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Benchmarking Water Use and Developing Strategies for Water Conservation in Swine Production Operations

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ABSTRACT The overall goal of the study was to reduce water consumption in swine operations to mitigate impact on water resources and to reduce production costs. A comprehensive literature review was conducted to identify water conservation strategies that can be adopted in swine operations, followed by a benchmark survey to determine current rate of water use in hog production operations in Saskatchewan. The comprehensive literature search showed that limited published work on innovative water conservation strategies that can lead to significant reduction in water use in swine barn operations is available. The benchmark survey revealed that there is a wide range of water usage and costs of water incurred per pig among barns which indicated significant opportunities to improve their water use efficiency and reduce costs. Various categories of existing conservation strategies were identified from the literature and from the survey, of which animal drinking and cleaning were identified as the top two areas where potential water savings can be achieved. Evaluation of selected conservation measures involving animal drinkers and different cleaning procedures were done in selected rooms at the barn facility of PSCI. Results indicated that relative to conventional nipple drinkers, the use of a drinking trough with side panel and constant water level saved significant amount of water through reduced water wastage without adversely affecting pig performance. High pressure washing using a conventional nozzle led to lesser time and water consumption during the cleaning process compared to other commercially-available nozzles. Further studies are needed to evaluate the performance of these water conservation measures in the other stages of production (i.e., breeding, farrowing, nursery) in order to provide a comprehensive economic analysis for the entire barn.

Keywords: Swine production, water consumption, pig drinkers, barn cleaning.

INTRODUCTION Water is a critical input in swine production, but it is often taken for granted because of the readily-available water supply at negligible cost in most swine production areas. In swine operations, water is used for animal drinking, cooling, cleaning, and domestic consumption. The rate of water use has impact on the overall production cost and on the environment. Indiscriminate use of water can increase the volume of waste water and manure slurry generated from the operation leading to added manure handling costs, while improper manure management particularly during land application can potentially lead to degradation of water bodies. Overall, very little effort has been done to assess the current water usage in various operations in swine facilities and to evaluate/develop measures to reduce overall water consumption. With increasing concern about the impact of swine production on air, land, and water, this research work was conceptualized to explore and develop measures that will enable swine operations to mitigate their impact on the environment.

The overall goal of this study was to reduce the rate of water use in swine operations, thereby reducing cost of production. Specifically, this study aimed to:

a. identify and compile the currently available water conservation management practices from work published elsewhere, and assess the applicability of these measures in swine production operations in Saskatchewan in terms of technical viability, economic costs for implementation, and benefits to the overall operation;
b. conduct a benchmark survey on actual water use per pig produced in representative swine operations in Saskatchewan; and
c. evaluate selected water conservation strategies implemented in an actual swine barn and assess their effectiveness in reducing overall water use.

MATERIALS AND METHODS

Comprehensive literature review Various scientific and industry publications available from universities, research institutions, publishers, and other related agencies in North America, Europe, and Asia were searched systematically to collect information on actual water use and existing water conservation practices that were developed and/or evaluated for swine production operations and other livestock facilities. The review included searches of library catalogues, databases of scientific publications, online resources, and other repositories of scientific and technical publications, in accordance with established procedures for conducting a scholarly review of literature.

Benchmarking survey across Saskatchewan A survey questionnaire was designed to gather information on actual water usage, water expenses, and production data over the last three years from several swine operations in Saskatchewan. Other information requested in the survey were type and size of the operation, average body weight of pigs sold or culled, and existing water conservation strategies (if any). The survey questionnaire was sent to 141 pork producers in Saskatchewan, which were determined from the PSCI and SaskPork databases. The three-year information on water use gathered from the survey was analyzed by calculating the average yearly volume of water used per pig sold (gallons/pig sold) and per 100-kg sold (gallons/100-kg pig sold); average yearly water expenses per pig sold ($/pig sold) and per 100-kg sold ($/100-kg pig sold) were also calculated.

