Translational Animal Science, 2023, **7**, txad040
https://doi.org/10.1093/tas/txad040
Advance access publication 24 April 2023
Housing and Management

Effect of different sow lactation feeder types and drip cooling on sow bodyweight, litter performance, and feeder cleaning criteria

Zhong-Xing Rao,[†,1] Kyle F. Coble,[‡] Mike D. Tokach,[†] Jason C. Woodworth,[†] Joel M. DeRouchey,[†] Robert D. Goodband,[†] and Jordan T. Gebhardt[||]

[†]Department of Animal Sciences and Industry, College of Agriculture, Kansas State University, Manhattan, KS 66506, USA
[‡]JBS Live Pork, Greeley, CO 80631, USA
[||]Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University, Manhattan, KS 66506, USA
[1]Corresponding author: goodband@ksu.edu

ABSTRACT

A total of 600 sows (line 3; PIC, Hendersonville, TN) were used to evaluate the effect of different lactation feeder types and drip cooling on sow farrowing performance and litter growth performance during the summer. For the feeder evaluation, the trial was conducted in two sequential groups with 300 sows per group. Five 60-farrowing-stall rooms with tunnel ventilation were used for each group. On approximately days 110 to 112 of gestation, sows were blocked by body condition score (BCS), parity, and offspring sire (lines 2 or 3 sires; PIC), then randomly allotted to one of three feeder types: 1) PVC tube feeder, 2) Rotecna feeder (Rotecna), or 3) SowMax feeder (Hog Slat). The three feeder types were placed in one of three stalls with the same sequence from the front to the end of all rooms to balance for environmental effects. For drip cooling evaluation, the trial was conducted during the 2nd group of 300 sows. Drippers were blocked in three of every six farrowing stalls to balance feeder type and environmental effects. After farrowing, sows had ad libitum access to feed. For litter performance data, only pigs from sows bred to line 2 sires were recorded. Line 3 sire pigs were not included in litter performance data, but sows of these pigs were included in sow body weight (BW) and feed disappearance data. After weaning, feeder cleaning time was recorded on a subsample of 67 feeders (19, 23, and 25 for PVC tube, Rotecna, and SowMax, respectively). There was no evidence of difference ($P > 0.05$) in sow entry BW, exit BW, BW change, and litter performance among the different feeder types. However, sows using the SowMax feeders had decreased ($P < 0.05$) total feed disappearance, average daily feed disappearance, and total feed cost compared to those fed with the PVC tube feeders. There was a marginal difference ($P < 0.10$) between feeder types in cleaning time, with PVC tube feeders requiring less time than the Rotecna feeders; however, cleaning time varied greatly between the personnel doing the cleaning. Sows with drip cooling had greater ($P < 0.05$) feed disappearance, litter growth performance, and subsequent total born, and reduced ($P < 0.05$) BW change. In conclusion, using a SowMax feeder reduced feed disappearance with no effects on sow and litter performance compared to a PVC tube feeder, and drip cooling improved sow and litter performance during summer.

LAY SUMMARY

During the lactation period, maximizing sow feed intake is important for sow health and litter growth. However, warm and humid climates increase the difficulties of maximizing lactation feed intake. Several factors can affect sow feed intake, including feeder type and environmental comfort. A good farrowing stall feeder type and water-cooling system should improve sow and litter performance. Therefore, we tested three types of lactation feeder [PVC tube feeder, Rotecna feeder (Rotecna, Agramunt, Spain), or SowMax feeder (Hog Slat, Newton Grove, NC)] and the effect of water dripper during summer. For the effect of feeders, there were no differences in most sow and litter performance between feeders, except sows on SowMax feeders had lower feed disappearance and feed cost per pig weaned compared to sows fed on PVC tube feeders with sows on Rotecna feeders being intermediate. Sows with drip cooling had greater feed disappearance and litter performance, and reduced sow body weight loss. In summary, SowMax feeder reduced feed disappearance with no effects on sow and litter performance compared to a PVC tube feeder, and drip cooling improved sow and litter performance during summer.

Key words: drip cooling, heat stress, lactation feeder, litter performance, sows

Abbreviation: BCS, body condition score; BW, body weight

INTRODUCTION

During lactation, maximizing sow feed intake is critical to reduce body reserve mobilization and sustain milk production for litter growth (Tokach et al., 2019). Lactation feed intake also affects sow longevity and subsequent reproductive performance (Patterson et al., 2011). However, sow farms located in warm and humid climates have difficulties maximizing lactation feed intake, which may lead to poorer performance of sows under heat stress (Bjerg et al., 2020; Zhang et al., 2022). Several factors can affect sow feed intake, including feeder type and environmental comfort (Tokach and Dial, 1992; Tokach et al., 2019; Bjerg et al., 2020). There are several types of lactation feeders for use in farrowing stalls. A good farrowing stall feeder should minimize feed wastage and spoilage and improve sow feed intake by enhancing the accessibility of feed

Received December 6, 2022 Accepted April 20, 2023.

and match the sow's feed intake pattern without causing pain or injury (Taylor, 1990; Peng et al., 2007; Choi et al., 2018). However, the difficulty of cleaning feeders also needs to be considered to avoid excess workload and cross-contamination of pathogens on the feeders to the next group of sows and litter.

