4-2012

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The importance of water in pork production

Abstract

• The unique chemical structure of water makes it well suited to fulfilling a diversity of essential roles in the body.

• Defining the water requirement of the pig is particularly challenging because intake can be affected by a number of metabolic, physiological, and behavioral factors and because ad libitum intake is not always a reflection of need.

• The quality of drinking water can be a serious problem in regions known to possess aquifers containing problematic ions such as sulfates, iron, manganese, or nitrates.

• Both the cost and the availability of water will almost certainly become a bigger issue in many regions of the world in the coming future.

Keywords
pig, requirement, water quality

Disciplines
Agriculture | Animal Sciences | Environmental Sciences

Comments
This article is published as Patience, John F. "The importance of water in pork production." Animal frontiers 2, no. 2 (2012): 28-35. doi: 10.2527/af.2012-0037.

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The importance of water in pork production

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Implications

• The unique chemical structure of water makes it well suited to fulfilling a diversity of essential roles in the body.
• Defining the water requirement of the pig is particularly challenging because intake can be affected by a number of metabolic, physiological, and behavioral factors and because ad libitum intake is not always a reflection of need.
• The quality of drinking water can be a serious problem in regions known to possess aquifers containing problematic ions such as sulfates, iron, manganese, or nitrates.
• Both the cost and the availability of water will almost certainly become a bigger issue in many regions of the world in the coming future.

Key words: pig, requirement, water quality

Introduction

Water is a fundamental requirement for all organisms, yet as a subject of research, it has received surprisingly little attention, especially in livestock production circles. There are many reasons for this seeming oversight. Water for livestock production in many regions is widely available, if not abundant, and at least in North America, is available at no or relatively little cost. Because it is not traded commercially, unlike vitamins, minerals, and amino acids, there has been little financial motivation to study it more thoroughly. There are exceptions, such as in northern Europe, where the quantity of water used for livestock production is a significant concern; consequently, research on water conservation has been a priority (Mroz et al., 1995).

Most nutritionists would suggest that as long as water is made freely available to the pig, deficiency symptoms can be avoided, so they would suggest that further research is not needed. Sadly, the assumed absence of deficiency symptoms is based more on a lack of investigation than on any empirical scientific evidence (Fraser and Phillips, 1989). The limited data that do exist would suggest that supplying good-quality drinking water to pigs ad libitum will avoid deficiency symptoms in most, but not all, situations. Nursing and newly weaned pigs and sows in early lactation appear to be the most at risk of experiencing inadequate intake (Fraser et al., 1990; McLeese et al., 1992; Torrey et al., 2008; Figure 1).

Water is a particularly difficult nutrient to study. Deficiency symptoms are not easily determined unless water insufficiency is extreme, and response criteria that work effectively in studies of other nutrients tend to be unsatisfactory, or at least incomplete, in the case of water. The pig, like other species, is well equipped with homeostatic mechanisms to conserve water when intake falls below a certain level; the production of hypertonic urine is but one example of adaptive mechanisms that are well advanced in all mammalian species (Koeppen and Stanton, 2001).

Behavior influences water intake. For example, when pigs are housed in metabolism crates, which are often required to study water balance in detail, both hunger and boredom can lead to a polydipsia, which increases water consumption 2- or 3-fold or more in some circumstances (Patience et al., 1987; Fraser et al., 1990). A similar situation can arise in sows housed in gestation stalls.

Finally, water is not as easy to measure as one might think initially. Determining the dry matter content of a carcass, or even a sample of feces, is complicated by the spontaneous movement of water across a concentration gradient; dried feed or feces tend to take on water from the more moist surrounding air, whereas wet feed or feces will tend to give up water to the drier air around it.

The one aspect of water utilization that has received considerable scientific attention in the past decade is the method of supply, driven more to avoid excessive use than to determine the minimum physiological needs of the pig (Brumm et al., 2000; Li et al., 2005). As the supply of water becomes an issue in more pork-producing regions, and as the cost of handling manure increases, further investigation of water delivery methods can be anticipated. As mentioned, compared with North America, Europe has a longer history, greater experience, and more scientific support on this topic.

Although water is a fundamental need of the pig, and deficiencies can lead to impaired performance, and in severe cases death, it remains a bit of an enigma. It is a subject that tends to receive very little serious attention until a problem occurs, and then surprise is expressed about how little we know.

