Water use patterns within each day: Variation between batches of growing pigs in commercial production systems

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Summary

Objective: To measure, describe, and compare the water use patterns within each day for multiple cohorts of weaner, grower, and finisher pigs in farm buildings.

Materials and methods: Prospective, observational cohort studies of the water use patterns within each day were conducted in 5 pig buildings using either a turbine or ultrasonic water flow meter attached to the main water pipe entering each building. Water use data were collected from multiple batches of pigs (second-stage weaners over eleven, 48-day periods and grower-finishers over 4 periods of 21-43 days). Semi-parametric models of pig water use patterns within each day were estimated using the brms software package in R. To estimate the interacting effects of time and pig body weight on water use by pigs, we used tensor product smooths for time and pig body weight.

Results: The water use pattern within each day varied between the cohorts, and the pattern of many cohorts changed as the pigs gained weight. Some patterns were unimodal and others were bimodal, with the main peak in water use occurring early afternoon to late afternoon.

Implications: Water use patterns of pigs within each day varied between and within cohorts. The water use pattern of one cohort cannot be used reliably to predict that of other cohorts, even if they are reared in the same building. Water use pattern data may be valuable for optimizing in-water antimicrobial dosing regimens.

Keywords: swine, drinking water, water flow, semi-parametric models, water medication

Received: December 20, 2021
Accepted: May 25, 2022

Resumen - Patrones de uso de agua en el mismo día: variación entre lotes de cerdos de crecimiento en sistemas de producción comercial

Objetivo: Medir, describir, y comparar los patrones de uso de agua en el mismo día para múltiples cohortes de cerdos destetados, en crecimiento, y finalización en edificios de una granja.

Materiales y métodos: Se realizaron estudios de cohortes observacionales prospectivos de los patrones de uso de agua en el mismo día en 5 granjas porcinas utilizando una turbina o un medidor de flujo de agua ultrasónico conectados a la tubería de agua principal que ingresa a cada edificio. Los datos de uso de agua se recopilaron de múltiples lotes de cerdos (destetados de segunda etapa durante once períodos de 48 días y cerdos de engorde durante 4 períodos de 21 a 43 días). Se estimaron modelos semiparamétricos de patrones de uso de agua por cerdo dentro de cada día utilizando el paquete del programa brms en R. Para estimar los efectos interactivos del tiempo y el peso corporal del cerdo en el uso del agua por parte de los cerdos, utilizamos productos tensoriales suavizados para el tiempo y el peso corporal del cerdo.

Resultados: El patrón de uso de agua dentro de cada día varió entre las cohortes y el patrón de muchos cohortes cambió a medida que los cerdos aumentaban de peso. Algunos patrones fueron unimodales y otros bimodales y el pico principal en el uso de agua se produjo desde la primera hora de la tarde hasta la final tarde.

Implicaciones: Los patrones de uso de agua de los cerdos dentro de cada día variaron entre y dentro de las cohortes. El patrón de uso del agua de una cohorte no se puede usar de manera confiable para predecir el de otros cohortes, incluso si se crían en el mismo edificio. Los datos del patrón de uso del agua pueden ser valiosos para optimizar los regímenes de dosificación de antimicrobianos en el agua.

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This article was derived from Stephen Little's PhD thesis, University of Melbourne, Parkville, Victoria, Australia.

Supplementary materials available at **https://doi.org/10.54846/jshap/1297suppl**.

Little SB, Woodward AP, Browning GF, Billman-Jocobe H. Water use patterns within each day: Variation between batches of growing pigs in commercial production systems. *J Swine Health Prod*. 2023;31(1):20-28. **https://doi.org/10.54846/jshap/1297**.

Résumé - Modèles d'utilisation de l'eau au cours de chaque journée: variation entre les lots de porcs en croissance dans les systèmes de production commerciale

Objectif: Mesurer, décrire et comparer les patrons d'utilisation de l'eau au cours de chaque journée pour plusieurs cohortes de porcs sevrés, en croissance et en finition dans les bâtiments de la ferme.