Evaluation of most promising strategies in an actual swine barn Based on the information gathered from the literature review and the survey, the identified water conservation strategies were assessed by a set of criteria that considered the following aspects: effectiveness in reducing water use, impact on manure production, and effect on pig performance and other operational aspects (i.e., air quality). Results of the analysis indicated that animal drinking and cleaning were the two activities in the barn where significant water savings can be potentially achieved. Thus, detailed evaluation of various options for these activities were implemented in selected rooms at the Prairie

Swine Centre Inc. (PSCI) barn facility in Saskatoon, SK, and the impact of the measures on water use rates of the barn was monitored.

Animal drinking

In this experiment, a preliminary assessment of several possible choices of drinker types was done and the three most promising ones were selected for evaluation in a swine grow-finish room. The room had inside dimensions of 14.3 m x 11 m with 14 equally-sized pens (1.9 m x 4.8 m). Each pen was equipped with a commercial feeder and a test drinker; the feeders were of the same type but the drinkers were those selected for evaluation. Each pen held 12 grower-finisher pigs. Prior to the start of the experiment, the animals were weighed and sorted such that the average starting weights in each pen was within ± 1 kg of each other.

As shown in Figure 1, the three animal drinkers used included 1) nipple drinker (Control), 2) nipple drinker with side panel, and 3) a trough with side panel and constant water level. Only 12 pens (out of 14 pens in the room) were used in this experiment. The 12 pens were divided into four (3 pens per group); each group represented one replicate trial. The three test drinkers were randomly assigned to the 3 pens of each trial. The first week of the experiment was designated as acclimatization period of pigs with the test drinker while the remaining weeks were for data collection.

The performance of drinkers in terms of water disappearance (use), water wastage, water contamination level as well as effect on average daily gain (ADG) and average daily feed intake (ADFI) were assessed throughout one growth cycle (12 weeks) covering grower to finisher stages. Water disappearance was monitored using a water meter (Model C700, Elster; scale of 1 L and minimum sensitivity of 0.473 L/min) attached to each type of drinker. Water wastage was determined by installing a water collector underneath the floor slats just beneath the drinker. The water depth in the collector was measured daily using a meterstick; the measured water depth was converted to water volume using a calibration curve relating water depth and volume. The water contamination level in the drinkers was measured by monitoring the microbial ATP (adenosine triphosphate) present in the water using a luminometer (Ensure, Hygiena, Camarillo, CA, USA). In addition, ADG of pigs was determined through the average growth rates during each test period while ADFI was calculated by dividing the total weight of feed consumed by the product of number of pigs and number of days on feed.

D1

D2

D3

Figure 1. Three types of animal drinkers used: nipple (D1), nipple with side panel (D2), and a trough with side panel and constant water level (D3).

Cleaning

This experiment involved two different cleaning strategies which included 1) water sprinkling (soaking) prior to high pressure washing and 2) use of different high pressure washing nozzles. Two types of grow-finish rooms at the PSCI barn were used. The first type of room had inside dimension of 7.3 x 19.8 m with fully slatted concrete flooring. It had 20 equally-sized pens (1.8 x 2.4 m) with 6 pigs per pen. The second type of room had inside dimension of 5.5 x 14.6 m with partially slatted concrete flooring. It had a capacity of 72 pigs, equally divided among 6 pens (2.0 x 4.1 m).

Each cleaning strategy was assessed based on its impact on the amount of water consumed, time spent during subsequent washing, as well as surface cleanliness. Water consumption (sprinkling and high pressure washing) was monitored using water meters (Model C700, Elster Metering, ON; scale of 1 L, minimum detectable flowrate, 0.473 L/min). Water meter readings before and after each task were recorded, and the difference corresponded to the amount of water consumed. Start and end times for each task (sprinkling and high pressure washing) were also recorded using a timer. In case the worker needed to stop (i.e., move feeders or penning) while performing the high pressure washing, the time loss was accounted and was not included in determining the total time spent on washing. Surface cleanliness before and after high pressure washing was assessed by monitoring by taking sample swabs in specified locations (total area = 100 cm^2) within the pen. The ATP levels, which is an indicator of surface contamination, from the sample swabs were then determined using a luminometer. Changes in the levels of ATP from the sample swabs before and after cleaning represented a measure of the effectiveness of the employed cleaning procedure.

