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Water quality issues in pork production

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1. Introduction

Water is present on earth in abundant quantities, covering 73% of the planet's surface and representing more than 1.6 trillion km^3. The abundance of water is not surprising, given that it is essential for life. Indeed, it is difficult to think of very many functions of the pig's (or man's) body that does not involve water, either physically or chemically (Mroz et al., 1995). While abundant, only 17% of the earth's water is fresh; the rest is seawater. Another 14% is chemically bound, filling important roles, but nonetheless unavailable for drinking. Another 2% is present as ice and snow, leaving only 0.5% available as fresh water; interestingly, of the total available drinking water, almost 98% is present in underground aquifers, with less than 2 percent present in lakes and rivers (de Moel et al., 2006).

A major problem with water is not the quantity present on earth, but rather its distribution. Even within the US, areas of water excess and of deficit exist.

Another problem with water availability involves its quality. Water may contain mineral or microbiological contaminants that can have adverse effects on people and animals consuming it. Technology exists to remove almost all contaminants, but cost and the availability of technical expertise of manage highly sophisticated treatment systems often dictates whether a particular source of water is viable for use.

Because in most major pork producing regions of the world, water is abundant, inexpensive and not traded commercially, it has rarely been a focus of significant research (Fraser et al., 1990). This helps to explain the dearth of information on a topic of such importance and, relative to many other nutrients, such ignorance. Water is taken for granted - until problems arise at which time pork producers are surprised by the inadequacy of information required to make rapid and effective management decisions.

Water is also a particularly difficult nutrient to study Classical approaches to the study of energy, amino acids, minerals and vitamins are extremely difficult, if not impossible, to apply to water. Further, analysis of water content, for example in feed, is simple to undertake, but it is actually quite difficult to achieve accuracy. We don't balance the pig's diet for water; we merely supply it ad libitum, and assume (falsely) that the pig will consume sufficient quantities to meet its biological needs (Fraser and Phillips, 1989). The question of water requirements becomes a bit more difficult when liquid feeding is adopted and the feed becomes the only source of water to the pig (Barber et al., 1991a, b).

But for the majority of production circumstances, water is a utility supplied to the pig, much like we obtain water and electricity and perhaps natural gas for our homes. Sometimes we worry about wasting water, revealed in how we select drinkers (Li et al., 2005; Torrey et al., 2008), sometimes we worry about where we supply water, revealed in how we provide drinkers to the pig (Phillips and Phillips, 1999; Deligeoris et al., 2006; Hurst et al., 2009; Brumm, 2010) and sometimes we worry about the quality of the water we provide to pigs (NRC, 1974; McLeese et al., 1992; Patience et al., 1995; Nyachoti et al., 2005) – the subject of this presentation.

2. Defining water quality

I start with a note of caution on the topic of water quality. Many organizations publish standards of water quality, but their relevance to the pig is highly suspect. Most water quality standards, such as those produced by the WHO, or by water agencies, refer to water quality as it relates to humans, not livestock – and many of those standards address aesthetic as opposed to health issues. The silliness of many people purchasing bottled water when perfectly acceptable water is available from the tap illustrates that for humans, the aesthetics of water is indeed important!!

When it comes to measuring water quality, as it relates to pork production, there are certain issues that are real, and there are others which are probably irrelevant. The dearth of research on water quality as it relates to pig production makes it difficult to be completely definitive in our discussions, but most water quality criteria published for humans have little if any relevance to the pig. This sounds like a strong statement, but for most criteria, with the possible exception of microbiological contamination, human standards are lower, or much lower, than will be tolerated by the pig, if they have any relevance at all. The following will attempt to separate out those criteria which are important to the pig, based on admittedly limited data in some cases.

Therefore, when addressing water quality, our focus should be on the impact of the water directly on the pig, or the impact of water quality on the delivery system which in turn could ultimately lead to impacts on the pig.

Specifically, this section will explain some of the more common measures of water quality, in the context of pork production. Water quality can be evaluated in terms of its physical, chemical and microbiological composition.

2.1. Physical

Physical attributes by themselves tend to be of little practical importance in pork production. Pigs are much more tolerant of – if not oblivious to - unusual colors and tastes in water, unless they are extreme. However, turbidity, color and odor can be symptoms of other problems that may need attention, as explained below.

Consideration of physical attributes of water tends to be most useful in determining other contaminants in the water. For example, what are causing odor problems, or what are causing off-colors and are they important to the pig?