In addition to feeder type, another factor influencing feed intake is environmental temperature. In hot environments, evaporative cooling can help reduce body temperature of swine (Godyń et al., 2020). Heat from the skin is dissipated through evaporation of sweat or water. Pigs have structures that morphologically conform with apocrine sweat glands in the skin but they do not sweat (Ingram, 1965) and therefore, cannot rely on evaporative cooling on their skin with sweat. Spray or drip cooling systems have been applied to provide skin evaporative cooling during warm weather. Drip cooling reduces the heat stress of a sow in a high-temperature environment and increases feed intake (Murphy et al., 1987; McGlone et al., 1988; Dong et al., 2001; Perin et al., 2016). However, there are few studies evaluating the effect of drip cooling in hot and humid environments. Furthermore, a limiting factor in drip cooling is high humidity. High humidity reduces the efficiency of evaporative cooling in removing heat (Godyń et al., 2020). Thus, it is theorized that drip cooling may not have significant effects on sows' performance in hot and humid areas. Therefore, the objective of this experiment was to evaluate the effect of lactation feeder type and drip cooling on lactating sow farrowing performance, litter growth, and feeder cleaning criteria in a hot and humid environment.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this study. The experiment was conducted at a commercial sow farm located in central Arkansas. There were 60 stalls per room. A total of five tunnel-ventilated farrowing rooms (300 stalls; 100 stalls per lactation feeder treatment) were used for each group. Evaporative cool cells were installed in all farrowing rooms and started circulating water at 26 °C. Each farrowing crate was equipped with a bowl waterer. The trial was conducted in two sequential groups for a total of 600 mixed parity sows (line 3, PIC, Hendersonville, TN). The first group of sows farrowed between June 6 and 18, 2021, and the pigs were weaned between June 24 and July 7, 2021. The second group of sows farrowed between July 2 and 15, and the pigs were weaned between July 25 and August 4, 2021. Daily high and low temperatures were recorded inside the rooms for the duration of this study (Figure 1). Relative humidity data was not recorded by room; therefore, data were retrieved from the closest weather station (17 km away), CXW weather station (Conway, AR; Figure 1). For the first group of sows (June 6 to July 7, 2021), the average daily temperature ranged between 22.0 and 27.1 °C with an average of 24.5 °C and the average daily relative humidity ranged between 58.9% and 96.6% with an average of 71.9%. For the second group of sows (July 2 to August 4, 2021), the average daily temperature ranged between 21.5 and 27.1 °C with an average of 24.7 °C and the average daily relative humidity ranged between 62.6% and 95.0% with an average of 75.1%.

Animals and Sow Lactation Feeders

Sows were inseminated with PIC line 2 (441 sows) and line 3 (159 sows) semen. On approximately days 110 to 112 of gestation, sows were moved from the gestation facility to the farrowing house, and blocked by body condition score (BCS), parity, and offspring sire line, then randomly allotted to farrowing stalls equipped with 1 of 3 feeder types with sow

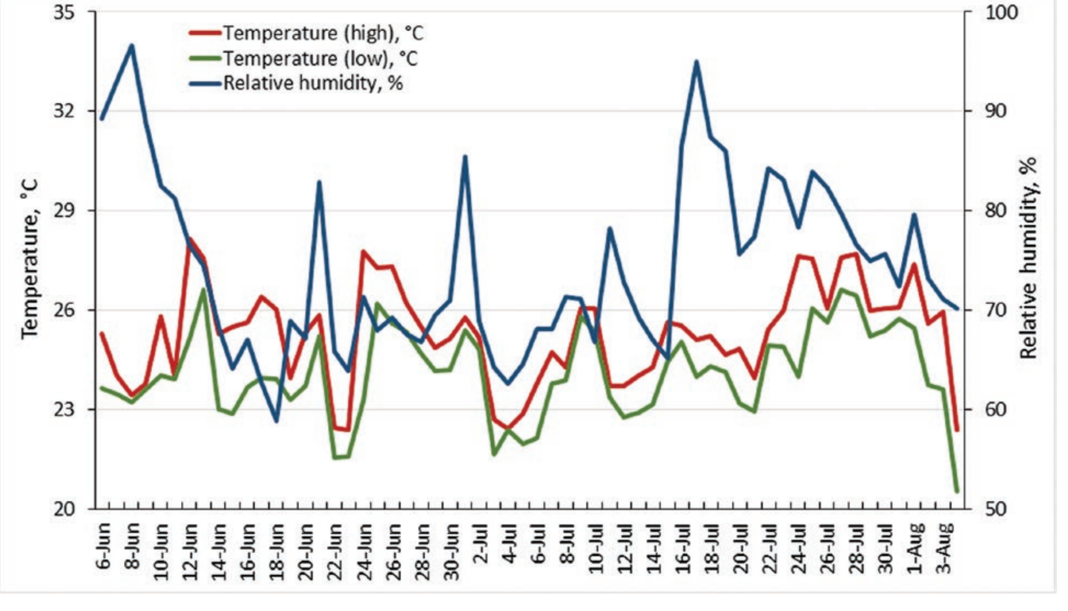

Figure 1. Room temperature and outdoor relative humidity data. Daily high and low temperatures were recorded inside the rooms for the duration of this study, and the humidity data were retrieved from the closest weather station, CXW weather station (Conway, AR; 17 km away). For the first group of sows (June 6 to July 7, 2021), the average daily temperature ranged between 22.0 and 27.1 °C with an average of 24.5 °C and the average daily relative humidity ranged between 58.9% to 96.6% with an average of 71.9%. For the second group of sows (July 2 to August 4, 2021), the average daily temperature ranged between 21.5 and 27.1 °C with an average of 24.7 °C and the average daily relative humidity ranged between 62.6% and 95.0% with an average of 75.1%.

