Dietary Modification for Reducing Electrical Conductivity of Piggery Wastewater

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ABSTRACT : A total of 108 pigs (including 36 starters, 36 growers, and 36 finishers) were randomly allocated to six treatments, which involved a 2 (Crude Protein (CP): 100 and 80% of control diet)×3 (Ca, P, Salt (CPS): 100, 80 and 60% of control diet) factorial design to evaluate the effectiveness of reducing CP and CPS in reducing wastewater EC in different stages. Another 72 starters were adopted to examine the effect of the six treatment diets (as mentioned above) on the growth performance of pigs. Activated carbon and Reverse Osmosis System (RO) were adopted to examine the reducing efficiency of wastewater EC, and ion analysis was also applied to compare with the wastewater EC in different stages of the metabolism trial. The results of wastewater EC of the six treatment diets in different stages of metabolism trial demonstrated that diminishing dietary CP or CPS decreased wastewater EC. The largest decrease of EC was approximately 30%, and was achieved with 20 and 40% reduced dietary CP and CPS, respectively. Pig growth performance deteriorated somewhat when dietary CP or CPS was diminished. Wastewater ion concentration was not always consistent with dietary CP or CPS content, except for NO_2^-, NH_4^+ and K^+, which were positively correlated with dietary CP or CPS in different stages. Activated carbon is not effective for reducing wastewater EC, while, RO system is effective (90% elimination rate) in reducing wastewater EC, but the EC of concentrated (excreted) water is around 10% higher than that of intact wastewater, representing an additional problem besides the high cost of RO system treatment. ***(Asian-Aust. J. Anim. Sci. 2005. Vol 18, No. 9 : 1343-1347)***

Key Words : Electrical Conductivity, Dietary Modification, Piggery Wastewater

INTRODUCTION

Electrical conductivity (EC) refers to the ability of an aqueous solution to carry electric current. This ability depends on the presence of ions, their total concentration, mobility, and valence, and the temperature of the solution. Most solutions composed of inorganic compounds are relatively good electrical conductors. Conversely, although some organic compounds dissociate in aqueous solutions which are very good electrical conductors, most molecules in organic compounds do not dissociate in aqueous solution.

Electrical conductivity becomes a problem when wastewater with an excessive EC level (above 750 μmhos/cm. 25°C; μS/cm) is used to irrigate crop fields. Typically, excessive EC level indicates excessive amounts of nutrients (salt) in the wastewater (Kenneth, 2003; Masters et al., 2005). Effluent water from pig farms in Taiwan is usually pumped into irrigation channels before flowing crop fields. According to Lin (1991), if the EC of irrigation water reaches 750 μS/cm, the soil EC level after two periods of irrigation will reach a threshold limit of 4,000 μS/cm at which crops cannot grow. However, the EC in effluent wastewater from most pig farms ranges 2,383 to 5,766 μS/cm (Lu et al., 1994), indicating that reducing EC levels in pig farm effluent is critical. Although bentonite has been typically added to abattoir effluent to ameliorate the highly toxic effect primarily high ammonia concentration on duckweed growth (Goopy et al., 2004), its specify referent effect on reducing EC in wastewater is limited. EC of water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminum cations. The ions in pig farm wastewater mainly come from slurry and washing water (for pig house cleaning). The variety of ions in slurry is a product of the composition of pig diets; therefore, decreasing dietary nutrient composition should reduce the EC level of wastewater excreted from pig farms. Investigations of the relationship between ions and diet are rare. This study attempted to determine the amount of EC in wastewater that can be eliminated by reducing crude protein (CP), calcium, phosphorus, and salt (CPS) content in pig diet.

MATERIALS AND METHODS

This study conducted five tests: a growth trial; metabolism trial; activated carbon (AC) test; reverse osmosis system (RO) test; and, ion concentration analysis.

Experimental diets

This study formulated 6 diets: 2 [crude protein (CP), 100 and 80% of control diet]×3 [calcium (C), phosphorus (P) and salt (S), CPS; 100, 80 and 60% of control diet, respectively]. The CP content of the control diets (100%) for starter (ST), grower (GR) and finisher (FN) were 20, 18 and 16%, respectively. The C, P and S content of control

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Table 1. Ingredients and diet formulations of control diets for starter, grower and finisher pigs (control diets, 100%)