Matériels et méthodes: Des études de cohorte prospectives et observationnelles des patrons d'utilisation de l'eau au cours de chaque journée ont été menées dans cinq porcheries à l'aide d'un débitmètre à turbine ou à ultrasons fixé à la conduite d'eau principale entrant dans chaque bâtiment. Les données sur l'utilisation de l'eau ont été recueillies auprès de plusieurs lots de porcs (les porcs sevrés au deuxième stade sur onze périodes de 48 jours et les porcs en croissance-finition sur quatre périodes de 21 à 43 jours). Des modèles semi-paramétriques des patrons d'utilisation de l'eau par les porcs au cours de chaque journée ont été estimés à l'aide du progiciel brms dans R. Pour estimer les effets interactifs du temps et du poids corporel des porcs sur l'utilisation d'eau par les porcs, nous avons utilisé des lissages de produits tensoriels pour le temps et le poids corporel des porcs.

Résultats: Le patron d'utilisation de l'eau au cours de chaque journée variait entre les cohortes, et le patron de nombreuses cohortes changeait à mesure que les porcs prenaient du poids. Certains patrons étaient unimodaux et d'autres étaient bimodaux, le principal pic d'utilisation de l'eau se produisant du début de l'après-midi au la fin de l'après-midi.

Implications: Les patrons d'utilisation de l'eau des porcs au cours de chaque journée variaient entre les cohortes et au sein de celles-ci. Le patron d'utilisation de l'eau d'une cohorte ne peut pas être utilisé de manière fiable pour prédire celui des autres cohortes, même si elles sont élevées dans le même bâtiment. Les données sur les patrons d'utilisation de l'eau peuvent être utiles pour optimiser les schémas posologiques d'antimicrobiens dans l'eau.

Growing pigs use 60% to 65% of the total volume of water consumed by the pig industry.[1] Water is an essential resource on pig farms and approximately 80% of total farm water use is for animal drinking, with the remaining 20% used for animal cooling and facility cleaning.[1] Pigs must maintain a balance between bodily water intake and output. Most (> 75%) of the total daily bodily water intake of a pig is water consumed by drinking.[2] Daily voluntary water use by pigs, ie, water consumed and wasted, is a function of their body weight (BW). This has been measured with various combinations of drinker types, heights, and water flow rates, and averages between 60 and 117 mL/kg BW across studies.[3-5] Water use by pigs is influenced by the time of day. Pigs drink mostly during daylight hours, with their bouts of drinking occurring within 1 to 2 hours of meals.[6-8] The peak period of water use occurs in the afternoon, sometimes with a secondary peak in the morning.[9-17]

Published studies that report the water use patterns of pigs within each day have varied widely in cohort sizes and study duration. Some studies have used water flow meters to describe water use patterns volumetrically, while others have used video recordings to describe water use patterns in terms of the time pigs spend drinking. The statistical methods used to analyze water consumption have not evaluated the dependence of water use by pigs in a given hour on their water use in previous hours (autocorrelation),[18] and changes in water use patterns within each day over successive days as BW increases have not been studied. This study aimed to describe and compare the water use patterns within each day for multiple cohorts of second-stage weaners (many of which were reared in the same building) and of grower and finisher pigs in 2 buildings. The objectives were to 1) assess the extent of variation in the water use pattern within each day across the cohorts, including those reared in the same building; 2) assess the extent to which the water use pattern within each day for each cohort changed as pigs gained weight; and 3) determine whether the water use pattern within each day for a cohort of pigs could be used reliably to predict the patterns of future pig cohorts in the same building or a building of similar design. The water use pattern within each day for a cohort of pigs has implications for in-water administration of antimicrobials and other additives, as it has a substantial impact on water flow rates in each pipe section of the building's water distribution system from hour-to-hour and therefore, on the time course of antimicrobial concentration in water available to pigs at drinkers in each pen. The water use pattern also affects the volume of medicated water consumed by pigs throughout the building hour-to-hour after the antimicrobial first arrives at the drinkers to which they have access.[19]

Animal care and use

An animal use protocol was not necessary for this study as no animals were involved. Water flow data were collected from meters installed in the main water pipe entering each building. Pigs within each building were reared according to routine commercial farm practices in compliance with the standards prescribed by the Australian Pork Industry Quality Assurance Program.