Figure 2. Sow lactation feeders, feeder trigger, and adjustment mechanisms. For feeder adjustment, the PVC tubes were pushed against the feeder wall by a screw to maintain the gap between the end of the PVC tube and the bottom of the feeder bowl with friction. The Rotecna and SowMax feeders had quick adjustment handles to control the amount of feed dropped (gap size) for each trigger by the sows. For the trigger mechanism, Rotecna has a ball structure that can be pushed up from all directions and opens a gap to allow feed to drop. SowMax has a rod that can be pushed sideways and opens a gap on the sides of the hopper to allow feed to drop.

as the experimental unit. The three feeder types were; 1) PVC tube; 2) Rotecna ball feeder (Rotecna); or 3) SowMax ad-lib sow feeder (SKU: 7150890500; Hog Slat, Figure 2). The PVC tube feeders were the existing feeders in this sow farm. New Rotecna and SowMax feeders were installed for this trial. All farrowing stalls had the same feeder bowl type. The feeder bowl height and width were 55.9 and 35.6 cm, respectively, with a 10.2 cm depth from the front tip to the base. Moreover, with the specific feed hopper design of each feeder type, the Rotecna feeder could hold approximately 12 kg of feed, and the SowMax feeder and the PVC tube feeder could hold approximately 10 kg of feed. The PVC tube feeder consisted of a 7.6-cm-diameter PVC tube installed perpendicularly to the base of the feeder bowl in the back-left corner. The feeder adjustment for the PVC tube feeder was conducted by adjusting the gap size between the bottom of the PVC tube opening and the inside of the base of the feeder bowl to control the feed flow from the feed hopper. As there was no mechanism to restrict the feed from flowing into the feeder bowl, sows did not need to trigger any mechanism and had continual access to feed in the bowl. The Rotecna feeder consisted of a round plastic bracket with a moveable ball structure at the bottom of the feeder. This was installed on the farrowing stall headgate with the bottom of the plastic bracket matching approximately the top edge of the feeder bowl. For feed delivery, sows were required to push up the ball, which opened a gap between the plastic bracket and the ball that allowed the feed to flow from the feed hopper to the feeder bowl. When pushed all the way up, the top of the ball stopped the feed flow by closing the gap at the bottom of the feeder hopper. When not triggered or pushed on by the sows, the ball dropped and closed the bottom-gap stopping the flow of feed. The amount of feed dropped from the Rotecna feeder was controlled by adjusting the distance (space) between the top- and bottom-gap. On the front side of the plastic bracket, there were seven settings from 0 to 6 with 0 fully closed restricting all feed flow and 6 allowing the greatest amount of feed to flow to the bowl when triggered by the sow. The SowMax feeder consisted of a rectangular metal box with a rod-like structure at the bottom of the feeder. This was installed on the farrowing stall headgate with the bottom of the metal box matching approximately the top edge of the feeder bowl. For feed delivery, sows were required to push the rod from side to side, which moved internal parallel plates that allowed feed to drop from the feed hopper to the feeder bowl. When not triggered by the sows, the plates restricted the feed from flowing to the feeder bowls. The adjustment for the SowMax feeder was controlled by adjusting the distance between the plates. On the side of the metal box, there were six distance settings from 0 to 5 with 0 fully closed constricting all feed flow and 6 allowing greatest feed flow when triggered by sow. The three feeder types were placed in the farrowing stalls in the same sequence (Rotecna, SowMax, and then PVC tube feeder) from the front to the end of all farrowing rooms to balance the environmental effect in each room (Figure 3). For the drip cooling evaluation, the trial was conducted during the second group of 300 sows. Water drippers were located above the stall and aimed at the shoulder of the sow. The setpoint of

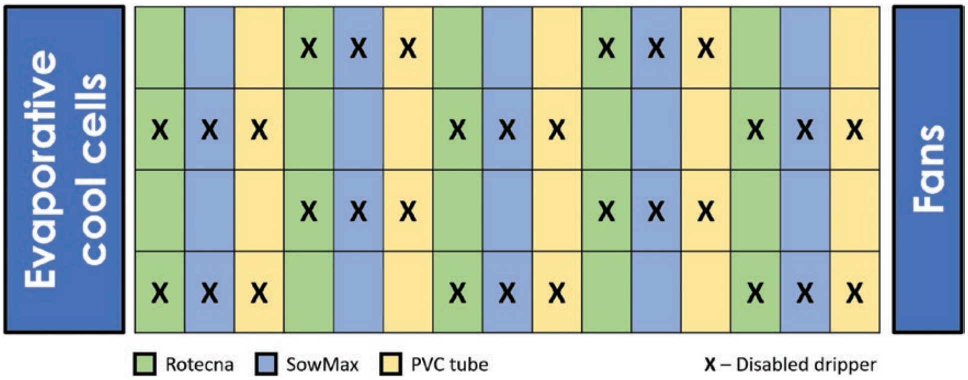

Figure 3. Example of lactation feeder type and drip cooling setup in a farrowing room. Five rooms with 60 stalls per room were used. Every cell represents a farrowing stall. Rotecna, SowMax, and PVC tube feeders were installed in green, blue, and yellow cells, respectively. Water drippers were disabled in cells that contain an "X".

the drip cooling system initiated at 24 °C and the system ran on a 10-min cycle (2 min on and 8 min off). Water drippers were disabled in three of every six farrowing stalls and the sequence changed between rows to balance the feeder types and the environmental effect in each room (Figure 3).