Ingredients (%)	Starter	Grower	Finisher
Corn, dent, yellow	60.1	64.9	67.0
Soybean meal, 44%	25.7	28.6	23.6
Skim milk	4.0	-	-
Wheat bran	-	-	5.0
Fish meal, 65%	5.0	1.5	-
Limestone	0.85	1.02	1.07
Monocalcium phosphate	1.58	1.66	1.32
Salt	0.40	0.50	0.50
L-lysine	0.01	0.02	0.11
DL-methionine	0.02	-	-
Vitamins[a]	0.10	0.10	0.10
Minerals[b]	0.10	0.10	0.10
Soybean oil	2.14	1.60	1.20
Nutrient composition (calculated)			
Crude protein (%)	20.0	18.0	16.0
Digestible energy (kcal/kg)	3,480	3,433	3,376
Calcium (%)	1.00	0.90	0.80
Phosphorus (%)	0.83	0.75	0.67
Lysine (%)	1.25	1.05	0.93

[a] Each kg of vitamin premix contained: retinol 1,800 mg; cholecalciferol 20 mg alpha-tocopherol 20 g; riboflavin 4 g; cyanocobelamin 0.02 g; pantothenic acid 12 g; niacin 40 g; folic acid 0.4 g; biotin 0.1 g; choline chloride 50 g.

[b] Each kg of trace mineral premix contained: Cu 4.5 g; Fe 70 g; Mn 15 g; Zn 80 g; I 0.3 g.

diet (100%) were respectively, 1.00%, 0.83% and 0.40% for the ST diet, 0.90%, 0.75% and 0.50% for the GR diet, and 0.80%, 0.67% and 0.50% for the FN diet.

The 80% or 60% of CP or CPS were calculated by multiplying the 100% levels by 0.8 or 0.6, respectively. Table 1 lists the dietary formulations of control diets for the ST, GR and FN.

Metabolism trial

A total of 108 female pigs (three growth stages, with 36 ST of 10 kg bodyweight, 36 GR of 50 kg bodyweight and 36 FN of 80 kg bodyweight) were randomly (by stage) assigned to 18 metabolism cages (6 cages for each stage). Six diets were fed to 6 pigs in each stage and water was provided *ad libitum*. Six 10-day periods (replicates) were conducted. Fecal and urine samples were collected over a 7-day period, starting after 3 days of feeding. Wastewater EC was measured and compared following a two-step treatment: solid/liquid separation, then the ST, GR and FN slurries were mixed together (MIX), followed by aerobic treatment (AE); and, effluent water (EF). Electrical conductivity was measured with a Conductivity Meter LF330/SET (WTW Wissenschaftlich-Technische Werkstatten, Germany) at 25°C.

Growth trial

Ninety weaned pigs (4 weeks old) were used to examine the effect of reduced dietary CP and CPS on pig growth. Pigs were randomly assigned one of the 6 diets; both diet and water were provided *ad libitum*. All pigs were reared in concrete pens with 3 pigs per pen. Pigs and feed were weighed at 2 weekly intervals to measure the effect of growth performance, average daily gain (ADG), average daily feed intake (FI) and feed conversion ratio (FCR) (Feed/Gain).

Activated carbon test

Seven nylon bags containing 0, 5, 10, 20, 40, 80 and 120 g of activated carbon (AC) were immersed in seven one-liter beakers, each containing effluent water (EC, 2,520 µS/cm). These beakers then were placed in a cool room. The EC values of the effluent water in each beaker were measured and recorded daily for roughly 1 month.

Reverse osmosis test

A family-type reverse osmosis (RO) system (Chanson R/O system, RO-138) was connected to a small submersible pump (YA-500A, TASHUMA) to draw effluent water (ECs were 2,520 and 4,460 µS/cm) into the RO system. Two outlets, with one that connected with a plastic tube for excretion (concentrated) water and the other one connected with a high-pressure tank for preserve pure water, were also connected to this RO system. The pure water (from the high-pressure tank) and the excretion (concentrated) water (from the plastic tube) were gathered for EC measurements.

Ion concentration analysis

Ion concentrations, including those of cations and anions, were determined with ion chromatography (IC) (Metrohm AG, Switzerland). A stainless steel column (4.6 mm ID×150 mm) was used for cation analysis (MCIGEL SCK01 B6079, Mitsubishi Chemical Co., Japan). An electron capture detector (ECD) was used for IC analysis. The mobile phase was 5 Mm HNO_3 and flow rate was 1.0 ml/min. A stainless steel column (5.5 mm ID×150 mm) was used for anion analysis (UICSep AN300, USA); its mobile phase was either 1.7 mM $NaHCO_3$ or 1.8 mM $NaCO_3$ and the flow rate was 2.0 ml/min. The injection volume for IC analysis was 20 ml/min. The injection volume for IC analysis was 20 µl.