Materials and methods

Data collection

Three studies of pig water use were conducted in commercial production environments on 3 farms located in southeastern Australia. Study 1 was conducted in second-stage weaner buildings A1, A2, and A3 on farm 1. These 3 buildings were identical in their dimensions and configuration (Table 1). Studies 2 and 3 were conducted in grower-finisher buildings B and C on farm 2 and farm 3, respectively. The mean age and approximate BW of each pig cohort upon entry to and exit from a building are provided in Table 1. The BW values were estimates from the generalized pig growth curve used by each farm. Pigs were fed *ad libitum* with a pelleted ration formulated to meet the nutritional requirements of weaner pigs and grower-finisher pigs as specified by the National Research Council (2012).[20] No health challenges were reported by farm staff during the measurement periods. For Study 1, water flow was continuously measured using a turbine water flow meter (Zenner GmbH) installed in the main water pipe entering each building. For Studies 2 and 3, water flow was measured using a clamp-on, doppler-type ultrasonic water flow meter with two transducers (Flexim Fluxus F601;

Table 1: Description of pigs and buildings in studies 1, 2, and 3

	Study 1	Study 2	Study 3
Farm	1	2	3
Building	A1, A2, and A3	B	C
Ventilation & lighting	Controlled	Natural	Natural
Temp, °C	27-18*	Min: 5-13† Max: 18-31†	Min: 3-5† Max: 14-15†
Daylight/d, hrs	18*	10-13†	9.5-11†
Feeders	Wet/dry feeders	Wet/dry feeders	Wet/dry feeders
Floor	Mesh, fully slatted	Concrete, partially slatted	Concrete, partially slatted
Cohorts	11	1	1
Pigs/cohort	2150	2116	2768
Sex	Male and female	Male and female	Male and female
BW at entry, kg‡	8.5	23	29
Entry age, d	35	63	72
BW at exit, kg‡	28	97	70
Exit age, d	82	161	127
Occupancy period, d	48	99	55
Pig flow	All-in, all-out	All-in, all-out	All-in, all-out
Pipe material§	Polyethylene	PVC	PVC
Pipe interior diameter, mm§	40	50	50
Drinker type	Bowl¶	Nipple (in wet/dry feeder)	Nipple¶
Pigs/drinker	15	7	7
Main water source	Underground water	50% underground water and 50% surface water	Town water
Water use measurement periods, d	48	43 (grower phase); 34 (finisher phase)	22 (grower phase); 21 (finisher phase)
Study period	Jul 2020-Mar 2021	Feb-May 2021	Jun-Aug 2021

* Set internal building temperature and lighting program.

† Based on local weather station data.

‡ Estimated bodyweight from the generalized pig growth curve used by each farm.

§ At entry to building where water meter installed.

¶ Drinkers in addition to nipple drinkers within wet/dry feeders.

BW = body weight; PVC = polyvinyl chloride.

Flexim GmbH). Volumetric flow rate data (recorded in increments of 2 minutes using the Zenner water meter and 1 minute using the Flexim Fluxus F601) for each measurement period were exported from each flow meter as a .csv file and summed in Microsoft Excel (Microsoft Corporation) to calculate water use per hour per day over the measurement period. The 1 and 2 minute observations of water flow rate were aggregated into 1 hour periods as described by Madsen and Kristensen.[9]

Estimation of models for cohort water use patterns

Models of pig water use patterns within each day were estimated using the software package brms,[21] which provides an interface to fit Bayesian generalized (non)linear multivariate multilevel models in R,[22] using the probabilistic programming language Stan.[23] The Bayesian inference method was used because it has some advantages over frequentist methods: a hierarchical structure that offered greater flexibility with the ability to readily use datasets of varying sizes and to specify and analyze complex hierarchical models, and a more coherent expression of uncertainty. As it employed a hierarchical generalized additive model (HGAM),[24] brms incorporated the dependence of pig water use in a given hour on their water use in previous hours and identified changes in water use patterns within each day over successive days as pigs gained weight.

Tensor product smooths for time and pig BW were used to estimate the interacting effects of time and pig BW on pig water use.[24] The effective sample sizes were evaluated and increased as necessary and the 'adapt_delta' argument altered to ensure that divergent transitions did not occur. For each model run in brms, for each smooth term, and group and population-level effects, chain convergence was assessed with the Rhat statistic and a value of 1.00 achieved, indicating that the chains had converged to a common distribution.[25] The final version of code used to fit the models in brms in R was:

```
R > Model <- brm(WATERPPIG_
L|cens(CENS)~1+s(TIME,DAY,
bs = 'fs')+t2(TIME,PIGWT), family =
Gamma(link = 'log'), data = (dataset),
cores = 4, iter = 4000, control = list(adapt_
delta = 0.99, max_treedepth = 12))
```

where s(TIME) is the population effect of time of day on water usage, s(TIME,DAY, bs = 'fs') is the day-level variation in the shape of water usage with time of day, and t2(TIME,PIGWT) is the population effect of both time of day and average BW on water usage. In the model, s(TIME) acted as a global smoother, whereas s(TIME,DAY) acted as a random smoother for each day. DAY was specified as a factor. We selected a gamma response probability distribution, as used in modeling human tap water use.[26] A cyclic spline function in R was not used to force alignment of each model's predictions at the end and start of the day.

