The importance of sow functional teat assessment and provision of supplementary milk to enhance performance of piglets reared in large litters

by Icely, S., Mansbridge, S.C., Mackenzie, A.M. and Stewart, A.H.

Icely, S., Mansbridge, S.C., Mackenzie, A.M. and Stewart, A.H. (2026) 'The importance of sow functional teat assessment and provision of supplementary milk to enhance performance of piglets reared in large litters', *animal,* 20(1), article 101737.

Animal 20 (2026) 101737

Contents lists available at ScienceDirect

Animal

The international journal of animal biosciences

The importance of sow functional teat assessment and provision of supplementary milk to enhance performance of piglets reared in large litters

S. Icely *, S.C. Mansbridge, A.M. Mackenzie, A.H. Stewart

Animal Science Research Centre, Harper Adams University, Shropshire TF10 8NB, UK

ARTICLE INFO

Article history:
Received 7 May 2025
Revised 4 December 2025
Accepted 5 December 2025
Available online 11 December 2025

Keywords:
Litter size
Nutrition
Pig
Postweaning
Preweaning

ABSTRACT

Rearing piglets in large litters where there are supernumerary piglets compared to functional teats presents a challenge in maintaining piglet health by avoiding successive fostering, whilst minimising mortality caused by starvation. Supplementary milk (**SM**) provision to litters during the suckling period has been shown to reduce preweaning mortality, but there has been no characterisation of which piglets consume SM and the subsequent performance effects. Using electronic identification (**RFID**) tags and an antenna at the SM bowl, it was possible to record the duration of each visit for each individual piglet. Multiplying individual piglet weight and duration of SM visits for each day, and summing for the litter showed a positive relationship with daily weighed litter SM consumption during lactation, yielding a regression equation with r^2 = 0.84. Therefore, the daily duration of visits to the SM bowl was considered a proxy measure of daily individual piglet SM consumption. Litter SM consumption during lactation, measured both by weighing SM and by calculation using the regression equation, was greater in litters where there were supernumerary piglets compared to functional teats (**IS**), than in litters where there were no supernumerary piglets (**S**). Litter weight at each timepoint was greater for IS litters than for S litters, but average piglet weight was lower. Piglets with very high duration of SM visits/d during the final week of lactation were lightest at weaning, and at d 54 postweaning, with the lowest postweaning average daily gain (**ADG**). Piglets suckling posterior teats had a higher duration of SM visits/d than piglets suckling anterior teats, throughout lactation. Piglets observed as non-sucklers on d 14 had the highest du/d throughout the suckling period and were lightest at weaning. The SM DM feed conversion ratio for non-suckling pigs predicted using the regression equation was 0.88. This was higher than the predicted 0.70 for piglets suckling sow milk, indicating lower efficiency of piglet growth from SM. This may be due to reduced fat and protein content of SM compared to sow's milk; therefore, further investigation of the composition of SM and refinement of the formulation is warranted. Validation of the methodology employed to estimate SM consumption from the duration of SM visits/d is also necessary.

Implications

Due to increasing sow prolificacy, piglets may be reared in litters where there are insufficient functional teats. Supplementary milk (SM) provision allows pig producers to capitalise on the greater prolificacy of hyperprolific sows. In this study, the daily duration of visits to the SM bowl throughout lactation was recorded for each piglet and used as a proxy for individual piglet daily supplementary milk consumption. Piglets with the highest daily duration of visits/d to the SM bowl during the final week preweaning were lightest at weaning, potentially due to the lower fat content of supplementary milk compared to the sow's milk.

Introduction

A significant challenge to the global pig industry is rearing piglets that are supernumerary to the number of available functional teats of the sows. In the UK over the last 10 years (from 2014 to 2024), average litter size born from indoor-housed sows has increased by 2.6 pigs/litter from 12.16 to 14.80 piglets/litter, with the top 10% achieving 16.5 piglets born alive/litter. However, average preweaning mortality has increased from 8.2 to 13% over the same period (Agriculture and Horticulture Development Board,

* Corresponding author.
E-mail address: sicely@harper-adams.ac.uk (S. Icely).

https://doi.org/10.1016/j.animal.2025.101737
1751-7311/

2024), potentially because the increase in the number of functional teats of the sow has failed to keep pace with the increase in the number of piglets born (Knap et al., 2023). The number of functional teats of modern sow genotypes typically ranges from 13 to 15 functional teats per sow (Vande Pol et al., 2021), and so many sows will be considered hyperprolific, farrowing more piglets than they have functional teats (Jensen et al., 2025).

Preweaning mortality is positively associated with the number of piglets per functional teat (Gourley et al., 2020; Kobek-Kjeldager et al., 2020a) and will occur within 2–3 days if a piglet has no functional teat to suckle (Stewart et al., 2010; Andersen et al., 2011).

The milk yield of sows with large litters may be insufficient, with Ocepek et al. (2017), reporting a positive relationship between litter size (range 10–17 piglets) and the amount of time piglets spent massaging the udder pre- and postsuckling (a sign of hunger), the number of piglets failing to access a functional teat, and the number of unsuccessful nursings characterised by no milk being let-down. Milk yield also typically reduces from anterior to posterior teats, resulting in lighter BW of posterior-suckled piglets (Nielsen et al., 2001; Huting et al., 2017).

A common consequence of greater litter size within a population is also a reduction in average piglet birth weight, and an increase in the number of light birth weight piglets, which have higher rates of mortality (Quiniou et al., 2002; Fix et al., 2010; Kobek-Kjeldager et al., 2020a), and lower growth rates pre- and postweaning (Quiniou et al., 2002; Douglas et al., 2014a; Huting et al., 2018).