The same corn-soybean meal-based lactation feed was fed to all sows. During the prefarrowing period, sows were provided approximately 0.91 kg in the morning and 0.91 kg during late afternoon, for a total of 1.82 kg per day of the lactation diet. After farrowing, sows were provided ad libitum access to feed. The hopper of each feeder type was filled to the top with lactation diet at least twice a day throughout the experimental period to provide sows with feed at all times. Feeder adjustments were made daily to achieve approximately 40% to 60% feed coverage on the base of the feeder bowl. Wet or moldy feed was removed from the feeder bowl when necessary. The spoiled feed was not weighed and defined as part of the total feed disappearance. Viable pigs from sows bred to line 2 sires (7,562 pigs from 441 sows) were individually tagged with an RFID tag within 24 h of birth. Line 3 sired pig data were not collected as both of their ears were occupied with the farm's specific breeder tags and did not have space left for the LeeO RFID tags; therefore, these line 3 sired pig data were not included in the litter performance data. However, the sows of these pigs were included in the sow BW and feed disappearance data. If cross-fostering was needed, pigs were cross-fostered within 24 h of birth and within feeder type and offspring sire line. The weaning age was between 19 and 22 d.

Data and Sample Collection

All animal and feed scales used in this trial were calibrated and verified with test weights to assure accuracy. The experiments' sow and litter data were recorded and stored using the LeeO system (Prairie Systems, Spencer, IA). An RFID tag was attached to each sow stall and identified as a location pen in the LeeO system. For sow data, the information (sow ID, parity, breeding date, and offspring sire line) of each sow was exported from the PigChamp system (Ames, IA) and then imported into the LeeO system. A walk-on platform scale was used to weigh sows before entering the farrowing house and at weaning. When sows were placed in the farrowing stall, they were also registered in the location pens in the LeeO system. The sow record cards were checked to assure the LeeO electronic system recorded and stored the data correctly. Feed carts equipped with scales were used to obtain the weight of each feed addition. Each feed addition was registered to the stall (location pen) with the date and weight recorded for calculating total feed disappearance data. Total feed disappearance was calculated by subtracting leftover feed in the feed hoppers at weaning from the cumulative feed addition during the lactation period. Total sow feed disappearance would represent the combination of feed intake as well as feed wastage. Subsequent sow performance data was obtained from the PigChamp system. Sows that were culled due to age, structural problems, or death were not included in the subsequent farrowing data analysis. For litter performance, viable line 2 sired pigs were registered under the sow and location pen, and individually weighed at birth and at weaning. Nonviable pigs (low birth weight or dead before ear tagging), stillborn, and mummies were recorded but not weighed. Any cross-fostering and mortalities throughout the lactation period were recorded. The data for pigs from sows bred to line 3 sires were not collected; however, the sows of these pigs were included in the sow BW and feed disappearance data. Although there were differences in sample sizes, the treatments were still well-balanced in terms of replication, BCS, sire line, and parity (Tables 1 and 2) for the measurements.

After weaning, three farm employees were designated to wash feeders and record cleaning times for several feeders per feeder type. The number of feeders used was 19, 23, and 25 for the PVC tube, Rotecna, and SowMax feeder, respectively. For economic data, the lactation feed cost was US$0.29/kg, litter value was US$1.54/kg of litter weight, and the labor cost for cleaning was US$15/h.

Statistical Analysis

Data were analyzed as a randomized complete-block design for one-way ANOVA in R program (R core team, 2022; Vienna, Austria). Sow (litter) or feeder (cleaning criteria) were considered as the experimental unit. Groups and farrowing rooms were the blocking factors for sow and litter data. Cleaning personnel was used as the blocking factor for the cleaning criteria. Feeder type and drip cooling were used as the fixed effect. The lmer function from the lme4 package was used for lactating sow BW, feed disappearance, litter growth performance, cleaning criteria, and economics. The glmer function (Poisson distribution) from the lme4 package was used for total born, litter size after cross-fostering, live born,

Table 1. The effect of sow lactation feeder type on sow and litter performance[1]

Item	PVC tube	Rotecna	SowMax	SEM	*P*-value
Sow body weight (lines 2 and 3 sire)					
N	157	153	151	–	–
Parity	2.8	3.0	2.9	–	–
Entry, kg	223.2	221.4	225.1	4.59	0.580
Weaning, kg[2]	194.0	194.9	193.6	2.75	0.725
Weight change, kg[2]	–31.4	–30.6	–31.8	2.75	0.725
Weight change, %[2]	14.1	13.7	14.2	1.22	0.724
All sow feed disappearance (lines 2 and 3 sire)					
N	198	194	191	–	–
Parity	3.0	3.1	3.0	–	–
Total feed disappearance, kg	134.7[a]	130.4[a,b]	127.6[b]	6.50	0.056
Daily feed disappearance, kg	6.3[a]	6.1[a,b]	5.9[b]	0.31	0.027
Lactation feed cost, $[3]	39.34[a]	38.09[a,b]	37.26[b]	1.899	0.055
Sows with litter performance (Only line 2 sire)					
N	145	145	142	–	–
Parity	3.5	3.6	3.5	–	–
Lactation length, d	21.5	21.5	21.5	0.43	0.994
Total feed disappearance, kg	142.2[a]	139.5[a]	131.9[b]	8.06	0.003
Daily feed disappearance, kg	6.6[a]	6.5[a]	6.1[b]	0.37	0.002
Lactation feed cost, $[3]	41.55[a]	40.74[a]	38.52[b]	2.354	0.003
Total born, n	17.5	17.2	16.8	0.35	0.356
Live born, n[4]	15.4	15.7	15.3	0.33	0.729
Viable live born, n[4]	14.0	14.5	13.9	0.32	0.418
Nonviable live born, n[4,5]	1.3	1.1	1.3	0.12	0.450
Stillborn, n[4]	1.1	0.9	1.2	0.11	0.215
Mummified, n[4]	0.2	0.2	0.1	0.04	0.389
Litter birth weight, kg[4]	20.1	20.1	19.7	0.37	0.600
Pig birth weight, kg[4]	1.5	1.4	1.4	0.02	0.156
Litter size at 24 h, n[4]	14.4	14.8	14.1	0.32	0.271
Litter weaning weight, kg[6]	73.3	74.6	74.4	2.43	0.588
Pig weaning weight, kg[6]	5.7	5.8	5.8	0.16	0.328
Litter weight gain, kg[6]	53.2	54.8	54.5	2.55	0.406
Litter average daily gain, kg[6]	2.5	2.5	2.5	0.11	0.452
Weaned, n[6]	12.9	12.9	12.9	0.31	0.991
Preweaned mortalities, % of live born[7]	18.7	17.9	16.8	1.09	0.440
Preweaned mortalities, % of litter size at 24 h[8]	10.5	11.0	9.3	0.83	0.285
Litter feed efficiency[9]	0.39[a]	0.40[a,b]	0.42[b]	0.074	0.021
Litter value, $[3,6]	113.15	115.05	114.78	3.752	0.588
Litter value over lactation feed cost, $[6]	71.39[y]	74.34[x,y]	76.06[x]	1.777	0.060
Feed cost per pig weaned, $[6]	3.26[a]	3.22[a,b]	3.02[b]	0.172	0.014
Feed cost per kg of litter weight gain, $	0.82[a]	0.77[a,b]	0.74[b]	0.021	0.031
Sow subsequent performance (Line 2 and 3 sire)[10]					
N	189	184	180	–	–
Parity	2.9	3.0	2.9	–	–
Bred by 7 d, %	80.0	76.3	78.5	3.81	0.395
Bred by 14 d, %	81.5	78.3	78.9	3.54	0.336
Bred by 30 d, %	95.2	93.6	94.4	2.27	0.257
Subsequent farrowing rate, %	90.4	89.4	85.4	2.98	0.314
Subsequent total born, n	16.2	16.2	16.0	0.40	0.901

