8-14 control > Palasweet = Palasweet+

Piglet behaviour: video tape analysis

Twenty-four hour video recordings were made of the first two days post weaning of three control replicates and three Palasweet+ replicates. Analysis was carried out on four one hour periods within each twenty-four hour recording,(every six hours), starting with the first hour of each twenty-four. At weaning the piglets were individually marked on the top of the head in order to aid identification during video analysis. During the preliminary analysis the number of visits to the drinkers made by individual pigs within the hour periods was recorded. At a later stage of analysis precise times spent at the drinkers for individual piglets during the first hour post weaning was recorded for one control replicate and one Palasweet+ replicate.

Table 5. Preliminary video analysis: Visits to drinkers by piglets for the Control and Palasweet+ replicates.

(median values per piglet)

Period	Control	Palasweet+	
First hour	4.0	10.0	* *
Day one	15.5	17.7	N.S.
Day two	10.0	11.5	N.S.

Piglet drinking behaviour (visits to drinkers) is summarised in Table 5. The values given are median values and represent drinker visits per pig within the time specified. Values given for day totals are the median total number of visits observed per pig in the four one hour periods analysed within the twenty-four hour period. In order to test whether visits to drinkers were significantly different between the treatments a nonparametric statistical method has been used, namely the Mann-Whitney U test. A nonparametric method has been used due to the nature of the measurements made. It can be seen from Table 5 that significantly more visits were made to the drinkers by the Palasweet+replicates than the control groups ($p<0.01$) during the first hour.

However there were no significant differences observed between the treatments for the first and second day totals.
A Spearman rank correlation was used to measure the degree of association between the number of visits in the first hour and the liveweight gain during the first week, and the number of visits observed in the first day and the liveweight gain in the first week for both the control and Palasweet+replicates. There were no significant correlations found.

Table 6. The number of visits and time spent drinking during the first hour for one control and one Palasweet+ replicate.

(median values per piglet)

	Control	Palasweet+	
Number of visits	4.0	9.0	* *
Total time (s)	37.5	45.5	N.S.

Table 6 summarises the results of one control replicate and one Palasweet+ replicate after a closer video analysis of the first hour. The control replicate made significantly less visits to the drinkers ($p<0.01$). There was no significant difference in total time spent drinking between the two treatments.A correlation of time spent drinking against liveweight gain during the first week was undertaken for both the control and Palasweet+ replicates. There were no significant correlations.

Appendix II

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