2.1.1. Turbidity

Turbidity is more of an esthetic attribute than a quality one. High turbidity may simply represent suspended colloidal material, such as silt or clay, in the water; at low levels, this means very little to the pig. However, it may also represent suspended microorganisms which may be of great importance. Turbidity, therefore, is a measurement that can be considered more qualitative than quantitative for the pig. If the water has a turbidity of less than 5 NTU's (Nephelometric Turbidity Units), then it is probably acceptable for pigs. If turbidity is above 5 NTU's, then additional measurements of chemical and microbiological content of the water should be undertaken to determine their cause. Furthermore, clay or silt suspended in water resulting in elevated turbidity could lead to problems with the water delivery system.

Turbidity may impact the effectiveness of sand filters and also impair the effectiveness of water disinfection.

NTU is generally the same as FTU (Formazin Turbidity Unit), TU (Turbidity Unit) and TU (Jackson Turbidity Unit), and equals 1 mg of SiO_2 per liter.

2.1.2. Color

Color, measured in TCU's (True Color Units), is not a concern for drinking water supplied to the pig, unless the color is due to an undesirable contaminant in the water. Other assays will be of much greater value to the pig than color; these include TDS, sulfate, hardness and microbiology.

2.1.3. Odor

Odor, measured in TON's (Threshold Odor Number), is not an issue for pigs. Fresh water should be almost free of any odors; however, if present, the cause of off-odors may be important, so further analysis is warranted. The most likely cause of off-odors would be microbiological contamination or the presence of organic compounds.

2.2. Chemical

2.2.1. Total dissolved solids

As imprecise as TDS is, it is still used as a means of determining the suitability of drinking water for swine. Total dissolved solids are due mainly to the presence of bicarbonate, chloride and sulfate salts of sodium, calcium and magnesium. Generally, if TDS is low – below 1,000 mg/L- then mineral contamination cannot be a problem and no further testing is required. If TDS is between 1,000 and 3,000 mg/l, then it could cause transient diarrhea, particularly in young swine; this would be particularly true if the predominant anion in the water is sulfate. Total dissolved solids between 3,000 mg/l and 5,000 mg/l is probably still acceptable (NRC, 1974), but needs to be watched carefully, and over 5,000 must be carefully scrutinized before being fed to pigs.

Simply stated, TDS is a broad-brush assay. If the results are low, then the water will be fine, in terms of mineral contaminants – with the exception of iron and manganese. As TDS increases, the risk of diarrhea increases. Pigs can adapt to a wide variety of water qualities, but the best option is always to select the water with the lowest TDS, if a choice is available. And if TDS is high, further analysis of the water is required to determine its composition. Some minerals, as discussed below, are a greater concern than others.

2.2.2. Conductivity

As the name suggestions, conductivity is a measure of the ability of the water sample to conduct an electrical current. A high conductivity suggests a high level of dissolved mineral ions in the water. If conductivity is high, it provides an indication that additional assays of the water sample are required, to determine the exact ions present. TDS is a preferred assay over conductivity because it is a direct measure of total inorganic contaminant content of the water.

Conductivity, sometimes also referred to as specific conductance, is reported in µS/cm (microSiemens per centimeter) or µmhos/cm (microomhos per centimeter) and can be converted to Total Dissolved Solids by multiplying by a factor (K), as follows:

$$\text{TDS (mg/l)} = \text{Conductivity} \times K$$

Unfortunately, the value of K can range from 0.75 to 0.55, depending on the water composition. For example, if the primary contaminants in the water are sodium and chloride, the factor will be 0.55; if the water is dominated by calcium bicarbonate, the factor will be 0.75. Often, 0.64 is used as an average.

2.2.3. pH

The pH of the water is a measure of the acidity or alkalinity of the water. The vast majority of water samples will fall within the acceptable range of 6.5 to 8.5. If the pH of the water is elevated, it can impair the effectiveness of chlorination. If the pH is low, certain water medications may precipitate out. The addition of pH modifiers to the water are known to interact with certain pharmaceutical products, such that great care must be taken when administering both via the drinking water (Dorr et al., 2009).