In post processing, we obtained the following from each model: 1) a single common smooth for all observations by pig BW; 2) a single common smooth for all observations by time of day; 3) smooths specific to pigs on each day within the period reared in the building; and 4) smooths specific to pigs at 3 points in time (expressed as BW) as they gained weight during the measurement period (these BWs equated to the 25th, 50th, and 75th percentiles of the range from entry BW to exit BW based on the farm's generalized pig growth curve). Visualization of the tensor product smooths showing the interacting effects of time of day and BW on water use provided the most insights into the water use pattern within each day for the cohorts studied. As a measure of model fit, the mean posterior distribution of the R^2 value of each model was estimated using bayes_R2 in R.[27]

Results

Second-stage weaners on farm 1

Eleven cohorts of second-stage weaners (35-82 days of age) were studied in buildings A1, A2, and A3. In 9 cohorts, the water use pattern within each day was bimodal (Figure 1 A1-2, A1-3, A2-1, A2-2, A2-3, A2-4, A2-5, A3-1, and A3-3) and the pattern of 2 cohorts were unimodal (Figure 1 A1-1 and A3-2). In building A1, one cohort had a unimodal pattern while the next cohort in the building had a bimodal pattern (Figure 1 A1-1 and A1-2). In the 9 cohorts with a bimodal pattern, the first peak varied from distinct to barely distinguishable and peak water use occurred at approximately 06:00 to 08:00 and 17:00 to 18:00. In the 2 cohorts with a unimodal water use pattern, peak water use occurred at approximately 15:00 to 18:00. The bimodality increased over each cohort's 48-day occupancy period, as pigs gained weight. The afternoon peak shifted 1 to 2 hours earlier in 5 cohorts, 2 to 3 hours later in 3 cohorts, and did not shift in 3 cohorts.

Grower-finishers on farms 2 and 3

In the cohorts of grower-finisher pigs (9-21 weeks of age) in buildings on 2 farms, the water use pattern within each day was unimodal. In the cohort in building B on farm 2, peak water use occurred at approximately 13:00 to 15:00 in both grower and finisher phases (Figure 2 B-1 and B-2). This contrasted with the cohort of grower-finisher pigs in building C on farm 3, in which peak water use occurred at approximately 16:00 to 17:00 in the grower phase and shifted 2 to 3 hours earlier in the finisher phase to approximately 13:00 to 15:00 (Figure 2 C-1 and C-2). Peak water use in the grower-finisher cohorts in buildings B and C spanned shorter periods than those of the afternoon peak in the weaner cohorts on farm 1.

Discussion

The main findings from the study were that 1) the water use pattern within each day of the pig cohorts varied and the pattern of many cohorts changed as the pigs gained weight; 2) some patterns were unimodal and others were bimodal, with the main peak in water use occurring in the early afternoon to late afternoon; and 3) the water use pattern within each day of a pig cohort can therefore not be used reliably to predict the patterns of other cohorts, even if they are reared in the same building.

Our finding that the water use pattern of pigs within each day varied between and within cohorts is consistent with studies of feed consumption patterns within each day.[28] Nearly all the cohorts with a bimodal pattern had an alternans pattern, with a large peak in the afternoon and a smaller peak in the morning that varied in prominence. As with the bimodal feed consumption patterns within each day in cohorts of growing pigs fed *ad libitum*,[29] the alternans, bimodal water use patterns within each day that we identified tended to become more pronounced over successive days as pigs gained weight.

Differences in the water use pattern within each day for pig cohorts across buildings and seasons of the year may be due to differences in factors that influence many behavioral patterns in pigs. These factors include pig genetics and

Figure 1: Smooths showing the interacting effects of time of day and bodyweight (BW) on the water use of pigs within each day over eleven, 48-day water use measurement periods in buildings A1, A2, and A3 on farm 1 between July 2020 and March 2021. Three consecutive cohorts were reared in building A1 (A1-1, A1-2, and A1-3). Five consecutive cohorts were reared in building A2 (A2-1, A2-2, A2-3, A2-4, and A2-5). Three cohort groups were reared in building A3 (A3-1, A3-2, and A3-3). The smooths are specific to pigs at 3 points in time (expressed as BW) as they gained weight during the measurement period. In each smooth, the band edges represent the limits of a 95% credible interval. The random effect of DAY is set to zero. Means of the posterior distributions of the R^2 values for the eleven models were: 0.66-0.87; 2.5th credible limit: 0.6-0.91; 97.5th credible limit: 0.67-0.93.