Larger litter sizes present both an opportunity and a challenge: the potential to increase productivity per sow, coupled with the need to minimise piglet preweaning mortality and maintain sow body condition. Negative quadratic relationships between sow lactational weight loss and wean to service interval, farrowing rate and number of piglets born in the subsequent parity were reported by Thaker and Bilkei (2005), when sow weight loss was above 10%, making this an important consideration for sow lifetime performance. These challenges have prompted increased interest in piglet preweaning nutrition. The provision of supplementary milk (**SM**) to litters is a method to support the sow in rearing large litter sizes by preventing possible starvation of viable piglets. When SM is provided to all litters *ad libitum* (utilising a bowl in each crate connected to a milk supply) from birth, it can increase numbers weaned per sow compared to where SM is not available (Stewart et al., 2010; Kobek-Kjeldager et al., 2020a). This allows litters to stay intact after initial fostering, reducing social stress and negative health and welfare implications associated with shunt-fostering or using nurse sows for both piglets (higher incidences of lameness and poor hygiene/diarrhoea: Sørensen et al., 2016; Nielsen et al., 2022) and sows (higher incidence of bursae on legs and udder damage: Sørensen et al., 2016). An advantage of SM over artificial rearing systems is that SM can be provided from birth, whereas commonly piglets are moved to artificial rearing accommodation between d 3 and d 7 (Muns et al., 2018), which may be too late to prevent starvation as piglets will die within 2–3 days without a teat to suckle (Andersen et al., 2011). In artificial rearing systems, formulated milk powder alone may not be sufficient for optimal performance of piglets (Lee et al., 2023).

Identifying which piglets consume SM within a litter, and the effect of level of consumption on pre- and postweaning performance, could inform management strategies for large litter sizes, but there is little research into which individual piglets benefit from SM provision, historically due to limited technological capabilities. The use of electronic identification (**RFID**) tags has allowed individual feed intake recording of weaners and finishers in numerous studies (for example, Hyun et al., 1997; Bruininx et al., 2002; Remus et al., 2019), but this is the first to utilise the technology to record individual piglet visits to the SM bowl. This study examined the effect of within-litter teat supply (number of piglets vs number of functional teats) on litter performance and litter SM consumption, and investigated the effect of birth weight and suckling position on individual piglet SM consumption. The hypotheses were: litters with insufficient functional teats would consume greater amounts of SM than litters where there were sufficient teats; SM consumption would increase from anterior to posterior suckling positions; heavy birthweight piglets would have the highest SM consumption.

Material and methods

Animals, housing and study design

Preweaning

Litters from multiparous (study average 4.2, range 1–6) sows (TN70 Large White × Landrace, JSR Genetics Ltd, UK) with a Tempo (JSR Genetics Ltd) terminal sire were utilised. Sows were vaccinated 3 weeks prior to farrowing against *Escherichia coli* (2 ml Porcilis Porcoli DF: Merck Sharp & Dohme UK Ltd, UK). Sows entered the farrowing room at 108 days of gestation. Three-week batch farrowing was practised, and litters were selected that were born within 3 days of each other. Four farrowing batches were used in this study, comprising 44 litters. Sows farrowed in standard fully slatted commercial farrowing crates (floor area 4.3 m^2), with a hessian sack and a plastic chew toy for enrichment, and piglets were weaned at an average of 27 days of age. Farrowing room temperature was set at 22 °C (Skov, Denmark) for the first 10 days of occupation and then reduced over seven days to 18 °C. Lighting was controlled by a timer, with the light period from 0600 to 2100 h. Sows were fed 3.5 kg/d of a standard lactation ration (Table 1) in two meals from the farrowing house entry, until the day after farrowing. Feed allocation then increased to 4 kg/sow per day, with a further 1 kg/d increase in allocation until day 12 postfarrowing. After this point, feed was offered up to a maximum of 16 kg/d, refusals were monitored, and subsequent feed was adjusted to reflect the previous day's intake. Water was provided *ad libitum* through a nipple drinker in the trough.

At farrowing, the number of functional teats was counted by manual expression of colostrum, where visible secretion of colostrum constituted a functional teat. Within 24 h of birth, piglets received the standard management procedures of tooth reduction (Dremel, UK), iron injection (1 ml Ferroferon 200 mg/ml: Iron4u, Denmark), and iodine spray to the navel. Boars were left intact. At this time, piglets were individually weighed and a half duplex RFID tag (MS tag round HDX; MS Schippers, UK) was inserted in their left ear for identification purposes. Split-suckling was practised in litters where the number of piglets exceeded the number of functional teats, by removing piglets from the heaviest half of the litter for 2 h in the morning and afternoon until fostering was performed. Experimental treatments were allocated by fostering at 24–48 h after birth, with half the sows having sufficient teats (**S**; litter size = n functional teats −1 piglet) and half having insufficient teats (**IS**; litter size = n functional teats +1 or 2 piglets). Sows were allocated to treatments based on minimal fostering, and the farrowing date was balanced between treatments. After initial cross-fostering, no further cross-fostering was performed. Supplementary milk (Table 1) was available to all litters *ad libitum* from birth until weaning, provided from a bowl within the farrowing pen. The bowl refilled when the piglet nudged a central metal pin with its nose. Procedures for recording SM consumption are detailed in the measurement section below. The buckets and tank were emptied and cleaned with hot water daily, and a dairy milk line cleaner (Wynnsan Milkstone Remover, Wynnstay Group PLC,

Table 1
Nutrient specifications (as-fed basis) of sow lactation diet, piglet milk replacer powder and mixed supplementary milk (SM).

Specification	Sow lactation diet[1] Entry to weaning	Milk replacer powder[2] From birth	Mixed SM[3] From birth
DM (g/kg)	860	950	143
CP (g/kg)	203	220	33
Crude fibre (g/kg)	35	0.0	0.0
Crude oil and fats (g/kg)	58	140	21
Crude ash (g/kg)	53	75	11.3
Total lysine (g/kg)	12	20	3.00
Total methionine (g/kg)	3.2	n/a	n/a
Calcium (g/kg)	7.0	9.0	1.35
Sodium (g/kg)	2.0	5.0	0.75
Phosphorus (g/kg)	4.7	7.0	1.05
Vitamin A (iu/kg)	10 000	25 000	3 750
Vitamin D3 (iu/kg)	1 875	10 000	1 500
Vitamin E (iu/kg)	125	500	75

[1] ABN Feeds Ltd (Peterborough, Cambridgeshire, UK).
[2] Supplied as Faramate (Volac International Limited, Royston, Hertfordshire, UK).
[3] Mixed at a rate of 150 g milk powder to 850 g water.

UK) was used between batches at a concentration of 2% to thoroughly clean and disinfect the system.

No preweaning creep was provided. Piglets were weaned at an average of 28 days old.