2.2.4. Hardness

Hardness is a measure of the multivalent cations in the water, primarily calcium and magnesium as carbonates, bicarbonates, sulfates and chlorides; it is generally expressed as calcium carbonate equivalents. Hardness has no known impact on health, per se, but it does impair washing due to an increased requirement for soap or detergents. Hardness can also lead to the accumulation of scale in water delivery, treatment and heating equipment. Thus, water hardness can lead to problems with water heaters, nipples drinkers, filters, etc. The United States Geological Survey considers water soft if hardness is < 60 mg/l as $CaCO_3$ and considers it very hard if > 180 mg/l (Chinn, 2009).

Some people attribute water quality problems with hardness, because hard water often, but not always, contains anions that are a concern. The Ca and Mg ions, if present as carbonates are generally a minor concern. If they are present as sulfates, then they can be a significant concern, as explained below.

2.2.5. Sulfate

Sulfate is a naturally occurring mineral in most groundwater sources, but is usually low enough in concentration to not cause any problems with pigs. However, in some instances, sulfates can exceed 1,000 mg/L or even 1,500 mg/L. While the intestinal tract of the pig is well supplied with transporters that can absorb sulfates, sulfates are often re-secreted back into the large intestine, resulting in an osmotic, or non-pathogenic, diarrhea (Maenz and Patience, 1997). Depending on the level of sulfates in the water, pigs can adapt over a period of weeks so that associated diarrhea is transient. The problem is most acute in newly-weaned pigs, as they have not been exposed to sulfates and perhaps are physiologically more susceptible as well. In any event, sulfates whether of magnesium or sodium origin, can lead to osmotic diarrhea. The impact is clearly dose dependent (Table 1). In general, sulfates less than 500 mg/L should be of no concern. As sulfates rise to 1,000 mg/L or more, then diarrhea will become an issue. The subject of sulfates and pig performance will be dealt with in more detail later.

There is one further issue related to sulfates in water. Some bacteria can extract the oxygen from sulfate, leaving H_2S or HS^- as the residue; H_2S creates the "rotten egg" odor that sometimes exists in water samples.

Table 1: Impact of elevated total dissolved solids and sulfates in the drinking water in weanling pig performance.

	Sulfates, mg/l		
	83	1,280	2,650
Total dissolved solids, mg/L	217	2,350	4,390
Calcium, mg/L	24	184	288
Magnesium, mg/Lw	15	74	88
Sodium, mg/L	24	446	947
Hardness, mg/L	124	767	1,080
pH	8.4	8.1	8.0
Ave. daily gain, g	430	430	440
Ave. daily feed, g	550	560	570
Feed:gain	1.28	1.31	1.30
Ave. daily water intake, L/d	1.60	1.84	1.81
Scour score (1-3)	1.07	1.30	1.46

Source: McLeese et al., 1992

2.2.6. Iron and Manganese

There are no known direct health issues associated with elevated iron and manganese in drinking water, but they can cause handling problems at even low levels. Iron and manganese tend to exist in ground waters in their reduced form (eg. ferrous, Fe^{+2}) and thus are soluble. However, as the water is extracted from the well and exposed to oxygen, they are oxidized (eg. ferric, Fe^{+3}) and rendered highly insoluble. Oxidized iron has a typical reddish-brown hue, while manganese tends to be darker – almost black. If present in the water, they can be seen as persistent discoloring of toilets and sinks, but more critically, coat water heater elements, drinker nipples, chlorinators, etc. Iron in the water should not exceed 0.3 mg/l, although staining can occur at levels as low as 0.1 mg/l (Chinn, 2009). The level of manganese should not exceed 0.05 mg/l (Chinn, 2009).

Iron in the water can also support the growth of iron bacteria. These organisms can cause foul odors and reduce well water output; both of these indications are caused by the accumulation of bacterial slime in the water or along the well casing. For example, if a well has the capacity to support a pull that is twice that required for the farm, the reduced flow due to iron bacteria can go unnoticed for an extended period of time, until the flow of the well falls below the farm demand. At this point, the iron bacteria will be well established and very difficult to manage.

2.2.7. Nitrates and Nitrites

Nitrates and nitrites are a particular concern in human drinking water, since babies are particularly susceptible to the "blue baby" syndrome, so called because nitrates and nitrites bind hemoglobin, reducing its oxygen carrying capacity and forming methemoglobin. Cattle are much more susceptible to nitrates than pigs, because rumen bacteria convert nitrates to the much more dangerous nitrites. Garrison et al. (1966) reported that 200 mg nitrates/l impaired growth rate and impaired vitamin A metabolism. Sorensen et al. (1994) fed even higher levels of nitrates, up to 2,000 ppm, to pigs from weaning to market and saw no adverse effect on any growth performance parameter, or on hemoglobin or methemoglobin levels in the blood. Both experiments used nitrate levels that are higher than typically seen in most water supplies. These data suggest that nitrate guidelines for human infants probably do not apply to pigs after weaning. This makes sense, since it is known in human medicine that infants on formula are most susceptible, and in pork production, nursing piglets have limited access to drinking water other than milk.