Table 1. Continued

Item	PVC tube	Rotecna	SowMax	SEM	*P*-value
Feeder cleaning criteria					
N	19	23	25	–	–
Time per feeder, s	43.6[y]	53.3[x]	51.0[x,y]	10.01	0.053
Cleaning cost per feeder, $[3]	0.18[y]	0.22[x]	0.21[x,y]	0.042	0.053

[1]A total of 600 mixed parity sows (PIC, line 3) that were bred to lines 2 and 3 sires were used with 200 sows per treatment. Pigs of sows bred to line 2 sires were included in the litter performance data. Sows were weighed on days 110, 111, or 112 of gestation, blocked by parity category and BCS, and allotted to treatment stalls at the time of entry to the farrowing house.
[2]Entry BW was used as a covariate.
[3]Lactation feed cost was US$0.29/kg.
[4]Total born was used as a covariate.
[5]Nonviable pigs were pigs with low birth weight or dead before ear tagging.
[6]Litter size at 24 h after cross fostering was used as a covariate.
[7]Preweaned mortalities, % of live born = [(Total dead after birth)/(Viable live-born + nonviable live-born)] × 100%
[8]Preweaned mortalities, % of litter size = [(Dead after cross-fostering)/(Litter size at 24 h)] × 100%
[9]Litter feed efficiency = Total litter weight gain/total feed disappearance.
[10]Subsequent performance data were obtained approximately 1 mo after weaning. Sows that were culled due to old age, structural problems, or death were not included.
[a,b]Means within a row with different superscripts differ ($P \le 0.05$).
[x,y]Means within a row with different superscripts differ ($0.05 < P \le 0.10$).

viable live born, and pigs weaned. The glmer function (negative binomial distribution) from the lme4 package was used for nonviable live born, stillborn, mummies, and subsequent total born. The glmer function (binomial distribution) from the lme4 package was used for subsequent farrowing rate, and bred by 7, 14, and 30 d data. The glmmTMB function (beta-binomial distribution) from the glmmTMB package was used for preweaned mortalities. Sow entry weight was used as a covariate for weaning weight and weight change. Total born was used as a covariate for farrowing performance at birth. Litter size at 24 h after cross-fostering was used as a covariate for litter growth performance and litter economic data. These covariates were used when they significantly improved ($P < 0.05$) the models based on Bayesian information criterion. For both groups of sows, there was no interaction ($P > 0.10$) between treatments (feeder types or drip cooling settings) and female type (gilt or sow) for all response variables (Data not shown). A Tukey/Sidak multiple comparison adjustment was used when appropriate. All results were considered significant at $P \le 0.05$ and marginally significant at $0.05 < P \le 0.10$.

RESULTS

Sow and Litter Performance

For the effect of sow lactation feeder, there was no evidence of difference ($P > 0.10$) in sow entry BW, weaning BW, BW change, and litter performance (Table 1). The results from all sows showed that sows fed with SowMax feeders had decreased ($P < 0.05$) total feed disappearance, average daily feed disappearance, and total feed cost compared to sows fed with the PVC tube feeders, while the results of sows fed with the Rotecna feeders were intermediate. Moreover, the results from sows with litter data showed that sows fed with SowMax feeders had decreased ($P < 0.05$) total feed disappearance, average daily feed disappearance, and total feed cost compared to sows fed with either the PVC tube or Rotecna feeders. Therefore, litter feed efficiency, feed cost per pig weaned, and feed cost per kg of litter weight gain were improved ($P < 0.05$) for sows fed using the SowMax feeders compared to sows fed with either the PVC tube or Rotecna feeders. There was no evidence of difference ($P > 0.10$) in subsequent reproduction performances (percentage bred by 7, 14, and 30 d after weaning, subsequent farrowing rate, and subsequent total born) between feeder types.