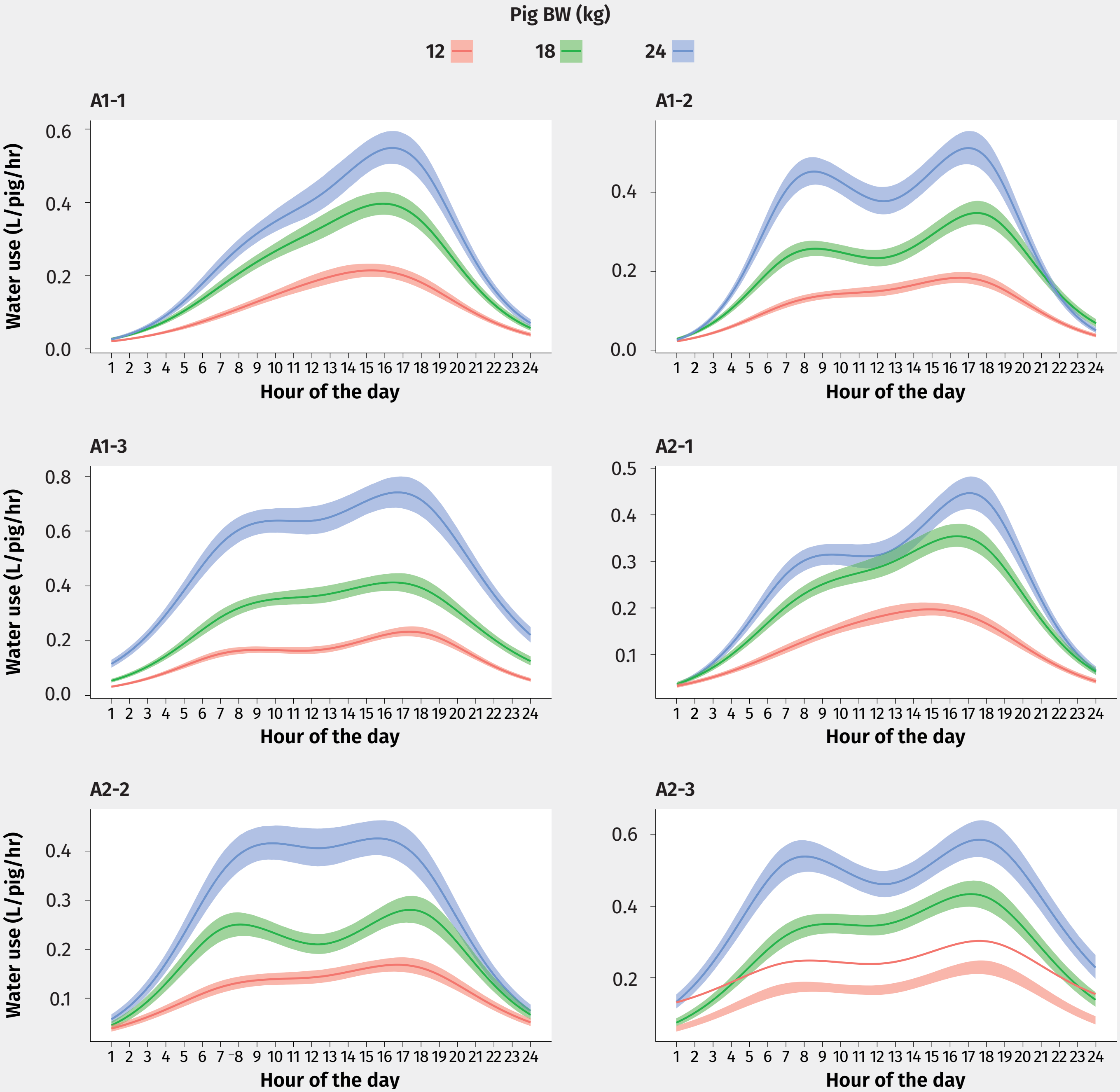


Figure 1: Continued