Water: A Global Perspective

Water is abundant on this planet, and unlike nonrenewable resources such as oil or gas, is constantly circulating through hydrological cycles. Consequently, the total amount of water will change only when measured in terms of geological time. Although abundant, 83% of the earth’s water is present as salt water. Another 14% of the total is chemically bound and thus unavailable for drinking. With another 2% of the total present as ice and snow, only 0.5% is available as freshwater. Indeed, of the total available freshwater, almost 98% is present in underground aquifers, with less than 2% present in lakes and rivers (de Moel et al., 2006).
Distribution of water supplies is a critical issue, such that localized areas differ in the adequacy of their water supplies (Oki and Kanae, 2006). Fortunately, in most parts of the United States and Canada, the supply of water is not a limitation to pork production. However, there are areas, such as parts of the Canadian prairies, where access to good-quality water is variable.

Measures of sustainable water supply generally consider only surface and subsurface runoff, measured as river discharge (Vörösmarty et al., 2000). The importance of the dynamic nature of water supplies is revealed in the fact that the world’s rivers contain about 2,000 km$^3$ of water, whereas total global annual water demand is almost double this quantity, at 3,800 km$^3$. However, the important number in this equation is the total annual flow of water, or discharge, which is estimated to be 45,500 km$^3$ per year (Oki and Kanae, 2006).

Therefore, on a global basis, there appears to be an ample supply of water. This would suggest that the supply of water in the future should not be a concern. On closer investigation, apart from the distribution issues mentioned previously, the supply of water from renewable freshwater sources fluctuates by season and by year and is further confounded by quality issues associated with both domestic and industrial waste discharge.

Many livestock regions, and centers of human population, obtain water from groundwater or surface water sources other than lakes and rivers. The water is being withdrawn from the same broad hydrological cycle, but from a different source within that cycle. The important consideration here is the balance between recharge rates for such groundwater resources compared with water removal rates. There is concern that some aquifers are being drawn down at a rate that exceeds recharging, resulting in depletion of reserves with very serious consequences in the long term (Terrell et al., 2002; Konikow and Kendy, 2005). Inevitably, this will result in competition for limited water resources among users in the future.

Vörösmarty et al. (2000) argue that increases in human population combined with industrial development will place considerable pressure on available water supplies in the relatively near future. If this is the case, then livestock production could find itself in increasing competition with many different users (domestic, industrial, agricultural, and recreational), with the result that both the cost and availability of water for food produc-

**Figure 1.** Making drinking water available to newborn piglets may be beneficial, especially if the sow’s milk production is compromised (source: J. F. Patience).
tion will become a much greater concern in the coming decades (Figure 2).

**Water: Where Chemistry and Physiology Meet**

Water is a remarkable chemical and possesses unique characteristics that make it particularly suited to its many roles in the body (Figure 3). These unique characteristics derive from the small size of the molecule combined with a dipolar structure that leads to binding interactions with solutes as well as with other water molecules (Israelachvili and Wennerström, 1996). Therefore, it is not surprising that water fulfills many important biochemical and physiological functions in the body, including thermal homeostasis, acid-base homeostasis, transportation, and lubrication, and is a participant in many chemical reactions. A particularly important role of water is the suspension of biologically important structures in an aqueous environment, including proteins, DNA, RNA, cells, and viruses.

Water possesses a relatively high specific heat, meaning that it can absorb a large quantity of heat energy for a given increase in temperature. The specific heat of water is 4.18 J/g°C. In comparison, the specific heat of alcohol is 2.40 and that of granite is only 0.79. This unique characteristic of water means that the body can absorb heat, derived either endogenously or exogenously, and will experience a much smaller change in temperature than would be the case if, for example, the primary body liquid were alcohol.

Although pure water is considered a neutral molecule with a pH of 7, water plays a large role in acid-base homeostasis. The very important bicarbonate buffer system in the mammalian body involves an equilibrium in which carbon dioxide combines with water to produce carbonic acid, which in turn dissociates into a free proton and a bicarbonate ion. This equilibrium finds importance in many parts of the body, but is particularly significant in the blood because it contributes to the removal via the lungs of relatively toxic carbon dioxide, produced in the peripheral tissues. The linkage of the bicarbonate buffer system with hemoglobin means that relatively large quantities of carbon dioxide can be removed from the body with a very small change in pH.