Postweaning

Pigs were weighed individually on day 54 postweaning (n = 607) to assess the effect of level of preweaning SM consumption, birthweight, and suckling position on postweaning growth. As such, there was no experimental design postweaning, solely a continuation of data collection for the preweaning SM consumption, birth weight and suckling position classifications. All healthy pigs that were weaned were included (two lame pigs were excluded). Pigs were weaned into fully slatted nursery pens of five pigs, or 25 pigs (floor area of 0.49 m^2/pig). Pens comprised of pigs from mixed litters varied preweaning SM consumption classification, and weights. Room temperature was set on a curve, commencing at 28 °C and reducing to 20 °C by d 54 postweaning. Lighting was manually controlled, with the light period from 0800 to 1600 h. Feed formulated to meet nutritional requirements was provided *ad libitum* through a three-space hopper. All pigs received the same nutritional specification and dietary regime detailed in Table 2. Environmental enrichment was provided through compressed straw blocks and a rubber chew toy.

Measurements

Weighing sows and piglets

Sows were weighed (+/- 1 kg: Eziweigh 7, Datamars, UK) and backfat measured at the last rib (**P2**) position (Dravet BF-8: BMV, China) on entry to the farrowing room and on the day of weaning. As sows were not weighed postfarrowing, in order to calculate weight change over lactation, a correction was applied to the sows' entry weight. This was calculated by three methods: The method of Vernunft et al. (2018) estimated $conceptus\ weight = litter\ weight + (litter\ weight/5.1)$. The method of Thomas et al. (2018, as used by Gourley et al. (2020) applied a ratio to the equations formulated by the National Research Council (2012), to correct for higher numbers of piglets born and included litter birthweight. Initially, the National Research Council (2012) equations were used to calculate the weight of the conceptus: $NRCconceptusweight = (exp(8.621 - 21.02 * exp(-0.053 * d) + (0.114 * ls))/1000$, where d = days of gestation and ls = litter size (born alive and stillborn). The ratio proposed by Thomas et al. (2018) was multiplied by the National Research Council (2012) conceptus weight, with the result subtracted from the weighed sow entry weight to yield the predicted sow weight at farrowing entry. $Ratio = lbw/(exp((9.095 - 17.69 * exp(-0.0305 * g)+$

Table 2
Nutrient specifications (as-fed basis) and feeding regimes for pigs postweaning.

Specification	1st phase [1]	2nd phase[2]	3rd phase[3]	4th phase/grower[4]
DM (g/kg)	880	860	860	850
CP (g/kg)	220	215	215	192
Crude fibre (g/kg)	20	20	25	43
Crude oil and fats (g/kg)	85	65	60	38
Crude ash (g/kg)	60	50	55	53
Total lysine (g/kg)	17	15.5	15	13
Total methionine (g/kg)	7	6	6	3
Calcium (g/kg)	7.5	7	7	7
Sodium (g/kg)	2.8	2	2	2.3
Total phosphorus (g/kg)	7.5	6.5	6.7	4.8
Vitamin A (iu/kg)	12 500	12 500	12 500	9 500
Vitamin D3 (iu/kg)	2 000	2 000	2 000	1 850
Vitamin E (iu/kg)	300	200	200	75

[1] 1st phase weaner was provided to supply 1 kg/pig from d 1 to d 4.
[2] 2nd phase weaner was provided to supply 2 kg/pig from d 4 to d 9.
[3] 3rd phase weaner was provided to supply 5 kg/pig from d 9 to d 17 (all from AB Neo (Peterborough, Cambridgeshire, UK)).
[4] 4th phase/grower diet fed thereafter to nursery exit (ABN Feeds Ltd (Peterborough, Cambridgeshire, UK)).

$(0.0878 * ls))/1000)$, where lbw = litter birth weight (kg), g = gestation length at point of weighing (d), ls = litter size.

The method of Mallmann et al. (2018, equation 4) predicted the sow's weight at farrowing, based upon the sows' entry weight, total piglets born and the interval between weighing and farrowing. $Sowweight = 8.45 + (0.93 * sw) - (1.18 * ls) + (1.15 * in)$, where sw = sow entry weight (kg), ls = litter size, in = interval between weighing and farrowing (d). Equation 4 was selected due to being validated by Mallmann et al. (2018) and having the highest r^2 and lowest SE.

For each piglet weigh point, a single day was chosen, with the quoted age at weighing based on the average weaning age of 27 days as a fixed reference point. Piglets were individually weighed at birth (±20 g: Bosche TWI weighing platform: Bosche, Germany), d 4, 18, 27 (weaning) and d 54 postweaning (±50 g: Ezi-weigh 7 and XRS stick reader: Datamars, UK). Birth weight bands were assigned to piglets for *posthoc* analysis, defined as group 1: < 1.00 kg; group 2: 1.00 to 1.50 kg; group 3: 1.52 to 2.00 kg; group 4: > 2.00 kg.

Supplementary milk consumption

In batches 1–3, to allow for calibration of weighed SM with other measured parameters, SM was weighed into a bucket suspended above the bowl to allow daily litter SM consumption to be weighed. In batch 4, SM was supplied by a central tank, with milk continuously pumped around the system. For both systems, milk was mixed at a rate of 150 g powder/1 l of mixed milk, and the amount added and refused was weighed each morning. To ensure that a consistent quantity of SM remained in the pipes when using the central tank system, and so did not affect the measurement of SM consumed each day, an excess of SM was added to the tank each day. This sometimes required additional SM to be weighed into the system in the afternoon. In the event of a leak, that day's SM consumption data were discarded. If the leak caused the pipes to empty, the system was reprimed with sufficient SM to fill the pipes, then SM was weighed into the tank to begin recording again.

For recording individual piglet SM consumption, the PigTrack® software system (Asserva, France) was utilised. The setup is shown in Fig. 1. Commencing from d 4, the SM bowl (A) was enclosed by a metal station with an adjustable-width entrance (B), ensuring only one piglet could visit at any time. Within the station, an antenna (C) recorded the RFID number, date, time and duration of each visit. The range of detection for each antenna was set to ensure that the RFID tag was detected only when the piglet had its head in close proximity to the SM bowl. The metal cladding ensured that RFID tags of piglets external to the station were not recorded, and there were metal bars on the floor to make lying in the station unattractive (D). The SM bowl was fed by a suspended bucket (E), or the central tank.