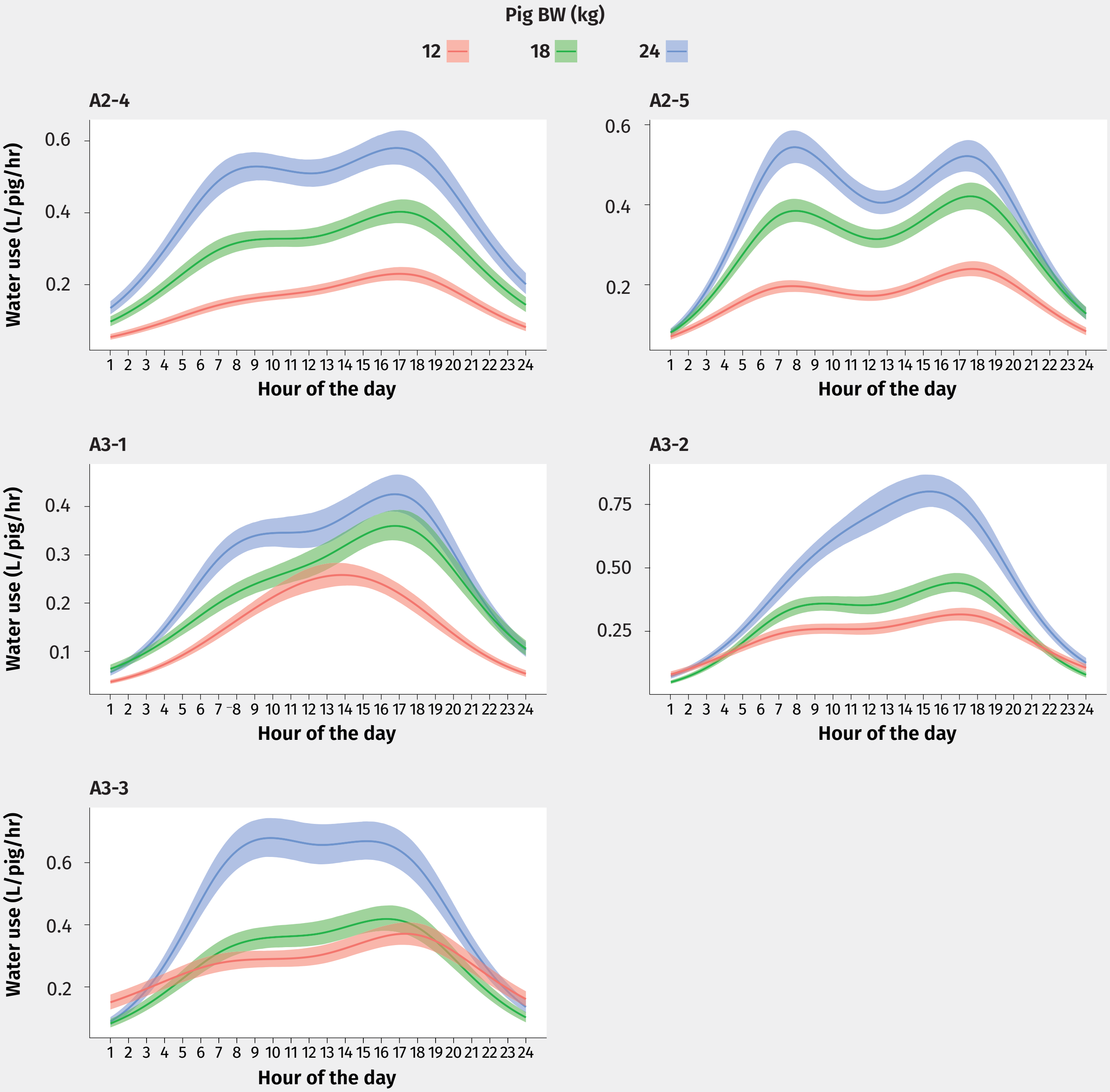
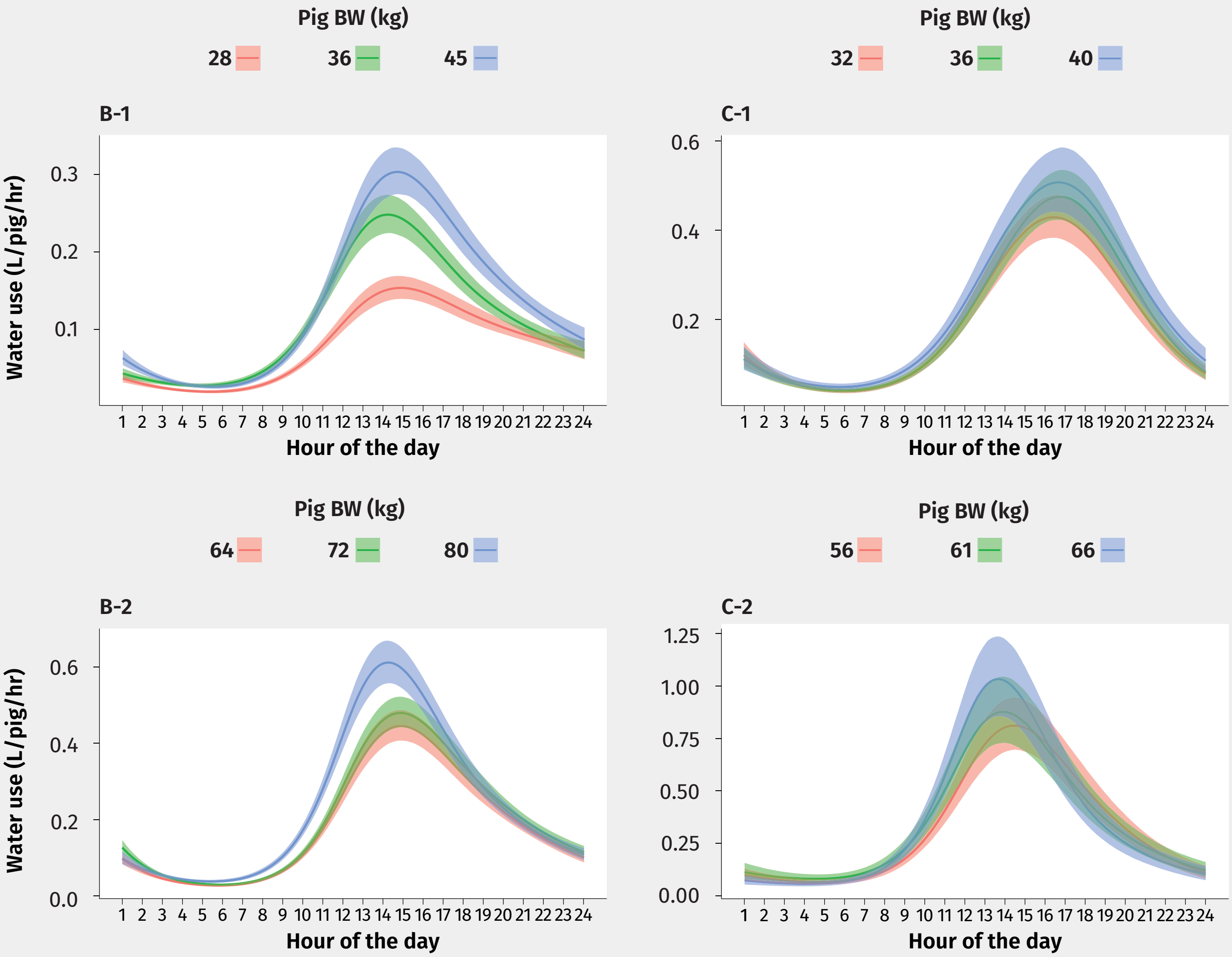