It is impossible to envisage any form of life without a fluid environment. Water, functioning as a solvent, is responsible for the movement of nutrients to cells and for the movement of metabolic end products from the cells for removal via the kidneys, lungs, and gut. Water also moves hormones and other chemical signals within and among cells, tissues, and organs. The capability of water to serve as such a successful solvent lies in its dipolar structure. For example, salt is readily dissolved in water. This is due to the large dielectric constant of water; thus, molecules linked by ionic bonds will dissociate in water and not in other solvents that have a different chemical structure.

Water is an inherent component of many chemical reactions. Simple but common examples include oxidation of carbohydrates, amino acids, and fatty acids, which release water and hydrolytic reactions that consume water. Indeed, it is impossible to think of a significant metabolic function in the body that does not involve water either directly or indirectly.

**Water Balance**

Shaw (2003) calculated that in a healthy growing pig living in a thermoneutral environment, drinking water represented about 86% of the total daily water supply. The remaining water was derived primarily from net metabolic processes (11%) and from the moisture in the feed (Figure 4). It is interesting that urine contributed only about 40% of water output plus retention. Growth accounted for about 5% and feces accounted for another 8%. The remainder would be explained by other losses, primarily respiratory evaporation. In their comprehensive review of water, Mroz et al. (1995) suggested that drinking water would constitute about 75% of the total daily supply and urine would constitute about 30% of output. They estimated that growth accounted for 14%, feces about 28%, and losses via the skin and lungs 29%.

![Figure 2](https://www.free-pictures-photos.com/).

In the future, livestock production will find itself in increasing conflict for access to available water supplies as demand by other users, including for recreational needs, increases (source: http://www.free-pictures-photos.com/).

![Figure 3](https://www.lsbu.ac.uk/water/molecule.html).

The unique chemical structure of water allows it to fulfill a diverse array of essential functions in the body. For example, its polar structure makes it a great solvent and also supports its role in acid-base balance and thermal homeostasis (source: Martin Chaplin, 2011; http://www.lsbu.ac.uk/water/molecule.html; licensed under a Creative Commons Attribution-Noncommercial-No Derive Works 2.0 UK: England & Wales License).
The important point is that drinking water represents the majority of water supply to the pig, but other sources are important as well. However, drinking water is important for more than quantitative considerations; through drinking water, daily supply can be regulated by the pig according to thirst mechanisms. Although thirst can be stimulated by behavioral influences, physiological regulation of water intake is achieved through an elegant interplay among osmotic, ionic, hormonal, and nervous signals, all directed at a central nervous system response (McKinley and Johnson, 2004). Thus, drinking water intake can be up- or down-regulated according to the daily needs of the pig. Other sources of water are much less carefully regulated.

Urinary is also important not only because it represents quantitatively a major vehicle for water excretion by the pig, but also because urine flow is the main mechanism for regulation of water output, controlled by aldosterone and arginine vasopressin (antidiuretic hormone) as well as by solute load (Robertson and Norgaard, 2002). Just as drinking water can be regulated to maintain necessary intake, urine output can be regulated to maintain necessary water removal from the body. Because dehydration and overhydration can be fatal, exquisitely sensitive mechanisms are present to ensure that a tight water balance is maintained.

When both feed and water are freely available to the pig, water intake will typically fall within the range of 2.1 to 2.7 kg of water per kilogram of feed (Shaw, 2003), although lower minimum ratios have been proposed (Mroz et al., 1995). Higher ratios have also been reported, often when water disappearance, rather than actual consumption, is being reported. A significant proportion of the reports in the scientific literature report disappearance, that being water that flows out of the drinker, as opposed to intake, that being water actually consumed by the pig. The difference is, of course, wastage. Wastage will increase depending on the water delivery device, water flow rates, barn temperatures, and pig behavior. Therefore, it is very important to distinguish between disappearance and intake.

Water intake can be influenced by diet composition, a fact that has been known for some time (Friend and Wolynetz, 1981; Brooks et al., 1984). Increased salt and protein are known to increase water intake (Pfeiffer et al., 1995; Suzuki et al., 1998; Shaw et al., 2006). The literature would suggest that decreasing dietary protein levels has only a modest effect on water intake, if at all, but excesses of protein definitely increase intake (Albar and Granier, 1996; Tachibana and Ubagai, 1997).