Although SM was provided from birth, the positioning of the recording station was delayed to d 4 so that piglets could locate the SM bowl before visibility of the SM bowl was restricted. The reliability of the antennae was validated for each station prior to the start of this study by performing a short pilot study. Videos with time stamps were recorded for 24 h, initially over four recording stations, and were cross-referenced with the RFID data. This was an iterative process; after each check, improvements were made to the system by adjusting antenna sensitivity, earthing the system, and changing the position of the radio receiver. Once the system was judged to be working on the four pilot stations, with no missing visits, video was recorded for 24 h over each station. These videos were checked during the peak usage period (1400–1600 h) to cross-reference with the RFID data, and it was observed that only visits < 4 s were missing from the RFID data.

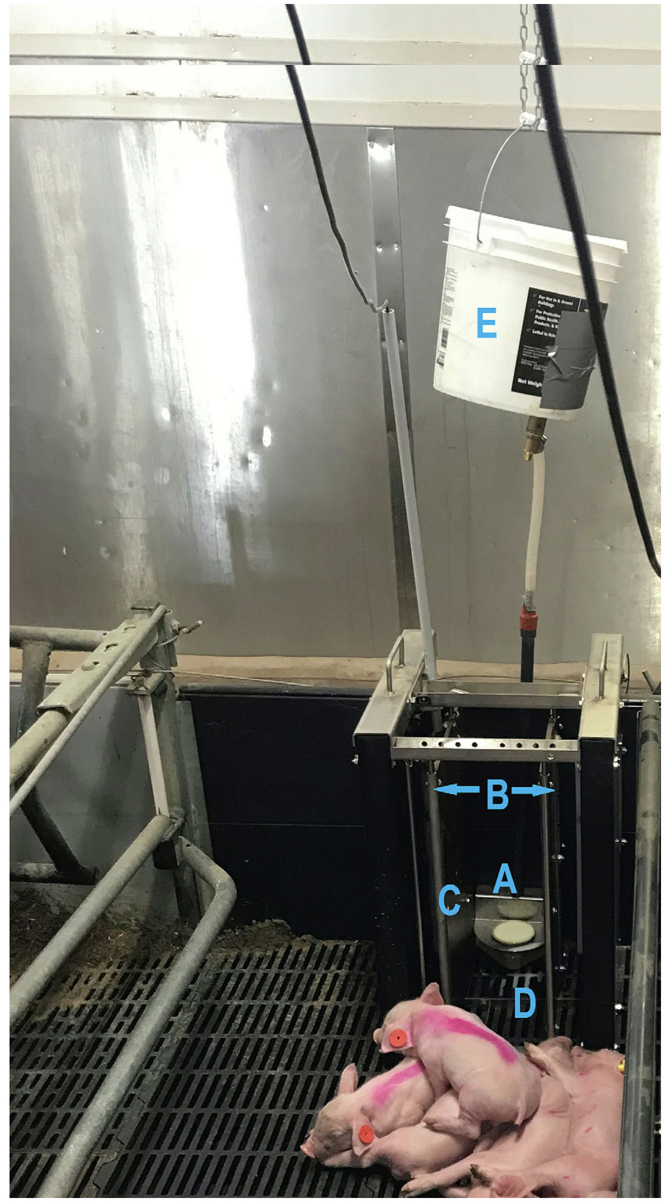

Fig. 1. Station for recording preweaning supplementary milk consumption of individual piglets. Image credit: Sarah Icely.

From the video recordings, no visit < 7 s resulted in SM consumption; therefore, 7 s was set as the lower limit of duration for inclusion in the data analysis (1% of visits rejected). For the upper limit of duration for inclusion in data analysis, if a piglet stayed for > 70 s, it was not drinking for the whole period, and 95% of visits were < 70 s. The longer visits were included in the analysis for visits/d, as SM consumption had occurred, but discarded from the duration of SM visits/d, as it was not possible to judge from the RFID data the length of time for SM consumption.

Supplementary milk consumption calculations

Using regression analysis, a function (Σwti*dui) relating daily litter SM consumption to the sum of individual piglet daily duration of visits to the SM bowl (dui, s), and daily individual piglet weight (wti, kg) was calculated :

$$Litter\ SM\ consumption(kg) = 0.000167 * (\sum wti * dui) - 0.378.$$

This was the minimal model obtained by stepwise elimination of non-significant terms; other terms included but rejected on the grounds of non-significance were litter size, litter weight and average daily gain (**ADG**). Daily piglet weight (kg) was calculated as: $weight\ at\ start\ of\ period\ (kg) + (day\ of\ period * ADG\ for\ period)$, with ADG in g/d, and was included as it was assumed that the rate of SM consumption by a piglet would show a positive correlation with piglet weight. A positive relationship between BW and the speed of a piglet draining the teat has been proposed by Quiniou et al. (2002), Drake et al. (2008) and Huting et al. (2018), and BW is positively associated with feeding rate (weight of feed consumed per second) in finishing pigs (Hyun et al., 1997).

To estimate individual piglet daily SM consumption, the estimated daily litter SM consumption was calculated using the litter SM equation above, and the piglet's contribution to this was calculated.

$Piglet's\ contribution = ((piglet\ wt * du / \sum wti * dui))$ where wt = wt (kg), du = duration (s) of visits to the SM bowl.

$$Piglet's\ SM\ consumption\ (kg) = Piglet's\ contribution * litter\ SM\ consumption\ (kg)$$

As an example, daily litter consumption of 5 kg SM equates to litter $\sum$wti*dui of 32203.59 ((5+0.378)/0.000167). If an 8 kg piglet has a daily duration of visits to the SM bowl of 200 s per d, it has a piglet contribution of 0.0497 ((8*200)/32203.59), resulting in a predicted daily piglet SM consumption of 0.25 kg (0.0497*5).

Consumption classes were assigned for *posthoc* analysis; for each piglet, the average of total duration of SM visits/d in the final week prior to weaning was used as a proxy for the level of SM consumption, with piglets split into quartiles: low = first quartile; medium = second quartile; high = third quartile; very high = fourth quartile. For assigning consumption classes, the duration of SM visits was used as a proxy instead of calculated piglet SM consumption, as duration was a directly measured parameter, the regression equation had not been validated, and piglets with very low duration of SM visits/d may have a calculated negative daily SM consumption.