Figure 2: Smooths showing the interacting effects of time of day and bodyweight (BW) on the water use of pigs within each day in 2 cohorts of grower-finisher pigs in buildings on 2 farms in February to May 2021 and June to August 2021, respectively. B-1 and C-1) Smooths for the 2 cohorts in the grower phase. B-2 and C-2) Smooths for the same 2 cohorts in the finisher phase. The smooths are specific to pigs at 3 points in time (expressed as BW) as they gained weight during the measurement period. In each smooth, the band edges indicate the limits of a 95% credible interval. The random effect of DAY is set to zero. Means of the posterior distributions of the R^2 values for the four models were: 0.76-0.85; 2.5th credible limit: 0.74-0.84; 97.5th credible limit: 0.77-0.86.



health status, building type, group size and stocking density, drinker type, number and position of drinkers in each pen, water flow rates from drinkers, water quality, diet, level of competition between animals for water and feed access, type and spatial arrangement of drinkers and feeders within each pen, day length, and climatic conditions.[7,13] Many of these variables were well controlled in the weaner buildings where water use patterns within each day were measured for consecutive pig cohorts reared in the same building or buildings of identical design. While the 2 cohorts of grower-finisher pigs shared the same genetics, they differed in other factors influencing behavioral patterns. Factors not controlled across cohorts were health status and social factors that may affect competition between animals for water.