Water intake is also increased by high ambient temperatures. Some researchers have reported increases in the water:feed ratio from about 2.5:1 at thermoneutral temperatures to 4:1 when temperatures increase substantially above the upper critical temperature (Patience et al., 2005). Huynh et al. (2005) also noted that relative humidity (RH) had a significant influence; the increase in the water:feed ratio was doubled at 80% RH as compared with 50% RH. Schiavon and Emmans (2000) suggested that for every degree centigrade increase in air temperature, water intake increases by slightly more than 0.1 L/d. This relationship was generally supported by Vandenheede and Nicks (1991).

Water intake is not solely under the influence of physiological requirements, because behavioral mechanisms are also involved (Fraser et al., 1990). It is well known that when bored, or heat stressed, pigs will play with drinkers; this will increase water disappearance, and at least in the instance of heat stress, intake. Pigs consume luxury amounts of water, well beyond what would be considered physiological need. Hunger-induced polydipsia occurs in limit-fed pigs, such as gestating sows, but can be seen in growing pigs as well (Yang et al., 1981). Schedule-induced polydipsia is also observed in swine and results in excessive water intake.

**Water Requirement**

The content of water in the body of the pig changes as the proportion of lean to lipid tissue declines with increasing body weight. Thus, the body of the newborn piglet contains about 85% water, and this declines to about 50% at market weight (Shields et al., 1983). Even in the adult animal, the quantity of water present in the body underscores the importance of maintaining adequate intake, especially when water needs are increased because of environmental or health stressors.

Having said this, unfortunately, it is extremely difficult to define a precise water requirement for the pig. Water cannot be studied like other nutrients because of the complexity of the many highly dynamic pools that exist within the body. For example, a drinking water deficit will result in potential dehydration with consequent renal compensation with no discernible impact on performance, at least in the short term (Fraser et al., 1990). Consequently, growth studies undertaken to evaluate water requirements must involve more than simple recording of growth performance outputs; indicators of the hydration status of the body should not be ignored, although such measurements bring their own unique challenges. Providing water:feed ratios that are less than those self-selected by the pig should therefore be implemented with caution, and only after the impact of water restriction on physiological outcomes is well understood (Figure 5).
The requirement of the pig for water will be influenced by many factors. For example, as feed intake increases, water intake typically increases as well, except in the case of newly weaned pigs, in which feed intake and water intake are surprisingly not linked (McLeese et al., 1992). Thus, developing water:feed ratios is not an appropriate foundation for defining requirements in all classes of pigs.

In addition, diet composition will influence water need. As dietary salt increases, so too does water intake under ad libitum conditions (Shaw et al., 2006). The pig can tolerate large amounts of salt in the feed, provided fresh water is freely available; if water becomes restricted, fatal salt poisoning may ensue. Water intake also increases with excesses of protein (Pfeiffer et al., 1995). Environmental temperature will also substantially increase water consumption (Mroz et al., 1995; Patience et al., 2005). Luxury intake due to stress, boredom, or hunger may alter the intake of the pig; in one report, daily intake varied from 1.7 to 16.8 L/d for pigs housed in metabolism crates (Patience et al., 1987).

If the water:feed ratio is accepted as a practical option, albeit with known limitations, (Mroz et al., 1995; Brumm et al., 2000; Shaw et al., 2006), one can estimate a water requirement for growing pigs of 2.5 L/kg of feed and for finishing pigs of 2.1 L/kg of feed. When pigs are fed liquid diets, the recommended water:feed ratio increases to 3:1 for growing pigs and 3.5:1 for finishing pigs; however, additional water from a drinker is always made available to the pig and is not considered in establishing the water:feed ratio mentioned previously.

**Water Delivery**

The delivery of water to the pig has changed in recent years. Although the typical nipple drinker affixed to the pen wall remains common, there is increasing use of wet-dry feeders, swinging drinkers, and dish drinkers; the primary motivation for this change is conservation of water. Growing pigs will spend about one-half hour per day drinking water (Xin and DeShazer, 1991; Gonyou, 1996) and about 85% of consumption occurs within 10 min of eating (Bigelow and Houpt, 1988).