Statistical analysis

Data on pig growth performance for ADG, FI, and FCR, wastewater EC values of MIX, AE and EF from metabolism trials, and ion concentrations of effluent water from different stages of metabolic trials were analyzed with GLM procedure developed by the Statistical Analysis Systems Institute (SAS, 1990). The interactions of CP and CPS for all criteria were not statistically significant. Consequently, the effects of treatments were analyzed using the GLM procedure as a two-way ANOVA. When ANOVA revealed a

Table 2. Effects of CP and CPS on EC levels of wastewater in different stages

Stage	CP^{a} (%)		Significance	CPS^{b} (%)			Significance	CP×CPS
	100	80		100	80	60		
ST^{c}	3,456	3,149	NS	3,371	3,354	3,183	NS	NS
GR^{d}	2,789	2,403	NS	2,681	2,622	2,461	NS	NS
FN^{a}	3,798	2,863	*	3,674	3,454	2,936	NS	NS
MIX^{f}	3,677	2,864	*	3,414	3,311	3,084	NS	NS
AE^{g}	3,285	2,762	**	3,322^{a}	2,882^{b}	2,874^{b}	*	NS
EF^{h}	3,140	2,709	**	3,233^{a}	2,774^{b}	2,766^{b}	**	NS

** $p<0.01$, * $p<0.05$, NS: $p>0.05$.
[a] CP: Crude protein. [b] CPS: Calcium, phosphorus and salt. [c] ST: starter. [d] GR: Grower.
[e] FN: Finisher. [f] MIX: Mix with. ST, GR and FN. [g] AE: Aerobic. [h] EF: Effluent.

Table 3. Effects of CP and CPS on growth performances of pigs

	CP^{a} (%)		Significance	CPS^{b} (%)			Significance	CP×CPS
	100	80		100	80	60		
ADG^{i} (g/d)	780	770	NS	785	779	762	NS	NS
FI^{j} (kg/d)	1.99	2.03	NS	1.97	2.08	1.99	NS	NS
FCR^{k}	2.59	2.61	NS	2.52	2.63	2.63	NS	NS

NS: $p>0.05$. [a] CP: crude protein, [b] CPS: calcium, phosphorus and salt, [i] ADG: average daily gain, [j] FI: feed intake, [k] FCR: feed conversion ratio.

significant effect, the difference among treatment diets was tested using Duncan's new multiple range test (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

Metabolism, growth trial and ion assay

Table 2 and 3 list the results of metabolism and growth trials. Higher dietary CP produced higher EC in wastewater, particularly for wastewater from the FN stage ($p<0.05$), MIX stage ($p<0.05$), AE stage ($p<0.01$) and in EF ($p<0.01$). Higher dietary CPS in wastewater also occurred, but only in the AE and EF stages was the EC of wastewater for 100% CPS significantly higher than for 80% or 60% of CPS. Similar results were also found for growth performances, with high CP or CPS indicating higher ADG, lower FI and improved FCR. However, growth performance (including ADG, FI and FCR, Table 3) did not differ statistically between the high and low CP or CPS groups.

As noted, wastewater EC is products of inorganic ions, which are from feed nutrients which, after digestion, absorption and then dissociated by microbes, are excreted by pigs into the wastewater. Theoretically, nutrient and inorganic ion levels in wastewater should increase as dietary nutrients increase; however, as a result of the different digestion and absorption efficiencies of nutrients in pigs, and the variable dissociation rate of nutrient to inorganic ions, higher dietary nutrients (CP and CPS in this study) may not always increase the amount of inorganic ions in wastewater. The ion concentrations (data not shown) Cl^-, NO_2^-, NO_3^-, PO_4^{-2}, SO_4^{-2}, Na^+, $NH_4^+$and K^+ were not always in proportion to high dietary CP or CPS. In this study, only NO_2^-, NH_4^+ and K^+ displayed were positively correlated ($p>0.05$) with CP in all stages. The responses of other ions to CP or CPS in different stages varied. This result of finding demonstrates that EC in piggery wastewater is not a function of any single ion in wastewater, but rather is likely produced by a group of ions in wastewater. Conductivity is a reflection of the strength of the predominant ions in water (Prygiel and Coste, 1993; Maasdam and Smith, 1994), and is linearly related to the sum of cations (Mccutheon et al., 1993; Hounslow, 1995). However, because large cations may occur in wastewater, this study did not analyze all major cations in the wastewater. Therefore, this study was unable to predict which group of ions can explain the EC results.