Suckling position

Suckling was observed on d 14, with the udder divided into anterior (anterior two teat pairs), posterior (posterior three teat pairs), centre (central teat pairs; at least two), shown in Fig. 2. Piglets not observed suckling were recorded as 'NONE'. At least two successful sucklings were observed to verify suckling position. A successful suckling was defined as all piglets being awake, and milk let–down observed.

Statistical analysis of data

All statistical analyses were performed in Genstat (20th Edition; VSNI, UK). Sow weight (kg) and backfat thickness at the P2 position (mm), sow feed (kg), number of piglets at each timepoint, litter weight (kg), average BW (kg) and weighed litter SM consumption (kg; total SM, SM/kg litter weight weaned, SM/piglet weaned) were analysed using sow as the experimental unit. Pig BW (kg) and piglet ADG (g/d) were analysed with piglet as the experimental unit. Performance data were analysed by linear mixed-effects models (**REML**), with sow and pen included as random model terms post-weaning. Normality was determined by examining the residuals. Where significance was determined at $P < 0.050$, a *posthoc* Bonferroni test was applied to determine differences between treatment means. Sow parity profile, piglet preweaning mortality (%) and the percentages of piglets in each SM consumption class that were from IS litters, or non-sucklers, were analysed by chi-square test. Individual piglet SM consumption data (visits/d and duration of SM visits/d, s) were observed to be non-normally distributed and were analysed by GLM with a Poisson distribution and logarithmic link function. Supplementary milk consumption data over time were analysed by repeated measures REML, antedependence order 1. This order was selected as there was a maximum of three data points for each piglet, and some piglets had one missing data point. Kolmogorov-Smirnov analysis was employed to compare the diurnal variation of SM consumption between S and IS litters, using litter as the experimental unit (% of daily duration (s) per hour of the day). Multiple regression was performed to analyse the relationship between litter SM consumption (kg) and other measured vari-

Fig. 2. Classification of piglet suckling positions: anterior (A), centre (C), posterior (P), non-suckling (NONE). Image credit: Sarah Icely.

ables, for each period d 4 to d 11, d 11 to d 18, and d 18 to weaning. The maximal model was fitted initially, with step-wise elimination of non-significant terms. The maximal model included piglet weight (kg), litter size, duration of visits (s), the function Σwti*dui (kgs), and litter growth rate (kg/d).

Results

Eight piglets died in IS litters after fostering to set litter size had occurred, but before d 4, resulting in six of the litters that had been allocated as IS having no supernumerary piglets compared to functional teats on d4. These litters were reassigned to the S treatment for analysis (with no additional fostering), as the mortality had occurred prior to beginning recording of SM consumption, which was considered the commencement of the study. A further two litters were completely excluded due to very poor sow milk yield, resulting in poor recording of RFID tags due to high competition at the SM bowl.

Two piglets were excluded from the postweaning data collection due to lameness.

Teat supply

Sow performance is detailed in Table 3. There was a similar proportion of gilts in S and IS, but tended to a lower proportion of S sows of parity 2–4 than IS sows, but a higher proportion of S sows of parity 5 and 6 ($P = 0.061$). There was no difference in functional teats at farrowing between S and IS ($P = 0.955$), but IS had a higher number of total piglets born ($P = 0.016$), and tended to have greater born alive ($P = 0.051$). Litter birth weight was higher for IS sows than S ($P = 0.013$), but average piglet birth weight was similar between S and IS litters ($P = 0.510$). There was no difference in piglet mortality from birth to d 4 between IS and S litters ($P > 0.050$): 53.2% of deaths were due to being laid on, 40.3% were non-viable (weak, low birth weight (average birth weight of non-viable piglets = 0.66 kg)). The remaining 6.5% were due to meningitis (two piglets), splayed at birth, savaged, chilled, blind anus, and bloated for an unknown reason (one piglet each).

At entry to the farrowing room (d 108 of gestation), there was no difference in weight between S and IS sows ($P > 0.050$), when considering total sow + conceptus weight (as weighed on d 108), or when the correction equations proposed by Vernunft et al. (2018), Thomas et al. (2018) or Mallmann et al. (2018) were applied. At weaning, there was no difference in sow weight or sow weight change during lactation using adjusted sow weight as calculated ($P > 0.050$). There was no difference in backfat measured at the P2 position between S and IS sows at entry or weaning, or the change in backfat over lactation, with both S and IS sows losing backfat ($P > 0.050$). Average sow feed intake per day was similar between S and IS sows ($P = 0.132$). There was no difference in total piglets born, litter birth weight or average piglet birth weight in the following parity between S and IS sows ($P > 0.050$).

On d 4, IS litters had a greater litter size compared to S by design (Table 4; $P < 0.001$). This difference in litter size was maintained

Table 3
Preweaning performance of sows with sufficient (S) or insufficient (IS) teats/piglet at d 4 postfarrowing.

Performance parameters	S	IS	SEM	*P*-value
n (litters)	29	15		
Litter age at weaning (d)	27.9	28.1		
Average parity	4.6	3.5		
Parity profile (n, %)				0.061
Parity 1	3, 10.3	2, 13.3		
Parity 2–4	6, 20.7	8, 53.3		
Parity 5 and 6	20, 69.0	5, 33.3		
Functional teats at farrowing (n)	14.69	14.67	0.332	0.955
Total piglets born (n)	16.93	19.93	0.973	0.016
Piglets born alive (n)	16.07	18.40	0.944	0.051
Litter birth weight (kg)	22.79	26.68	1.211	0.013
Average piglet birth weight (kg)	1.40	1.34	0.065	0.510
Mortality birth to d 4 (%)[1]	14.6	17.5		NS
Sow weight at entry (kg)	276.0	277.5	8.78	0.892
Adjusted sow weight at farrowing (kg)[2]				
Vernunft et al. (2018)[3]	248.7	245.6	8.25	0.753
Thomas et al. (2018)[4]	233.6	225.7	8.49	0.442
Mallmann et al. (2018)[5]	249.1	247.5	8.40	0.881
Sow weight at weaning (kg)	253.8	245.4	9.93	0.495
Sow weight change (kg)[6]				
Vernunft et al. (2018) [3]	5.02	−0.12	3.399	0.298
Thomas et al. (2018)[4]	18.5	20.4	4.81	0.741
Mallmann et al. (2018)[5]	3.03	−1.47	4.008	0.360
Backfat at P2 prefarrowing (mm)	16.6	18.3	1.4	0.393
Backfat at P2 weaning (mm)	14.7	14.8	1.14	0.956
Change in backfat entry to weaning (mm)	−1.82	−3.46	0.959	0.242
Sow feed per d (kg)	10.09	9.44	0.245	0.132
Total piglets born in following parity (n)	16.24	17.46	1.092	0.405
Litter birth weight in following parity (kg)	23.76	24.07	1.522	0.904
Average piglet birth weight in following parity (kg)	1.44	1.35	0.130	0.620