The recommended limit of nitrates plus nitrites in drinking water for swine is 100 mg/l and nitrite alone should not exceed 10 mg/l (Chinn, 2009). However, drinking water for humans is recommended to contain no more than 10% of these levels.

2.2.8. Sodium

Sodium is not a concern in drinking water by itself, unless it is at levels that exceed the kidneys' ability to handle – like brine. Such levels do not exist in drinking water in my experience. However, cations like sodium are associated with an anion in the water; if this anion is sulfate, it will lead to diarrhea, as sodium sulfate, also known as Glaubers Salts, is a powerful laxative. If the cation is chloride, there is little cause for concern, and if the cation is carbonate or bicarbonate, the water may have a higher pH.

It is important to note that simple ion-exchange water softeners replace calcium and magnesium with sodium, and thus elevate the levels of sodium in the water.

2.2.9. Magnesium

Magnesium by itself would be of little concern in the water. As mentioned previously, it contributes to water hardness. Also, like sodium, it is associated with a counter balancing anion; if the anion is sulfate, it is called Epsom salts and has a potent laxative effect on the pig. (Please see discussion on sulfates above).

Magnesium can be removed from the water through ion exchange water softening. The magnesium ion will be replaced with sodium in a 1:2 ratio; while this will reduce the hardness of the water, it will have no impact on the incidence of diarrhea in the pig, because sodium sulfate is also a potent laxative.

2.2.10. Chloride

Chloride is not normally elevated in either groundwater or surface water. If it is high (> 400 mg/l), it will impart a metallic taste to the water which so far does not appear to adversely affect the pig. If drinking water is high in chloride, the quantity of salt in the diet can be reduced concomitantly; however, this can only be done if sodium is also elevated in the water, or a source of sodium other than NaCl is included in the diet.

Sometimes, nitrates are removed from well water using anion exchange, in which nitrates are replaced with chloride. Thus, nitrate removal in this manner will elevate chloride levels in the water. However, since nitrates are generally present at low levels, the net impact on chloride levels will usually be minimal.

2.3. Microbiological

The microbiological quality of water is often considered the primary issue in water quality discussion. The presence of pathogenic organisms in the water can lead to disease breaks in the herd and make it almost impossible to achieve the highest level of performance. Surface water is at greatest risk, due to the higher chance of contamination, but groundwater can also contain pathogens. For example, water can contain bacteria such as e. coli, salmonella and shigella, viruses such as enterovisuses and protozoa, such as cryptosporidium and giardia. Also, certain algae in the water can lead to gastroenteritis.

3. Water treatment

The technology exists to modify drinking water in any number of ways to achieve a final product that meets minimum quality standards. Treatment systems for human water supplies are highly sophisticated and capable of removing a wide array of organic and inorganic contaminants. For example, some estimates indicate that water flowing down the Mississippi River is used 7 times from the headwaters in Minnesota to the Gulf delta!!

These processes can be very expensive and require oversight by highly qualified personnel. Such levels of sophistication are rarely employed in agricultural settings, unless unusual conditions exist. However, some aspects of water treatment technology have been adapted to farm applications when the need arises.

3.1. Removal of colloids

If physical attributes need to be corrected, the use of activated charcoal is commonly recommended. It can adsorb many of the constituents that impact taste, color and odor and also remove some organic impurities as well.

3.2. Water softening

Water can be softened; the most common and simplest treatment system is ion exchange, which replaces calcium and magnesium with sodium. There is no logic to softening drinking water, unless the water is so hard that it plugs drinkers, etc. However, office water, used for laundry or showering, may be softened to reduce the demand for soap.

3.3. Removal of sulfates

The most common way to reduce or remove sulfates from the water is through reverse osmosis. However, this tends to be quite expensive, both in terms of initial capital cost and on-going operating costs, so is not normally adopted by pork producers.