Due to the number of factors to be evaluated, this test was divided into two parts. Part 1 was done to evaluate the effect of water sprinkling (for 45 minutes) during high pressure washing of swine rooms with fully and partially slatted concrete flooring. The most effective procedure (with or without sprinkling) in each type of room was carried out in part 2 tests to assess the different high pressure washing nozzles. As shown in Figure 2, the four types of nozzles tested were conventional nozzle, Y-nozzle, water broom, and 4-in-1 nozzle. Each type of room was divided into four areas; each area was washed using the four different nozzles. This test was replicated five times.

Analysis of results

For tests involving animal drinking and cleaning, the effect of the treatments (i.e. drinkers, water sprinkling, high pressure washing nozzles) on the monitored parameters (water use, water loss, contamination levels, ADG, ADFI, and time spent during high pressure washing) was analyzed by following a randomized block design with ANOVA. The replicate trials were the blocking factor, of which the different treatments were evaluated randomly. Analyses of the main and interaction effects of the independent variables (treatments) on the dependent variables (monitored parameters) were done using Mixed Model procedure in SAS.

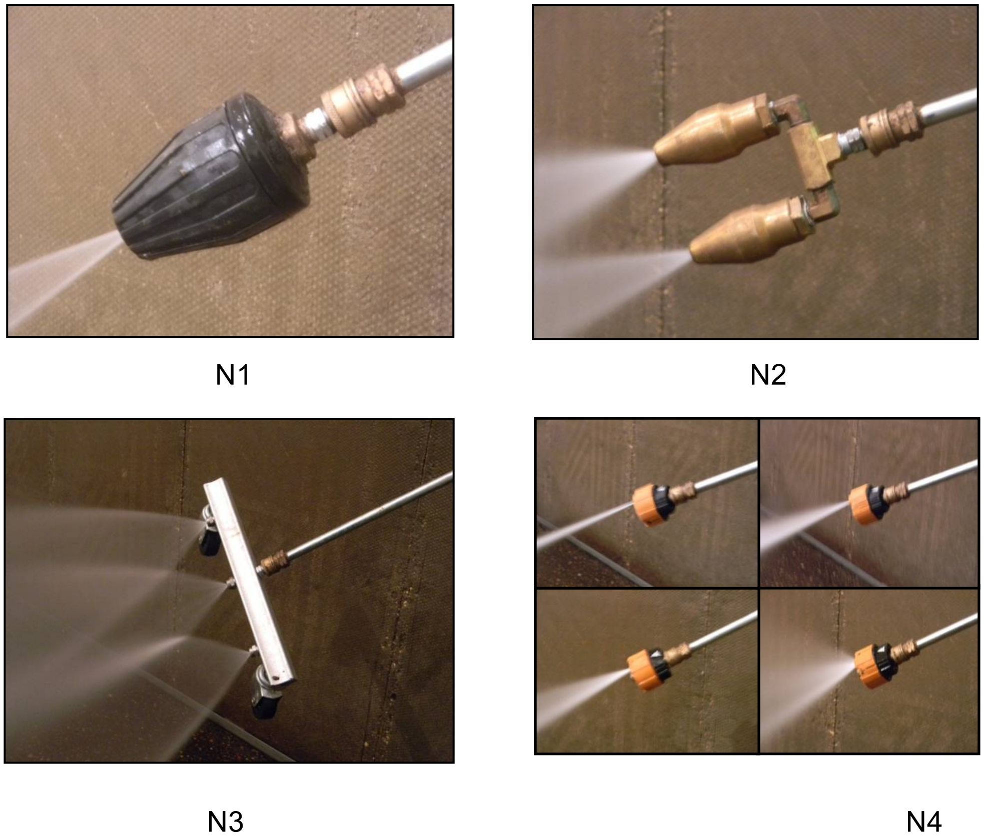

Figure 2. Four different types of power washing nozzles used: conventional nozzle (N1), Y-nozzle (N2), water broom (N3), and 4-in-1 nozzle (N4).