[1] Includes piglets fostered onto sows from non-trial litters.
[2] Sow weight minus conceptus weight.
[3] Calculated as $sow\ weight\ at\ entry - (litter\ weight + placenta\ weight)$, where $placenta\ weight = litter\ weight/5.1$ (Vernunft et al., 2018).
[4] Calculated using the Thomas et al. (2018) correction to National Research Council (2012), subtracting conceptus weight from entry weight. $NRC\ conceptus\ weight = (exp(8.621 - 21.02 * exp(-0.053 * d) + (0.114 * ls))/1000$, where d = days of gestation and ls = litter size born (alive and stillborn). The ratio proposed by Thomas et al. (2018) was multiplied by the National Research Council (2012) conceptus weight. $Ratio = lbw/(exp((9.095 - 17.69 * exp(-0.0305 * g) + (0.0878 * ls))/1000)$, where lbw = litter birth weight (kg), g = gestation length at point of weighing (d), ls = litter size.
[5] Calculated using equation 4 from Mallmann et al. (2018), estimating sow weight postfarrowing from entry weight, litter weight and the interval between entry and farrowing $Sow\ weight = 8.45 + (0.93 * sw) - (1.18 * ls) + (1.15 * in)$, where sw = sow entry weight (kg), ls = litter size, in = interval from weighing to farrowing (d).
[6] Sow weaning weight minus adjusted sow weight at entry.

Table 4
Preweaning performance of litters, and postweaning performance of piglets, from sows with sufficient (S) or insufficient (IS) teats/piglet at d 4 postfarrowing.

Performance parameters	S	IS	SEM	*P*-value
n (litters)	29	15		
Litter age at weaning (d)	27.9	28.1		
Piglets/litter d 4 (n)	13.72	15.93	0.344	<0.001
Piglets/litter weaned (n)	13.48	15.60	0.363	<0.001
Mortality d 4 to weaning (%)	1.75	2.07		NS
Litter weight d 4 (kg)	29.38	32.54	1.269	0.050
Average piglet BW d 4 (kg)	2.14	2.04	0.069	0.269
Litter weight weaned (kg)	118.0	127.8	3.51	0.030
Average piglet weaning weight (kg)	8.77	8.20	0.182	0.015
Total litter SM consumed (kg)[1]	51.0	103.2	16.31	0.031
SM consumed/kg litter weight weaned (kg)[1]	0.39	0.78	0.118	0.026
SM consumed/pig weaned (kg)[1]	3.62	6.51	1.056	0.062
Postweaning				
n (individual pigs)	380	245		
Average BW weaning (kg)	8.74	8.24	0.128	0.003
Average BW d 54 (kg)	43.0	42.0	0.45	0.106
ADG weaning to d 54 (g/d)	631	621	7.0	0.249

Abbreviations: SM = supplementary milk; ADG = average daily gain.
[1] Weighed supplementary milk consumed from d4 to weaning.