Installing a system in each farm building that continuously measures the daily water use of each growing pig cohort would be a valuable tool to the consulting veterinarian and herd manager by providing easily interpretable visual representations of water use patterns within each day over the preceding 7 days. It would enable regular checks to confirm that pigs were able to drink to satiety without restriction in the hour of peak water use. This would involve measuring flow rates from drinkers throughout the building to ensure they remain within the recommended range (0.25-0.5 L/min for weaner pigs and 0.5-1 L/min for grower-finisher pigs).[30] It would also be important to confirm the number of pigs per drinker in each pen was not above the recommended maximum. Historical data on pig water use patterns within each day may also be useful in designing a water distribution system for a new building or planning improvements to improve hydraulic performance of a water distribution system in an existing building.

Such a visual display system would also enable veterinarians and herd managers to optimize in-water dosing regimens for administering antimicrobials and other additives. By commencing an antimicrobial dosing event when pig water use is in an ascent phase and approaching a peak, the proportion of the total dose consumed throughout the building in the first 3 hours after the antimicrobial arrives at the drinkers could be maximized. Likewise, between-animal variation in the dose consumed by pigs accessing drinkers at different points along the water distribution system could be minimized. This would likely lead to a more rapid rise in antimicrobial concentration in plasma and at the site of infection in a high proportion of the pigs dosed, and earlier attainment of the pharmacokinetic-pharmacodynamic target that best predicts antimicrobial efficacy.[31,32] This should also help suppress emergent antimicrobial resistance by minimizing the length of time that the plasma antimicrobial concentration lies in the mutant selection window just above the minimum inhibitory concentration.[33,34] Using water use patterns within each day to design dosing regimens would also be valuable when administering other additives for which the degree of efficacy is dose dependant including vaccines, parasiticides, direct-fed microbials, and potential new therapeutic products such as bacteriophages.

The water use of pigs may be measured at a building level using either a turbine flow meter, electromagnetic flow meter, or ultrasonic flow meter attached to the main water pipe entering the building. Factors to consider when determining whether a particular water meter type and model is suitable for use on farm include the water flow range, level of accuracy and repeatability, sensitivity to poor water quality, ease of installation, portability, reliability, longevity, and cost. Characteristics of 3 types of water flow meters are provided in the supplementary materials. The water distribution systems in many conventional pig buildings (such as building B on farm 2) are over-sized relative to their typical peaking factor, ie, maximum daily use rate divided by the mean daily use rate.[35] As a consequence, water flow rates and velocities through main pipe sections in these water distribution systems tend to be very low over many hours each day. Water meters used in such buildings to measure water use patterns within each day must therefore be highly accurate at very low water velocities. For this study we chose to use a higher-end model of ultrasonic water meter that specified a minimum measurable flow velocity (0.01 m/s, with 1% variable error and 0.005 m/s fixed error). Other ultrasonic flow meter features found to be of value were its noninvasive installation (no pipe cutting was necessary), portability, ability to cope with particulate material in pipes, robustness due to absence of any moving parts, protection from rodent damage with stainless steel transducer cables, a protective, hard-shell carry case, ability to report water flow in either direction in a looped pipeline, and ability to reliably and quickly export data from the transmitter unit directly to a personal computer with a USB cable (ie, without relying on Bluetooth or Wi-Fi).

This is the first study of its kind and should be considered a first step in gaining a thorough understanding of the water use patterns of pigs within each day. Further studies are required to better understand the extent to which water use patterns of pig cohorts vary and the factors that influence pig water use patterns within each day, such as internal building temperature and humidity levels and patterns within each day. A limitation of this study was that water use was only measured at the building level and did not quantify the variation in water use at the pen or individual animal level. Furthermore, this study did not distinguish between the two components of pig water use, namely water consumed and water wasted.

Implications

Under the conditions of this study:

- Water use patterns within each day varied between and within cohorts of pigs.
- The water use pattern of one cohort cannot be used to predict those of others.
- Water use pattern data may be useful to optimize in-water antimicrobial dosing.

Acknowledgments

The authors wish to thank Rivalea Australia and SunPork Farms for their assistance with data collection for this study. This research was supported by a National Health and Medical Research Council Centre for Research Excellence grant for the National Centre for Antimicrobial Stewardship (grant No. 1079625). Little was the recipient of a Faculty of Veterinary and Agricultural Sciences Post-Graduate Research Scholarship from The University of Melbourne.

Conflict of interest

None reported.

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