RESULTS AND DISCUSSION

Comprehensive literature review Despite the intensive and systematic effort exerted on searching past studies, the literature search yielded only very limited number of published work on water conservation measures relevant to the livestock industry. The search was expanded to include wider range of information sources (even in other languages), but limited additional information was obtained. Overall, the results of literature search yielded only few potential water conservation strategies including the use of different drinkers (Torrey et al., 2008; Magowan, 2007; McKerracher, 2007; Almond, 2002; Phillips and Phillips, 1999), diet manipulation (Almond, 2002) and different cooling (Adin et al., 2009; Haeussermann et al., 2007) and cleaning strategies (Hurnik, 2005; Almond, 2002).

Benchmarking survey A total of 29 survey forms was received from different swine barns, however not all returned forms have all the requested information filled out. The respondents represented a wide range of size and type of operations in Saskatchewan. Table 1 shows a summary of the rate of water use and cost of water for barns that provided the information necessary to calculate these parameters; some other respondents provided incomplete information on this part of the survey but contributed data on other aspects of the survey. Results showed that for farrow-to-finish barns, the volume of water use ranged from 67 to 2070 gallons per pig sold and the water expenses ranged from $0.07 to $2.70 per pig sold. For farrow-to-wean barns, the volume of water use ranged from 1,907 to 4,641 gallons per pig sold and 867 to 1,856 gallons per 100-kg pig sold. For grow-finish operations, the volume of water use ranged from 164 to 509 gallons per pig sold and water cost from $0.03 to $0.07 per pig sold. For nursery barns, the volume of water use ranged from 1,018 to 1,684 gallons per pig sold and 3,588 to 6,122 gallons per 100-kg pig sold. Although water expenses can not be computed for some of the barns due to incomplete information provided, the computed water expenses and volume of water per pig sold show a wide range of values, indicating that significant opportunities for savings are possible particularly for barns currently with high water consumption and costs.

Table 1. Summary of information collected from survey on rate of water use and water expenses.

Type & Size of operation	Water source	Rate of water use (3-yr average)		Estimated cost of water usage (3-yr average)	
		Gallons / pig sold	Gallons / 100-kg pig sold	$/pig sold	$/100-kg pig sold
Nursery (24,000 feeders/weanlings)	Dugout	1,684	6,122	$0.62	$2.25
Nursery (23,360 feeders/ weanlings)	Own groundwater well	1,018	3,588	$0.11	$0.38
Grow-Finish (10,000 feeders/weanlings)	Own groundwater well	509	432	$0.07	$0.06
Grow-Finish (7,600 feeders/weanlings)	Dugout	311	262	$0.05	$0.04
Grow-Finish (10,000 feeders/weanlings)	Own groundwater well	297	251	$0.04	$0.03
Grow-Finish (12,500 feeders/weanlings)	Dugout	246	207	$0.03	$0.03
Grow-Finish (4,500 feeders/weanlings)	Own groundwater well	164	305	No data	No data
Farrrow-to-Wean (6,000 sows)	Dugout	4,641	1,856	$0.49	$0.20
Farrrow-to-Wean (6,000 sows)	Dugout	4,640	1,856	$0.49	$0.20
Farrrow-to-Wean (1,300 sows)	Own groundwater well	1,907	867	No data	No data
Farrow-to-Finish (620 sows)	Own groundwater well	2,070	1,558	$0.28	$0.21
Farrow-to-Finish (300 sows)	Own groundwater well	781	658	$0.33	$0.28
Farrow-to-Finish (450 sows)	Own groundwater well	465	400	No data	No data
Farrow-to-Finish (600 sows)	Own groundwater well	369	294	$0.18	$0.14
Farrow-to-Finish (280 sows)	Municipal water system	337	398	$2.70	$3.19
Farrow-to-Finish (1,200 sows)	Own groundwater well	333	300	No data	No data
Farrow-to-Finish (1,200 sows)	Own groundwater well	305	889	$0.11	$0.35
Farrow-to-Finish (1,250 sows)	Own groundwater well	284	444	$0.07	$0.11
Farrow-to-Finish (500 sows)	Own groundwater well	274	388	No data	No data
Farrow-to-Finish (1,200 sows)	Own groundwater well	272	396	No data	No data
Farrow-to-Finish (1,200 sows)	Own groundwater well	258	643	$0.08	$0.21
Farrow-to-Finish (450 sows)	Own groundwater well	67	58	$0.11	$0.10