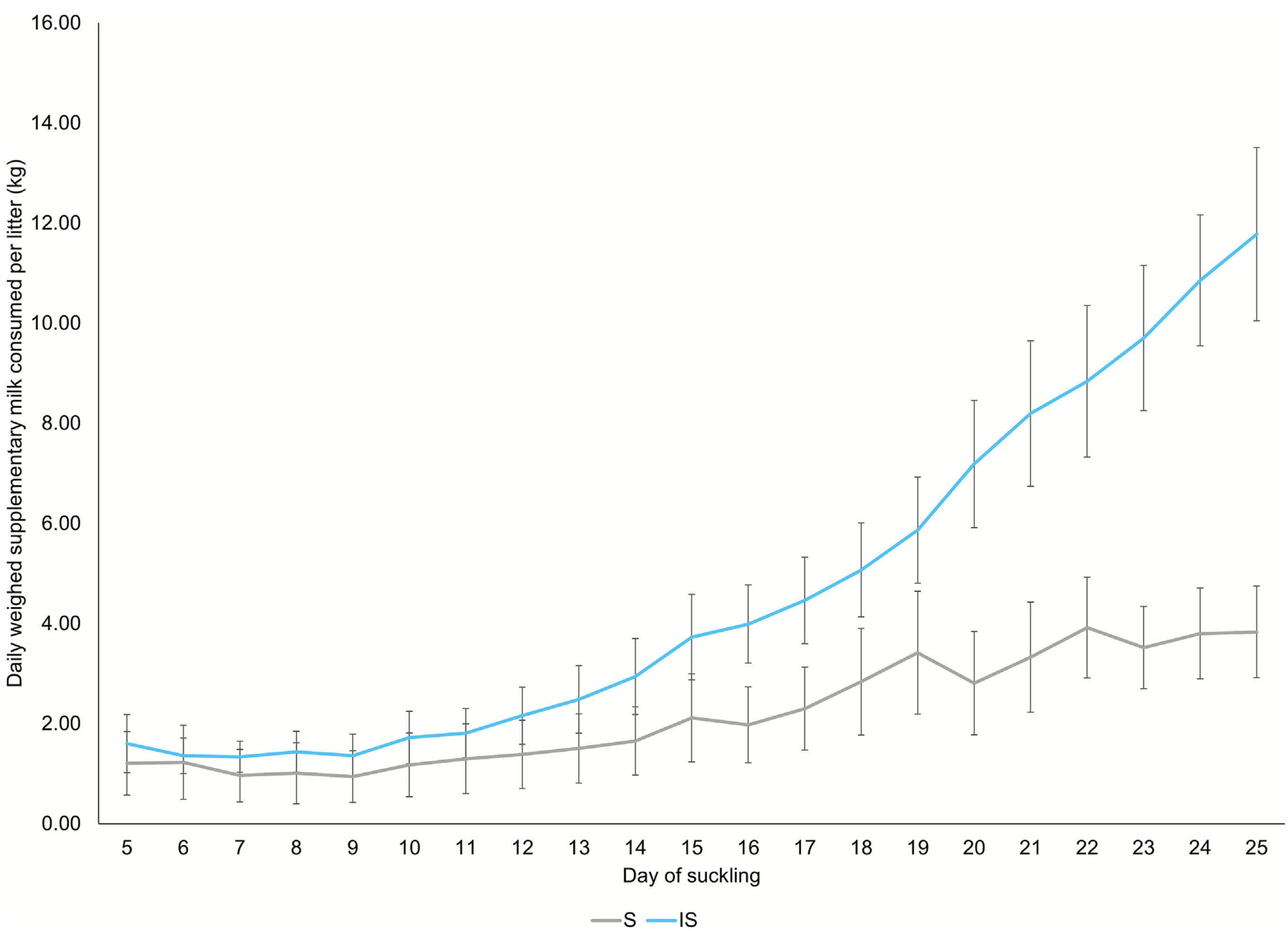

Fig. 3. Effect of insufficient (IS) or sufficient (S) sow functional teats/piglets on preweaning weighed litter supplementary milk consumption per day. Error bars denote SEM.

until weaning ($P < 0.001$). Litter weight at d 4 tended to be heavier for IS litters than S litters ($P = 0.050$), although average piglet weight at d 4 was similar ($P = 0.269$). Litter weight weaned was heavier in IS litters compared to S litters ($P = 0.030$), but average piglet weight at weaning was lighter in IS litters compared to S litters ($P = 0.015$). There was no difference in mortality from d 4 to weaning between S and IS litters ($P > 0.050$).

Litters from IS sows consumed more SM in total over lactation ($P = 0.031$) and per kg litter weaning weight ($P = 0.026$), and tended to consume more SM per piglet weaned ($P = 0.062$). Daily weighed

SM consumption per litter was similar between S and IS litters until d 14 (Fig. 3); thereafter, IS litters had a higher rate of increase of daily weighed SM consumption ($P < 0.050$). Pigs from IS litters were lighter at weaning ($P < 0.001$), but at d 54 postweaning, pigs from S and IS litters were similar in weight ($P = 0.106$), with similar ADG from weaning to d 54 postweaning ($P = 0.249$).

Table 5
Comparison of the relationships between litter SM consumption (kg) and total duration (s) of supplementary milk (SM) bowl visits per litter, or a function multiplying individual piglet weight (kg) by piglet duration (s) of SM bowl visits (Σwti*dui), during the preweaning period.

Relationships	SE	Adjusted variance accounted for	*P*-value linear
d 4 to d 11			
Weighed SM vs total duration	0.452	0.113	0.060
Weighed SM vs Σwti*dui[1]	0.480	N/A[2]	0.332
d 11 to d18			
Weighed SM vs total duration	0.767	0.657	<0.001
Weighed SM vs Σwti*dui	0.837	0.592	<0.001
d 18 to d weaning			
Weighed SM vs total duration	1.94	0.678	<0.001
Weighed SM vs Σwti*dui	1.56	0.791	<0.001
Combined d 4 to d weaning			
Weighed SM vs total duration	1.53	0.727	<0.001
Weighed SM vs Σwti*dui	1.17	0.839	<0.001

Abbreviation: SM = supplementary milk.
[1] Σwti*dui: calculated by multiplying daily individual piglet weight (kg) and daily individual piglet duration of visits to the SM bowl (s), then summing for the litter.
[2] Residual variance exceeded the variance of response variate.

Supplementary milk consumption

Postdata cleaning, 94% of visits recorded by the RFID system were deemed acceptable for inclusion in the data analysis. When the preweaning period was divided into weekly sections, the minimal model associating daily litter SM consumption (kg) and measured variables was based upon litter total daily duration of visits (s) with the highest adjusted variance accounted for from d 18 to d 26 (Table 5). Combining the weekly sections into a single period resulted in a higher adjusted variance accounted for. Including the function $\sum$wti*dui (sum of individual piglet weight (kg)*individual duration of visits (s) for all piglets in the litter) further increased adjusted variance accounted for and lowered SE, for the period from d 18 to d 26, and for the entire preweaning period. The relationship for the whole preweaning period was defined as:.$litterSMconsumed(kg) = (0.000167 * (\sum wti * dui)) - 0.378$

There was no difference in the diurnal variation of the percentage of total duration of visits to the SM bowl between S and IS litters ($P = 0.223$; Fig. 4). Duration of visits was low between 2000 to 0600 h; thereafter, duration of visits increased to a small peak in activity between 0800 to 0900 h. Duration of visits was low (but greater than overnight) between 1000 to 1200 h, before reaching the apex at 1600 h.

Piglets classified as high or very high SM consumers from d 18 to weaning were heavier at birth than those classified as medium SM consumers, with low SM consumers intermediate ($P < 0.05$; Table 6), but at weaning, very high SM consumers were lighter in BW than all other classifications ($P < 0.05$). The classification of very high SM consumers had a higher percentage of piglets from IS litters ($P < 0.001$) and a higher percentage of non-sucklers than the other classes ($P < 0.001$). The classifications of low, medium and high SM consumers differed in piglet SM consumption through