For the effect of drip cooling, sows provided with drip cooling had greater ($P < 0.05$) weaning BW, total feed disappearance, average daily feed disappearance, feed cost, and feed cost per pig weaned, and decreased ($P < 0.05$) BW change and percentage BW change (Table 2). There was no evidence of difference ($P > 0.10$) in litter criteria at farrowing, except sows without drip cooling had a greater ($P = 0.042$) percentage viable live born than sows with drip cooling. At weaning, litter weaning weight, pig weaning weight, litter weight gain, and litter ADG of sows provided drip cooling were greater ($P < 0.05$) than sows without drip cooling. There was no evidence of difference ($P > 0.10$) in litter feed efficiency, percentage weaned pigs, or mortalities. For subsequent reproduction performance, sows provided drip cooling had an increased ($P = 0.009$) subsequent total born compared to sows without drip cooling with no evidence of differences ($P > 0.10$) in subsequent farrowing rate and percentage of bred by 7, 14, and 30 d after weaning.

Cleaning Criteria

Rotecna ball feeders tended to have a greater ($P < 0.10$) cleaning time and cleaning cost compared to the PVC tube feeders (Table 1); however, the results were highly variable among the people who washed the feeders (Figure 4). Regardless of the feeder type, the range of cleaning time per stall for the three people was from 30 to 71 s (person 1), 30 to 39 s (person 2), and 40 to 102 s (person 3), respectively.

DISCUSSION

Feeder Type

The setup of this study only allowed us to collect feed disappearance data, which is a combination of feed intake and feed wastage. However, because there was no evidence of differences in sow body weight change and litter performance between feeder types, we speculate that sows fed with any of the feeder types had similar actual feed intake. Therefore, the differences in feed disappearance might have been affected by the differences in feed wastage between feeder types. Because the only mechanism for the PVC tube feeder type to control feed flow is the gap size between the bottom of the PVC tube

Table 2. The effect of drip cooling on sow and litter performance[1]

	Drip cooling			
Item	Without	With	SEM	*P*-value
Sow body weight (Line 2 and 3 sire)				
N	124	121	–	–
Parity	2.9	2.9	–	–
Entry, kg	217.3	218.7	7.98	0.731
Weaning, kg[2]	188.9	192.5	3.13	0.028
Weight change, kg[2]	–34.1	-30.5	3.13	0.028
Weight change, %[2]	15.5	13.9	1.41	0.023
All sow feed disappearance (lines 2 and 3 sire)				
N	149	145	–	–
Parity	3.1	3.2	–	–
Total feed disappearance, kg	121.3	135.2	8.62	<0.001
Daily feed disappearance, kg	5.5	6.2	0.40	<0.001
Lactation feed cost, $[3]	35.46	39.50	2.52	<0.001
Sows with litter performance (only line 2 sire)				
N	108	111	–	–
Parity	3.5	3.7	–	–
Lactation length, d	21.9	21.9	0.57	0.926
Total feed disappearance, kg	127.0	144.4	9.98	<0.001
Daily feed disappearance, kg	5.8	6.6	0.41	<0.001
Lactation feed cost, $[3]	37.10	42.17	2.91	<0.001
Total born, n	17.6	17.6	0.40	0.989
Live born, n[4]	15.9	15.7	0.38	0.754
Viable live born, n[4]	14.6	14.4	0.37	0.592
Nonviable live born, n[4,5]	1.2	1.3	0.14	0.351
Stillborn, n[4]	1.0	1.3	0.14	0.204
Mummified, n[4]	0.2	0.3	0.06	0.554
Litter birth weight, kg[4]	20.6	20.0	0.40	0.201
Pig birth weight, kg[4]	1.4	1.4	0.02	0.371
Litter size at 24 h, n[4]	14.8	14.5	0.37	0.610
Litter weaning weight, kg[6]	71.7	75.0	3.25	0.034
Pig weaning weight, kg[6]	5.5	5.8	0.22	0.025
Litter weight gain, kg[6]	51.2	55.0	3.27	0.015
Litter average daily gain, kg[6]	2.3	2.5	0.11	0.012
Weaned, n[6]	12.9	13.0	0.35	0.846
Preweaned mortalities, % of live born[7]	18.2	18.4	1.20	0.890
Preweaned mortalities, % of litter size at 24 h[8]	11.4	10.2	0.95	0.332
Litter feed efficiency[9]	0.39	0.41	0.014	0.215
Litter value, $[3,6]	110.67	115.77	5.01	0.034
Litter value over lactation feed cost, $[6]	73.42	73.59	2.646	0.944
Feed cost per pig weaned, $[6]	2.90	3.27	0.223	<0.001
Feed cost per kg of litter weight gain, $	0.77	0.82	0.029	0.234
Sow subsequent performance (lines 2 and 3 sire)[10]				
N	145	134	–	–
Parity	3.0	3.0	–	–
Bred by 7 d, %	74.6	74.7	3.96	0.987
Bred by 14 d, %	75.4	77.7	3.96	0.644
Bred by 30 d, %	97.3	93.8	3.0	0.120
Subsequent farrowing rate, %	83.0	85.8	3.17	0.522
Subsequent total born, n	15.2	16.8	0.59	0.009

[1]A total of 300 mixed parity sows (PIC, line 3) that were bred to lines 2 and 3 sires were used with 150 sows per treatment. Pigs of sows bred to line 2 were included in the litter performance data. Sows were weighed on days 110, 111, or 112 of gestation, blocked by parity category and BCS, and allotted to treatment stalls at the time of entry to the farrowing house.
[2]Entry BW was used as a covariate.
[3]Lactation feed cost was USD 0.29/kg
[4]Total born was used as a covariate.
[5]Nonviable pigs were pigs with low birth weight or dead before ear tagging.
[6]Litter size at 24 h after cross fostering was used as a covariate.
[7]Preweaned mortalities, % of live born = [(Total dead after birth)/(Viable live-born + nonviable live-born)] × 100%
[8]Preweaned mortalities, % of litter size = [(Dead after cross-fostering)/(Litter size at 24 h)] × 100%
[9]Litter feed efficiency = Total litter weight gain total feed disappearance.
[10]Subsequent performance data were obtained approximately1 mo after weaning. Sows that were culled due to old age, structural problems, or death were not included.