The list of conservation measures and the percentage of participating barns that employed the measures are shown in Table 2. Almost all barns have power washer with straight conventional nozzle attachment. About 76% of the barns pre-soaked the rooms before cleaning but only few use soap or warm water for cleaning. Among the drinkers, nipple drinkers were used by most barns and more than half of the participating barns used wet-dry feeders. Only few barns used bowls, troughs and ball-bite drinkers. Few barns used drippers to cool pigs/sows and 45% used spray/mist. Less than half of the participants adjust their nipple drinkers as the pigs grow and only 69% regularly inspected pipelines and drinkers for leaks. The rest of the barns fixed leaks as they noticeably occur.

The overall results of the survey showed that there are various opportunities to improve water use by choosing the right combination of conservation measures for application to areas where highest savings can be achieved.

Table 2. Existing water conservation measures employed in the respondent barns.

Water conservation measures	Percentage of respondent barns that employ the measure
1. Power washing w/ straight nozzle attachment	97%
2. Use of nipple drinker	97%
3. Pre-soaking rooms prior to cleaning	76%
4. Regular inspection of leaks	69%
5. Use of wet/dry feeder	59%
6. Use of warm or hot water for cleaning	52%
7. Use of spray/mist for cooling pigs	45%
8. Adjustment of nipple drinkers as pigs grow	41%
9. Use of drinking troughs	34%
10. Use of soap/cleaning agents	31%
11. Use of ball-bite drinker	14%
12. Use of drippers for cooling	10%
13. Use of drinking bowls	10%

Evaluation of most promising strategies in an actual swine barn Based on the results of literature review and the survey conducted, a total of 28 water conservation measures were identified. These conservation measures were evaluated by its applicability to areas with the highest contribution to the total water consumption in the barn as well as by using an assessment criteria that considered the following aspects: effectiveness in reducing water use, impact on manure production, and effect on pig performance and other operational aspects (i.e., air quality). As shown in Table 3, previous research conducted in Manitoba swine barns showed that animal drinking represented about 80% of the total water consumption in the barn; the rest was contributed by animal cooling, cleaning and domestic use (Froese, 2003). In addition, the application of the assessment criteria revealed that the use of high pressure nozzles during cleaning had the greatest potential for water savings. Based on the evaluation of the conservation measures identified in the literature review and the survey, animal drinking and cleaning were shown as the activities in the barn where highest water savings can be potentially achieved and thus, implemented in an actual swine barn for further evaluation.

Table 3. Summary of assessment of various categories of potential conservation measures.

Water conservation measure in different areas	Percent of the total water consumption in the barn[1], %	Assessment rating , %
A. Animal Drinking	80%	
1. Use of float bowl drinker		90%
2. Use of wet/dry feeder		89%
3. Use of push-lever bowl drinker		84%

B. Cooling pigs/sows	10-15%	
1. Use of spray/mist (Fan + Sprinkler)		80%
C. Cleaning	5-10%	
1. Use of high pressure water broom		96%
2. Pre-soaking rooms		78%

[1]Data from study of Froese, 2003.