Wang and Yin (1997), who investigated the correlation between EC and inorganic ions from the water of the Great Miami River, found EC was negatively correlated with NO_2^- plus NO_3^- (weak correlation, $r = -0.1633 \sim -0.2745$). However, in this investigation, when higher dietary CP produced higher EC in wastewater, NO_2^- plus NO_3^- were positive correlated (weak correlation, $r = 0.045 \sim 0.280$) with CP. Whether the different results in these two studies result from differences in water treatment requires further investigation.

Activated carbon test

Activated carbon (AC) filters have been employed in water purification systems primarily for removing taste and odor. Activated carbon effectively removes organic compounds such as volatile organic compounds, pesticides and benzene. Moreover, AC can also remove small amounts of metals, chlorine and radon (Rios et al., 2003). This investigation used 7 different quantities of AC to examine the efficiency of reducing EC by AC. Experimental results (Table 4) indicated that the EC of wastewater was lowest around on days 15-19 for 0, 5, 10, and 20 g of AC and then increased slowly. However, the EC level increased starting on the 2nd day until the end of the test for the 40, 80 and

Table 4. Effects of activated carbon treatment on the change of effluent water EC

Days	Activated carbon[a] (g)						
	0	5	10	20	40	80	120
1	2,520	2,520	2,520	2,520	2,520	2,520	2,520
2	2,480	2,550	2,610	2,660	3,000	3,620	3,920
6	2,300	2,410	2,500	2,600	2,700	3,650	3,760
8	2,160	2,300	2,400	2,530	2,680	3,690	3,800
15	2,070	2,190	2,230	2,410	2,630	3,730	3,910
19	2,100	2,230	2,190	2,340	2,620	3,810	3,990
23	2,130	2,310	2,210	2,360	2,640	3,910	4,100
27	2,150	2,420	2,210	2,370	2,640	4,010	4,170
33	2,170	2,570	2,220	2,400	2,640	4,140	4,200
36	2,190	2,630	2,240	2,450	2,650	4,370	4,280

[a] Activated carbon was packed in a fine nylon bag during the test period.

120 g AC treatments. As a result of the self-cleaning properties of water, the EC of the control group (0 g) decreased to 82% of that of the initial wastewater EC on day 15; the same trend was assumed for the 5, 10 and 20 g treatments. However, EC increased with increasing amounts of AC and test time. Bacterial growth during testing could account for the increasing AC content and testing time also elevating EC concentration in the wastewater. Activated carbon can promote bacterial growth, especially when not used for a few days or when not changed at proper intervals. Most bacterial cells are negatively charged to varying degrees, and there are a few rare instances of bacterial cells, such as *S. maltophilia*, that are positively charged. The longer the test time last, the more bacteria that may die. When dead bacteria are degraded to organic and inorganic compounds, EC of wastewater may be elevated. This process may explain why EC increased when AC amounts and test time increased. This result demonstrated that AC is not a good material for reducing wastewater EC under long-term use.

Reverse osmosis system test

Osmosis is the process in which water flows through a semi-permeable membrane that blocks the transport of salts or other solutes. When two water volumes are separated by a semi-permeable membrane, water will flow from the low solute concentration side to the high solute concentration side. The flow can be reversed by applying external pressure on the higher solute concentration side; this process is called reverse osmosis (RO). In this study, a family-type of RO system was adopted to test the efficacy of RO on reduction of wastewater EC. There are two outlets in an RO system: a clean (low EC) water outlet for drinking water; and, a high EC (ion concentrated) outlet for disposable water. In this work two EC levels of original wastewater processed with RO were 2,520 and 4,460 μS/cm, respectively. Following RO system treatment, the EC of clean water (for drinking) was 279 and 388 μS/cm, respectively. The EC elimination rate was around 90% ($p<0.01$), indicating that the RO system efficiently eliminated EC (or ions). However, the EC of disposable (ion concentrated) water was around 10% higher (2,746 and 4,995 μS/cm, respectively) than that of the EC of original wastewater, creating a problem in addition to the high treatment cost of using an RO system to reduce piggery wastewater EC.

CONCLUSION

EC of pig farm wastewater can be reduced by reducing dietary CP and CPS concentrations. The optimum reduction rate is 30% (from 3,808 to 2,656 μS/cm for the FN stage, and from 3,737 to 2,634 μS/cm for the MIX stage), but for the EF stage, the reduction rate is 27% (from 3,297 to 2,433 μS/cm). Although AC can be used to remove organic compounds, it does not do a good job of reducing pig farm wastewater EC. The RO system can efficiently remove EC from wastewater, however, the high EC level of concentrated water excreted using the RO system represents another problem besides high treatment cost in applying the RO system.

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