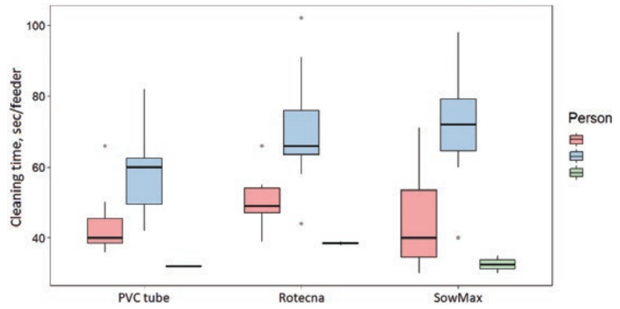

Figure 4. Feeder cleaning time per feeder by personnel. After weaning, the feeders were washed by three farm employees and the cleaning times for several feeders per feeder type were recorded. The number of feeders used was 19, 23, and 25 for the PVC tube, Rotecna, and SowMax feeder, respectively. Each color represents a distinct farm employee. The results varied highly between the people who washed the feeders. The range of cleaning time for the three people was from 30 to 71 s (red), 40 to 102 s (blue), and 30 to 39 s (green), respectively.

and the base of the feeder bowl, the PVC tube has an almost continual flow without restriction. On the other hand, the SowMax and Rotecna feeders require sows to trigger the feed drop mechanism to deliver feed to the base of the feeder bowl. Our target during this study was to maintain feed coverage of the bowl to be 40% to 60% covered. Though the feed coverage was not recorded, we observed that the feeder bowls of the PVC tube feeders had a greater frequency of excessive feed coverage than the other feeder types, even with daily adjustment. Additionally, the Rotecna and SowMax feeders can be easily adjusted to prevent excessive feed in the feeder bowl. When sows are eating, excessive feed in the feeder bowl might have a higher chance of being pushed out and resulting in feed wastage. Therefore, PVC tube feeders used in this study resulted in greater feed disappearance than the SowMax feeders with the Rotecna feeder intermediate. Moreover, excessive feed in the feeder bowl has a greater chance of spoiling and being contaminated because of exposure to water and saliva. Spoiled feed may cause feed refusal and reduce sow performance (Kanora and Maes, 2009). Peng et al. (2007) evaluated a self-fed feeder with ball mechanism similar to the Rotecna feeder. They observed that the self-fed feeders had a greater ($P < 0.05$) feed disappearance but improved ($P < 0.05$) litter performance compared to the hand-fed sows; however, their trial was conducted during the fall and winter seasons and the self-fed feeders used were wet–dry feeders while the hand-fed feeders were not. Moreover, because of the limited number of feedings per day, hand-fed sows might not have had access to feed at all times compared to sows with the self-fed feeders that had feed storage hoppers. They concluded that the improvement was a consequence of sows having the choice of when to eat and the desired moisture level. Choi et al. (2018) also observed sows with electronic self-fed feeders had greater ($P < 0.05$) feed intake and piglet ADG and reduced ($P < 0.05$) BW change compared to conventional feeders during summer. They suggested that it was due to the fermentation of residual feed in the conventional feeders that caused feed refusal. One concern about self-fed feeders is whether sows can learn how to operate them effortlessly. In our trial, sows had access to the feeders 1 to 3 d before farrowing to be familiar with the feeders. Farm staff were cognizant of any feed intake problems and were instructed to trigger the Rotecna or SowMax feeders if it was apparent a sow was not eating.

Another concern about different feeder types is the difficulty of cleaning which affects the cleanliness and the labor required (time and cost). We observed differences in the time required to wash a feeder, but we also observed large variation between people responsible for washing the feeders. This variation may come from the difference in the experience of cleaning and the personal standards of cleanliness. One potential confounding factor on cleaning time was that the farm crew had more experience cleaning the PVC tube feeders than the SowMax and Rotecna feeders, which might have unintentionally given PVC tube feeders an advantage in reducing cleaning time.

Drip cooling

Contrary to the theory that drip cooling may have no benefit in a hot and humid environment, our results suggest that drip cooling improved sow and litter performance. For sows with drip cooling, feed disappearance was increased, which led to greater feed cost and feed cost per pig weaned; however, these sows had reduced BW loss and improved lactation performance, indicated by the greater weaning pig weight and litter value. Moreover, we also observed that sows with drip cooling had an increase in the number of total born in the subsequent farrowing compared to sow without drip cooling. Other research has observed that drip cooling reduced ($P < 0.05$) sow body temperature, respiration rate, and BW loss, and increased ($P < 0.05$) feed intake and litter weaning weight in warm and humid environments (Murphy et al., 1987; Dong et al., 2001). In a hot and dry environment (approximately 40% relative humidity), McGlone et al. (1988) observed that lactating sows with drip cooling had increased ($P < 0.05$) feed intake and reduced ($P < 0.05$) BW change and respiration rate during heat stress. These results suggest that sows with drip cooling experienced less heat stress than sows without drip cooling in hot environments. Similarly, sprinkler systems in a finishing facility increased ($P < 0.05$) ADG and reduced ($P < 0.05$) respiration rate of pigs compared to a control without cooling systems in farm located in a humid tropical area (Huynh et al., 2006). In addition, Barbari and Conti (2009) observed that sows preferred areas with high air velocity and drip cooling more than areas with only high air velocity or only drip cooling when they were housed in a hot and humid environment. Our study also suggests that drip cooling could be advantageous in hot and humid environments where the facility is tunnel-ventilated and has high air velocity.