Animal drinking

Figure 3 shows the performance of the test drinkers in terms of water disappearance (water use), water intake, and water wastage. Water intake was assumed to be the difference of water disappearance measured from the water meters and the water wastage measured from the water wastage collectors installed under each drinker. Due to problems with the installation of water wastage collectors, monitoring water wastage at the early part of the trials was not possible, thus the data collected were water disappearance (water intake plus water wastage) only. However, in parts of the trial where water wastage was measured, it was found that about 60% less water wastage was achieved when a trough with side panel and constant water level (1.27 L/day-pig) was used compared to the nipple drinker alone (3.77 L/day-pig) and the nipple with side panel (3.57 L/day-pig) (Figure 3). Significant difference ($p<0.05$) in water wastage between the trough with side panel and constant water level and the nipple drinkers was observed, with the biggest difference occurring when pigs were nearly at market weight. This observation led to lower total water disappearance (consumed + wastage) in trough with side panel and constant water level (6.7 L/day-pig) compared to the nipple drinker (8.175 L/day-pig) and the nipple with side panel (8.025 L/day-pig). Even with the substantial decrease in water disappearance, the net water intake of the pigs from the trough with side panel and constant water level (after subtracting the water wastage) was still within the water intake requirements for grower-finisher pigs (4.5 – 10 L/day-pig).

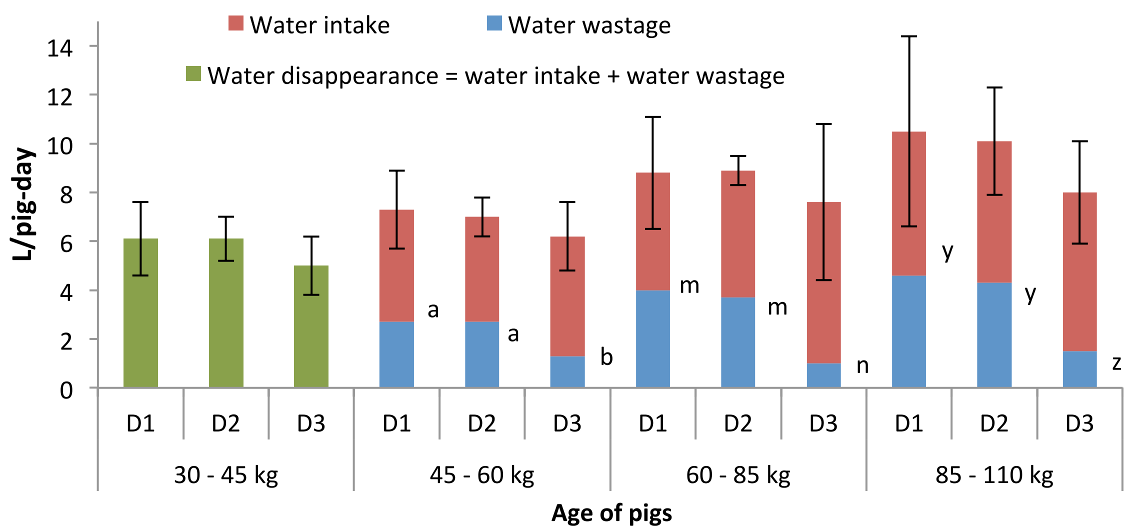

Figure 3. Effect of different types of drinkers on water disappearance, intake and wastage, n=4. Means (water wastage) with the same letters are not significantly different ($p>0.05$) from each other. D1 – Nipple; D2 – Nipple with side panel; D3 – Trough with side panel and constant water level.

The effect of the drinkers on microbial ATP counts as well as ADG and ADFI is shown in Table 4. The water in the trough had significantly higher microbial ATP (adenosine triphosphate) levels (indicating contamination with organic material) than the water drawn from nipple drinkers. However, this did not affect pig performance since the use of the trough with side panel and constant water level had no significant effect (*p>0.05*) on average daily gain and average daily feed intake of pigs. Further investigation is needed to find out the type of microorganisms present in the water in the trough and its potential effects on the pigs other than ADG and ADFI.