Nipple drinkers remain the most common vehicle for the delivery of drinking water to pigs in North America, but they also account for the greatest waste of water. Brooks (1994) reported 60% waste in growing pigs and Fraser and Phillips (1989) reported 23 to 80% waste in sows, although it is generally accepted that wastage will depend on flow rate as well as mounting method and position. To ensure adequate access to water while minimizing wastage, nipple drinkers should be mounted at shoulder height of the pig if angled 90° from the wall, or 20% above the shoulder if mounted downward at a 45° angle (Figure 6). Thus, the height of nipple drinkers should be adjusted as the pigs grow. It is also desirable to mount the drinkers so pigs must drink “straight on” rather than at an angle; mounting drinkers in corners will help to accomplish this (Gonyou, 1996). Swinging nipple drinkers are becoming increasingly common in the North American pig industry.

Bowl drinkers help to reduce water wastage (Bekaert and Daelemans, 1970) but must be carefully managed to avoid excessive fouling, which occurs if improperly positioned in the pen. Bowl drinkers have also been shown to encourage water intake in nursing piglets. Wet-dry feeders, which allow the pig to eat feed either in dry form or to mix it with water prior to consumption, also reduce wastage and tend to increase feed intake (Gonyou and Lou, 2000). Other types of waterers representing a very small portion of the market include troughs and straw drinkers, the latter requiring pigs to suck water from the water line.

**Figure 5.** Defining water requirements of pigs is a very difficult task. Simple growth studies, measuring only short-term growth performance, may miss changes in physiological state that can affect long term health and well-being (source: J. F. Patience).
Selection of the optimal water flow rates will help to encourage adequate intake without excessive waste. To this end, the flow rate should be about 500 mL/min for nursery pigs, 750 mL/min for growers and finishers, 1,000 mL/min for gestating sows, and 1,500 mL/min for lactating sows (Gonyou, 1996).

Water Quality

Most guides on water quality contain standards that address both aesthetics and health issues (National Research Council, 1974). The former have been developed with the preferences of humans in mind, and really do not address the needs of livestock. If aesthetics influences pig consumption of water, this has never been documented scientifically. However, an aesthetic problem might also be an indicator of something more fundamentally wrong with the water that could have health implications. For example, if turbidity or odor is high, the cause could be something of concern to pork producers. It is important, however, to understand that some so-called water quality criteria have little, if any, relevance to the pig; the challenge is to differentiate those that are important from those that are not.

The quality of a water sample is evaluated according to three broad criteria: physical, chemical, and microbiological. Physical criteria include such qualities as color, turbidity, and odor. These are of minimal consideration in pork production. As mentioned, if color, odor, or turbidity is high, a pork producer should look for the cause, which may have health and or productivity implications.

Water can become contaminated with very serious microbial contaminants, such as Salmonella, Shigella, cholera, Campylobacter, enteroviruses, Cryptosporidium, and Giardia, as further described by McAllister and Topp (2012) in the present issue. All can pose serious threats to the health and well-being of pigs. Chlorination, or another form of disinfection, can control some organisms but not all, so water supplies need to be carefully evaluated in terms of their potential for contamination; surface sources are at greater risk than groundwater. Poorly located or constructed wells, which allow for leaching or surface water runoff into the well, increase the risk of contamination (Curriero et al., 2001). The methods used for disinfection will be dictated by the potential microbial risks involved but could include sand filtration, free chlorine, chloramines, or ozone. Newer technologies are also evolving, such as the use of chitosan, photocatalytic titanium dioxide, fullerol, and carbon nanotubes (Li et al., 2008).

Chemical contamination tends to be the greatest concern to pork producers, although the nature and magnitude of the problem are very regional and depend on the exact source of the water. For example, some groundwater sources derived from specific aquifers will be naturally contaminated because of their geological origin (Toth, 1999; Herczeg et al., 2001). An understanding of the local geology will help the producer anticipate potential mineral contaminants in groundwater obtained in a specific location and at a specific well depth.

The presence of contaminants can be the result of poorly designed, located, or constructed wells. For example, nitrate contamination of wells can evolve geologically, but may also be derived from point sources such as proximity to septic drainage beds or fertilizer runoff (Power and Schepers, 1989).