3.4. Removal of Iron and Manganese

Both iron and manganese can be reduced in drinking water through the use of specific filters. However, aeration followed by a settling tank are somewhat effective for iron removal (Table 2) and the cost is low. To maximize the quantity of iron removed from the water, chlorination ahead of the settling tank is recommended; this also helps to avoid bacterial growth in the cistern. The process is most effective when the pH is above 7.5 (Vigneswaran and Visananthan, 1995). Chlorination also helps to prevent microbiological contaminaton of the water in the settling tank. The settling tank needs to be cleaned from time to time to remove accumulated iron and/or manganese. Filtration after the settling tank is recommended for the final step in the removal of iron.

Removal of manganese by aeration and filtration is not recommended. It occurs maximally at a pH > 9.5 which is much higher than most water supplies. Also, the sedimentation time is much longer (Vigneswaran and Visananthan, 1995), so this process is much more effective with iron than with manganese.

Table 2: Effect of aeration and 7 days settling on water composition (mg/l).

	Day	
Item	**0**	**7**
pH	7.92	8.06
Total dissolved solids	2,388	2,378
Hardness	761	760
Sulfates	1,268	1,248
Sodium	446	432
Calcium	183	189
Magnesium	75	72
Chloride	40	45
Potassium	10	11
Nitrates	1.0	1.0
Nitrites	0.3	0.3
Iron	2.5	0.6

Source: Tremblay et al. (1989) reported by Patience et al., 1995.

3.5. Disinfection

Disinfection of water supplies is a critical component of any treatment system. Water should be monitored and when microbial contamination rises, disinfection needs to be initiated.

The most common form of disinfection is chlorination, which will use either chlorine gas, sodium hypochlorite (liquid) or calcium hypochlorite (solid). The objective of adding chlorine to the water is to create the disinfecting compounds hypochlorous acid (HOCl) and hypochlorite ion (OCl), according to the following equilibrium:

$$HOCl \leftrightarrow OCl^{-} + H^{+}$$

Hypochlorous acid is the most effective disinfectant and is favored in water with a lower pH. The effectiveness of chlorination will be reflected in two parameters: the concentration of free chloride in the water and the contact time. The preferable "free chlorine" concentration in the water is 0.3 mg/L to 0.5 mg/l; at these levels, the required chlorine contact time, assuming a pH of 7.5, is between 25 and 60 minutes in most cases. Other factors impact the effectiveness of chlorination, namely pH, temperature and the presence of interfering compounds in the water.

A particular problem with chlorination is the presence of organic matter, which requires the addition of higher levels of chlorine to achieve desired free chlorine levels. If the water contains organic matter, a person trained in chlorination should be consulted to ensure adequate, but not excessive, chlorine is added to the water. Errors in adding chlorine to the water can be fatal to pigs, so caution is required. However, at least one study conducted on a commercial farm suggests that pigs can tolerate 2 ppm of free chlorine without impairing performance (Nyachoti et al., 2005).

Chlorination is not effective against Cryptosporidium.

Alternatives to chlorine are becoming increasingly common in pork production, just as they are in human drinking water supplies. Examples include the use of ozone, potassium permanganate, UV rays, chloramines and chlorine dioxide (Vigneswaran and Visananthan, 1995).

If iron bacteria are a problem, shock chlorination can be employed, although the impact is often transient, and the procedure may need to be repeated numerous times to achieve lasting benefit. One approach is to mix 25 parts of household bleach with 900 parts of water, pouring this into the well and leaving it there overnight. This water must not be consumed, so water lines and the well must be flushed thoroughly until a fresh water supply resumes before turning water lines back on.

4. Water quality effects on performance

My focus now will be on the effect of water high in sulfates on pig performance. Diagnosing the true nature of the problem can be extremely difficult, because in my experience, what we see with our eyes is not often reflected in what we measure as animal performance. By this, I mean that high sulfate water causes profuse diarrhea, which of course, is a pathology of gastrointestinal function. However, concurrently, we often see performance – rate and efficiency of gain - that is unimpaired!! The two seem incongruous. We are presented with pigs that are dirty and clearly suffering from watery diarrhea but they are growing very well.

The data in table 1 illustrates the point. Four week old pigs were fed one of three sources of water. The low sulfate water came from a city water source, while the other two came from a farm. The highest sulfate level is extremely high - higher than is typically seen in commercial practice. However, some aquifers contain water that is very rich in minerals. In this experiment, the water is well characterized, and it is clear that the water contains very high levels of sodium, and to a lesser extent calcium, sulfate. The pigs clearly had severe diarrhea, as evidenced by the scour score which increased with the level of sulfates in the water in a dose responsive manner. Yet, the growth performance was excellent, and the pigs drank more of the highly mineralized water as well. All of these findings were consistent with studies run prior to, and since, this study.