Table 4. Mean (± SD) of microbial ATP counts and pig performance of the different drinkers.

Parameters	Nipple	Nipple with side panel	Trough with side panel
Microbial population (ATP), RLU[1]	48 ± 24^{a}		3293 ± 3418^{b}
Average daily gain (ADG), kg/pig-day[2]	1.03 ± 0.10	1.04 ± 0.08	1.02 ± 0.08
Average daily feed intake (ADFI), kg/pig-day[2]	2.75 ± 0.50	2.91 ± 0.53	2.74 ± 0.47

[1]RLU is relative light units; as indicated by the different letters denoting the mean values, nipple drinkers and trough with side panel and constant water level are significantly different (*p<0.05*) from each other (n=16).
[2]ADG and ADFI are not significantly different (*p>0.05*), n=4.

Cleaning

Table 5 shows the effect of water sprinkling (soaking) on water consumed and time spent during subsequent high pressure washing. As expected, water sprinkling in fully and partially slatted concrete flooring resulted to significantly higher (*p<0.05)* water consumption than without sprinkling, mainly due to the additional water used during the sprinkling step. In addition, the time spent during the subsequent high pressure washing in a fully slatted concrete flooring with water sprinkling led to about 0.2 min/m^2 less than without sprinkling, although the difference was not significant (*p>0.05*). These results indicated that in a swine room with fully slatted concrete flooring, high pressure washing can be done without water sprinkling. However, significantly more time (*p<0.05*) was needed when washing a partially slatted concrete flooring without sprinkling than with sprinkling. This could be due to the thick crust of manure usually deposited in the solid floor area of the partially-slatted pen, which needed additional time to clean if not pre-soaked with water.

Table 5. Mean ± SD of water consumed and time spent during subsequent high pressure washing when cleaning a swine room with and without sprinkling, n=5.

Type of room/ flooring	Parameters per unit floor area	With sprinkling[1]	Without sprinkling
Fully slatted	Water consumed, L/m^2	28.4 ± 1.8^{a}	22.9 ± 2.6^{b}
	Time spent (washing only), min/m^2	1.7 ± 0.2^{y}	1.9 ± 0.2^{y}
Partially slatted	Water consumed, L/m^2	40.8 ± 1.0^{c}	34.9 ± 0.7^{d}
	Time spent (washing only), min/m^2	2.2 ± 0.1^{m}	2.9 ± 0.1^{n}

[1]Mean values denoted with same letters along the same row are not significantly different (*p>0.05*) from each other.

The above tests indicated that water sprinkling was not a significant factor in subsequent high pressure washing, thus the experiment involving different types of high pressure washing nozzles was carried out without water sprinkling. As shown in Figure 4, the use of the conventional nozzle led to the lowest water volume consumed and time spent in washing rooms with partially and fully slatted concrete flooring among all test nozzles. The conventional nozzle had a zero degree tip but due to its rotating capability, the resulting water stream spanned about 15 to 25 degrees (with respect to straight or zero-degree line) and formed a circular pattern. This unique feature may have achieved the desirable combination of high impact pressure necessary to break up and wash out the manure deposited on the floor and good cleaning coverage.