Drinking water contains a wide array of potential mineral contaminants, ranging from calcium and magnesium to heavy metals. The greatest concern to pork producers tends to be specific cations, such as sodium and magnesium, and anions, such as sulfates. Other contaminants can also be of concern, such as potassium, iron, manganese, or nitrates and nitrites, but other than localized situations, the former generate the greatest number of complaints.

Excessive levels of magnesium and sodium, primarily when present as sulfate salts, can lead to problems with diarrhea. The diarrhea will be osmotic in nature and will tend not to be associated with production problems unless the levels are extremely high. Veenhuizen et al. (1992) reported that concentrations of sulfate salts of sodium or magnesium or their combination up to 1,800 mg/L did not cause performance problems in weanling pigs, although fecal moisture content rose substantially. Patience et al. (2004) undertook a detailed study of water quality on a commercial farm and reported that sulfate levels of 1,650 mg/L did not impair either the rate or the efficiency of growth in weanling pigs, although diarrhea was clearly present (Figure 7). Numerous other studies have drawn the same conclusion (Anderson and Stothers, 1978; Maenz et al., 1994), that even young pigs have the capacity to handle large loads of sulfate salts in the drinking water without an adverse effect on performance. It is very expensive to remove sulfates from drinking water, including both the initial capital cost for equipment and ongoing operating costs, making such systems prohibitive to install on most farms.

Iron and manganese contamination of drinking water leads to mechanical problems in the water delivery system. Both minerals are present in groundwater in the soluble reduced form; pumping water to the surface exposes them to air, resulting in highly insoluble oxidized forms. The precipitated minerals cause all manner of problems with drinkers and other equipment installed in the water delivery system. Both iron and manganese oxides can be removed from the water through a number of methods, the least expensive of which is filtration.

Hardness of water is another concern for pork producers, but the issue is a mechanical one as opposed to being a health-related concern. Hardness reflects the sum of all multivalent cations present in the water and
may not be solely responsible for the development of methemoglobinemia. Recent analyses have suggested that high nitrate levels in drinking water are less susceptible to the problem. However, even in human infants, more formula is contaminated with nitrates or nitrites, methemoglobinemia (blue baby syndrome) can ensue. Baby pigs are much less likely to receive drinking water through milk replacers until they are older and therefore less susceptible to the problem. However, even in human infants, more recent analyses have suggested that high nitrate levels in drinking water may not be solely responsible for the development of methemoglobinemia (Fewtrell, 2004).

Nitrates could be a concern in drinking water for swine, but the tolerable levels in drinking water for swine are higher than those accepted for humans (Garrison et al., 1966; Sørensen et al., 1994). The reason is simple. Susceptibility to nitrates and nitrites is highest in the very young. Human infants may receive formula, and if the water used in making formula is contaminated with nitrates or nitrites, methemoglobinemia (blue baby syndrome) can ensue. Baby pigs are much less likely to receive drinking water through milk replacers until they are older and therefore less susceptible to the problem. However, even in human infants, more recent analyses have suggested that high nitrate levels in drinking water may not be solely responsible for the development of methemoglobinemia (Fewtrell, 2004).

**Conclusion**

Water is a central constituent of the body of the pig, fulfilling many critical functions essential to life. Its unique chemical structure makes it particularly effective in fulfilling these roles. Because intake can be affected by a number of pig and nonpig factors, and because intake is not always a satisfactory reflection of need, defining the water requirement of the pig is particularly challenging. The quality of drinking water can be a serious problem, but it tends to be isolated in regions known to possess aquifers containing problematic minerals such as sulfates, iron, manganese, or nitrates. Although water is abundant and inexpensive in many parts of the world where pigs are raised, the prospect of greater agricultural and nonagricultural demand on water resources suggests that both cost and availability could become issues in many more parts of the world. Therefore, the most efficient use of this valuable resource is essential as we move further into the 21st century.

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**Figure 7.** The effect of reverse osmosis (RO) treatment of drinking water high in total dissolved solids and sulfates on average daily gain (ADG; SEM = 0.011 kg/d), average daily feed intake (ADFI; SEM = 0.019 kg/d), and gain:feed ratio (SEM = 0.013) evaluated under commercial farm conditions (data from Patience et al., 2004).

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![Diagram showing the effect of RO treatment on various parameters](image-url)
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About the Author

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April 2012, Vol. 2, No. 2