When I worked in the feed industry, we were often faced with customers dealing with water quality problems. When I had the opportunity to do research on the subject, I jumped at the chance. Yet, after many trials both on campus and on farm, the results were always the same – high sulfate water with attendant diarrhea was not associated with impaired pig performance.

Our results were met with skepticism. How could pigs that looked so bad be performing so well? It was clear that a more definitive, large-scale, on-farm study was required. The opportunity to fill this need presented itself, when a 1,200 sow single site farrow –to-finish operation invited us to undertake a study of water quality. They were using ground water that was very high in sulfates (1,650 ppm) and already had a reverse osmosis unit operating on site.

We enthusiastically accepted the invitation and completed two 4-week studies with pigs weaned at 3 weeks of age. There were 12 double pens and 1 single pen of barrows assigned per water treatment. In experiment 1, in addition to studying water source, two delivery systems – nipple versus bowl – were compared, while in experiment 2, the addition of ZnO to the feed was studied. The ground water contained about 3,100 ppm TDS while the RO water contained 219 ppm. The two waters contained 1,650 and 29 ppm sulfate, respectively. The performance results are presented in Table 3.

It is clear from these data that water with such a high sulfate content had no adverse effect on pig performance.

Extensive tissue analysis revealed that high sulfate water lowered brain calcium, and elevated kidney and liver calcium. Otherwise, all mineral levels in the brain, kidney, liver and muscle were unchanged by water treatment. Finally, nutrient digestibility was measured during the course of the experiment, revealing that apparent total tract digestibility of dry matter, energy, nitrogen or fiber in spite of the profuse diarrhea. This was a very intensive study, conducted under farm conditions, and again, we failed to observe any meaningful impact of water quality on weanling pig performance.

These results, indicating that pigs can tolerate high levels of sulfates in the drinking water without adverse impacts on growth performance but with blatant osmotic diarrhea, agree with many other studies, conducted in our own lab (McLeese et al., 1992; Maenz et al., 1994) and by others (Veenhuizen et al., 1992; Gomez et al., 1995). Indeed, Maenz et al (1994) exposed 28-day old pigs fed high levels of mineral in the drinking water with a concurrent cold stress and still observed no adverse effects due to water quality.

5. Conclusions

There is only one reasonable conclusion from all of these studies. Pigs can tolerate relatively high levels of sulfate in the drinking water without suffering impaired performance – provided the associated diarrhea is non-pathogenic in origin. If impaired performance is observed in the presence of high sulfate water, then other causes should be investigated.

There are still many unanswered questions on the topic of water quality in pork production. For example, does high sulfate water impair sow productivity, or the health of their off-spring? Does the presence of high sulfate water, and attendant osmotic diarrhea, make pigs more susceptible to pathogenic diarrhea? There simply is insufficient or no data available.

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Table 3: Comparison of the performance of weaned pigs given high sulfate ground water or the same water treated by reverse osmosis.

	Untreated		Reverse osmosis		SEM
	Nipple	Dish	Nipple	Dish	
Experiment #1					
Initial wt., kg	5.97	5.85	5.73	6.06	
Final wt., kg	21.25	21.39	20.18	21.77	0.89
ADG, g/d	437	444	413	449	11
ADFI, g/d	675	665	637	668	19
Gain:feed	0.651	0.672	0.650	0.673	0.013
Feed:gain	1.53	1.49	1.54	1.49	
Water disappearance, L/d	2.972	1.666	2.636	1.679	0.234
Experiment #2					
Zinc Added (3,000 ppm)	-	+	-	+	
Initial wt., kg	5.84	5.85	5.85	5.89	
Final wt., kg	19.36	18.54	19.37	19.33	0.23
ADG, g/d	410	385	410	407	7
ADFI, g/d	674	607	654	642	16
Gain:feed	0.611	0.607	0.654	0.642	0.016
Feed:gain	1.64	1.65	1.53	1.64	

Source: Patience et al., 2004
Effect of drinker significant: gain:feed ($P < 0.10$), water disappearance ($P < 0.001$)
Effect of zinc significant: ADG ($P < 0.05$)
Interaction between zinc treatment and water source significant: ADFI ($P < 0.05$)

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