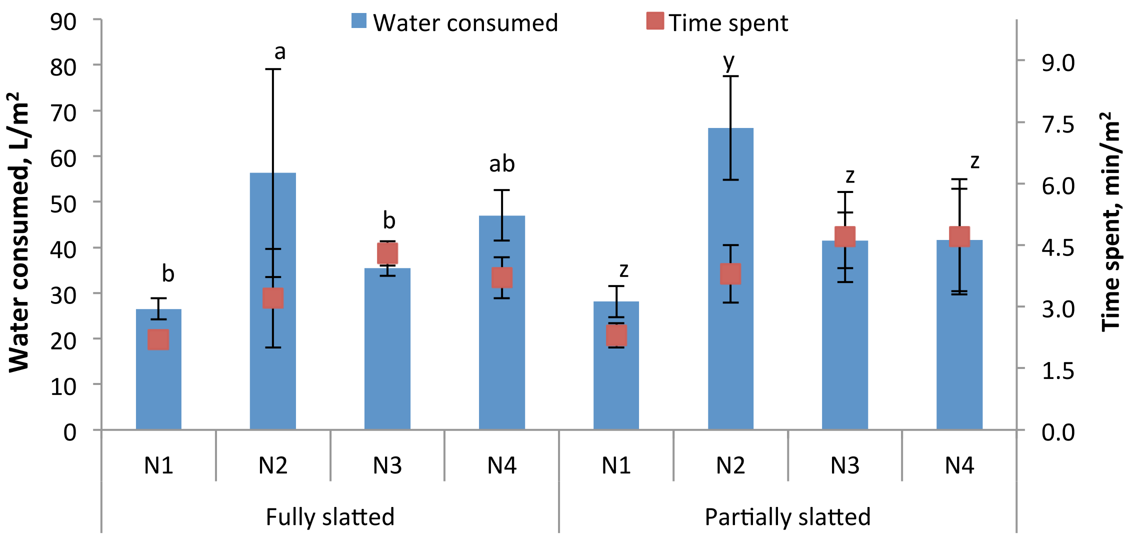

Figure 4. Effect of different types of nozzles on time and water consumption during high-pressure washing, n=5. Means with the same letters within the same type of flooring are not significantly different ($p>0.05$) from each other. N1 – Conventional nozzle; N2 – Y-nozzle; N3 – Water broom; N4 – 4-in-1 nozzle.

Table 6 shows the effect of the different types of nozzles on surface cleanliness. The conventional nozzle achieved the highest significant reduction ($p<0.05$) in microbial ATPs of concrete surfaces (measured before and after washing) among all test nozzles. This could be due to the high impact pressure created by the conventional nozzle on concrete floor. On the other hand, the use of the Y-nozzle achieved 81.2% reduction in microbial ATPs on plastic penning, the highest among all nozzles. This was not significantly different ($p>0.05$) from the conventional nozzle but significantly different ($p<0.05$) from the water broom and the 4-in-1 nozzle.

Table 6. Mean reduction (in %) in microbial ATPs on concrete and plastic surfaces (before and after cleaning) using different nozzles, n=10.

Surface	Conventional nozzle	Y-nozzle	Water broom	4-in-1 nozzle
Concrete	62.6 ± 6.7^{a}	34.4 ± 5.4^{b}	16.0 ± 5.2^{b}	33.0 ± 3.5^{b}
Plastic	68.5 ± 6.0^{mn}	81.2 ± 3.8^{m}	53.3 ± 5.3^{n}	54.9 ± 10.1^{n}

Mean values denoted with same letters along the same row are not significantly different ($p>0.05$) from each other.

CONCLUSIONS The comprehensive literature search yielded a number of potential water conservation strategies but most of these were either previously adopted or were tried out in swine barns to some extent; no new or unique water conservation measures developed in other applications that can be practically applied in existing swine production operations for significant potential reduction in water consumption were identified. Additionally, the benchmark survey revealed that many producers currently do not keep track of their water usage in their operations, and thus had no information on the quantity of water they use nor the water expenses incurred in running their operations. Evaluation of selected conservation measures involving animal drinkers and different cleaning procedures revealed that relative to conventional nipple drinkers, the use of a drinking trough with side panel and constant water level saved significant amount of water (8.175 L/day-pig vs. 6.7 L/day-pig) through reduced water wastage (3.77 L/day-pig vs. 1.27 L/day-pig) without adversely affecting pig performance. High pressure washing using a conventional nozzle led to lesser time and water consumption during the cleaning process. Also, high pressure washing in fully slatted concrete flooring can be done without prior water sprinkling (soaking).

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