In conclusion, the SowMax feeder appeared to reduce feed wastage without limiting sow feed intake. This resulted in improved production efficiency and economic savings. Moreover, drip cooling increased sow feed disappearance which improved sow and litter performance in a hot and humid environment. These results provide information on management practices that can improve sow farm production.

ACKNOWLEDGMENTS

We would like to thank the farm staff at the JBS Sandy River farm (Morrilton, AR).

Contribution no. 23-020-J from the Kansas Agric. Exp. Stn., Manhattan, KS 66506-0210, USA.

Conflict of Interest Statement

None declared.

LITERATURE CITED

Barbari, M., and L. Conti. 2009. Use of different cooling systems by pregnant sows in experimental pen. *Biosyst. Eng*. 103:239–244. doi:10.1016/j.biosystemseng.2009.02.016

Bjerg, B., P. Brandt, P. Pedersen, and G. Zhang. 2020. Sows' responses to increased heat load - A review. *J. Therm. Biol*. 94:102758. doi:10.1016/j.jtherbio.2020.102758

Choi, Y., A. Hosseindoust, J. Kim, S. Lee, M. Kim, A. Kumar, K. Kim, Y. Kim, and B. Chae. 2018. An overview of hourly rhythm of demand-feeding pattern by a controlled feeding system on productive performance of lactating sows during summer. *Ital. J. Anim. Sci*. 17:1–9. doi:10.1080/1828051X.2018.1438214

Dong, H., X. Tao, J. Lin, Y. Li, and H. Xin. 2001. Comparative evaluation of cooling systems for farrowing sows. *Appl. Eng. Agric*. 17:91–96. doi:10.13031/2013.1930

Godyń, D., P. Herbut, S. Angrecka, and F. M. Corrêa Vieira. 2020. Use of different cooling methods in pig facilities to alleviate the effects of heat stress - a review. *Animals*. 10:1459. doi:10.3390/ani10091459

Huynh, T. T. T., A. J. A. Aarnink, C. T. Truong, B. Kemp, and M. W. A. Verstegen. 2006. Effects of tropical climate and water cooling methods on growing pigs' responses. *Livest. Sci*. 104:278–291. doi:10.1016/j.livsci.2006.04.029

Ingram, D. L. 1965. Evaporative cooling in the pig. *Nature*. 207:415–416. doi:10.1038/207415a0

Kanora, A., and D. Maes. 2009. The role of mycotoxins in pig reproduction: a review. *Vet. Med*. 54:565–576. doi:10.17221/156/2009-VETMED

McGlone, J. J., W. F. Stansbury, and L. F. Tribble. 1988. Management of lactating sows during heat stress: effects of water drip, snout coolers, floor type and a high energy-density diet. *J. Anim. Sci*. 66:885–891. doi:10.2527/jas1988.664885x

Murphy, J. P., D. A. Nichols, and F. V. Robbins. 1987. Drip cooling of lactating sows. *Appl. Eng. Agric*. 3:200–202. doi:10.13031/2013.26673

Patterson, J. L., M. N. Smit, S. Novak, A. P. Wellen, and G. R. Foxcroft. 2011. Restricted feed intake in lactating primiparous sows. I. Effects on sow metabolic state and subsequent reproductive performance. *Reprod. Fertil. Dev*. 23:889–898. doi:10.1071/RD11015

Peng, J., S. A. Somes, and D. Rozeboom. 2007. Effect of system of feeding and watering on performance of lactating sows. *J. Anim. Sci*. 85:853–860. doi:10.2527/jas.2006-474

Perin, J., T. S. Gaggini, S. Manica, D. Magnabosco, M. L. Bernardi, I. Wentz, and F. P. Bortolozzo. 2016. Evaporative snout cooling system on the performance of lactating sows and their litters in a subtropical region. *Cienc. Rural*. 46:342–347. doi:10.1590/0103-8478cr20141693

R Core Team. 2022. R: a language and environment for statistical computing. Vienna, Austria: R Core Team.

Taylor, I. A. 1990. *Design of the sow feeder: a systems approach* [PhD dissertation]. Ann Arbor: University of Illinois at Urbana-Champaign.

Tokach, M. D., and G. D. Dial. 1992. Managing the lactating sow for optimal weaning and rebreeding performance. *Vet. Clin. North Am. Food Anim. Pract*. 8:559–573. doi:10.1016/s0749-0720(15)30704-0

Tokach, M. D., M. B. Menegat, K. M. Gourley, and R. D. Goodband. 2019. Review: nutrient requirements of the modern high-producing lactating sow, with an emphasis on amino acid requirements. *Animal*. 13:2967–2977. doi:10.1017/S1751731119001253

Zhang, X., L. Yang, M. Wang, J. Zeng, S. Long, T. He, and Z. Chen. 2022. Effect of precision air supply cooling system with different cooling air speed on reproductive performance, stress status, immunoglobulin, and fecal microbiota of lactating sows. *J. Therm. Biol*. 108:103249. doi:10.1016/j.jtherbio.2022.103249