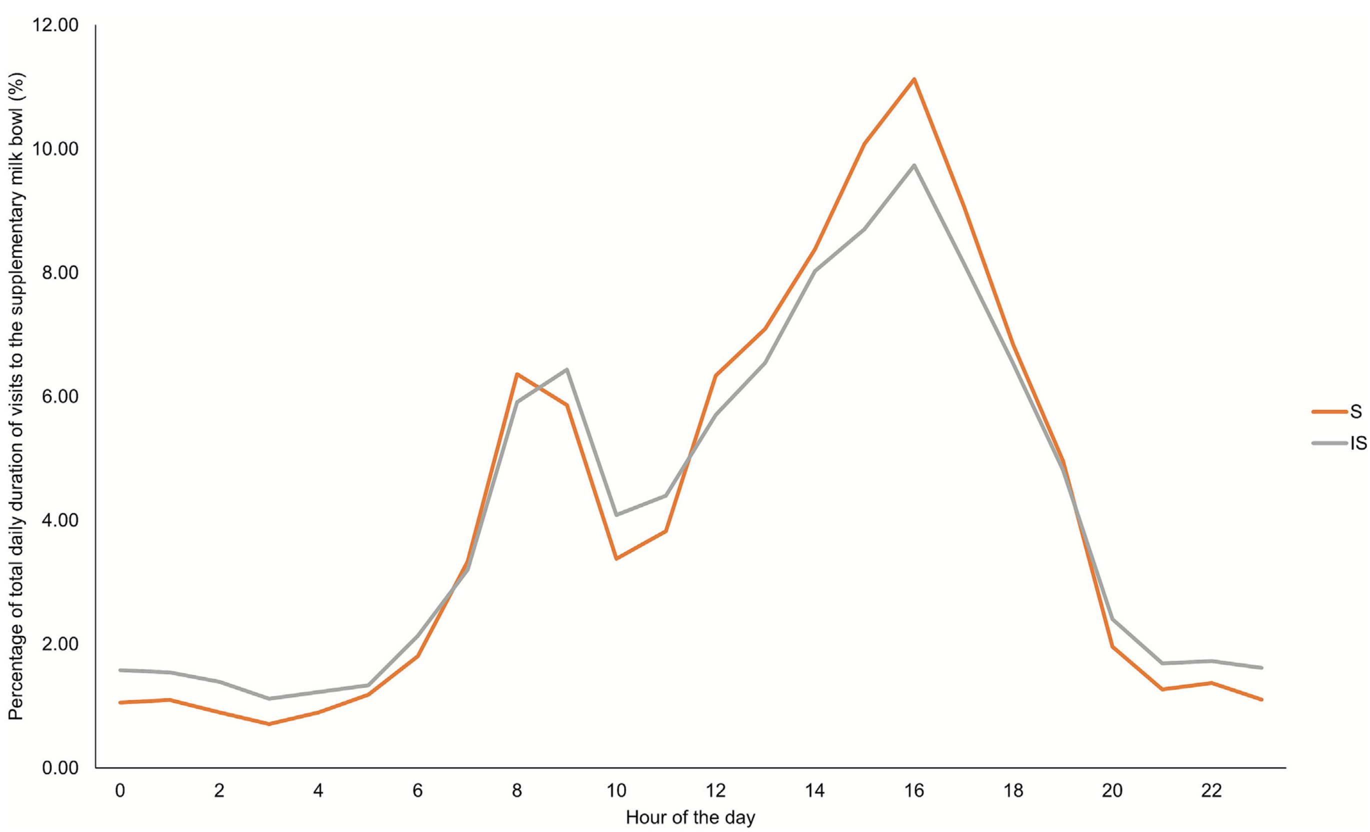

Fig. 4. Diurnal variation in supplementary milk (SM) consumption for litters from sows with sufficient (S) or insufficient (IS) functional teats/piglets.

Table 6
Pig performance pre- and postweaning, visits/d and duration of SM visits/d to the supplementary milk (SM) bowl during the suckling period, in relation to level of duration of SM visits/d (low, L; medium, M; high, H; very high, V) during the final week prior to weaning.

Performance parameters	SM consumption classification[1]				SEM	*P*-value
	L	M	H	V		
n (piglets)	156	156	157	156		
Estimated SM consumed/d d 18 to weaning (kg ± s.d)[2]	0.10 ± 0.133	0.18 ± 0.144	0.33 ± 0.165	0.82 ± 0.457		
Average birth weight (kg)	1.44^{ab}	1.38^{b}	1.49^{a}	1.51^{a}	0.028	0.004
Average BW weaning (kg)	8.64^{a}	8.54^{a}	9.11^{a}	7.89^{b}	0.157	<0.001
Percentage of piglets in class from IS litters (%)	30.1	26.3	39.5	60.9		<0.001
Percentage of non-sucklers in class (%)	3.85	1.28	3.18	12.18		<0.001
Visits/d (n)						
d 4 to 11	1.02^{b} (2.8)	1.42^{b} (4.1)	1.53^{b} (4.6)	2.30^{a} (9.9)	0.213	<0.001
d 11 to 18	1.11^{d} (3.0)	1.66^{c} (5.3)	1.90^{b} (6.7)	2.93^{a} (18.8)	0.092	<0.001
d 18 to weaning	1.02^{d} (2.76)	1.87^{c} (6.5)	2.55^{b} (12.8)	3.61^{a} (36.8)	0.083	<0.001
Total duration of visits/d (s)						
d 4 to 11 (s)	4.13^{c} (62)	4.64^{bc} (103)	4.72^{b} (112)	5.53^{a} (253)	0.172	<0.001
d 11 to 18 (s)	4.16^{d} (64)	4.75^{c} (115)	5.00^{b} (149)	6.16^{a} (471)	0.104	<0.001
d 18 to weaning (s)	4.04^{d} (57)	4.98^{c} (146)	5.71^{b} (301)	6.82^{a} (919)	0.091	<0.001
Postweaning						
Average BW d 54 (kg)	42.6^{ab}	42.4^{ab}	44.3^{a}	41.1^{b}	0.56	<0.001
ADG weaning to d 54 (g/d)	627^{ab}	624^{ab}	651^{a}	606^{b}	8.6	0.002

Abbreviations: SM = supplementary milk; ADG = average daily gain. Different superscripts within a row denote significance differences at $P < 0.05$.
[1] Supplementary milk consumption classification based on daily duration of visits to the SM bowl (du/d) from d 18 to wean where: L = First quartile of consumers; M = second quartile of consumers; H = third quartile of consumers; V = fourth quartile of du/d.
[2] Calculated by multiplying the individual piglet's contribution to litter ∑wti*dui: (piglet wt*du)/ ∑wti*dui, where wt = weight (kg) and du = duration of visits (s), by the calculated litter SM consumption from d18 to weaning, where litter SM (kg) = 0.000167*(∑wti*dui)-0.378. Visits/d and duration/d analysed using GLM with Poisson distribution and logarithmic link function due to non-normality. Results are presented as transformed value (backtransformed mean).

the suckling period for both duration of SM visits/d and number of visits/d ($P < 0.001$). From d 4 to d 11, very high SM consumers had higher visits/d and duration of SM visits/d than the other classifications, and high SM consumers also had higher duration of SM visits/d than low SM consumers ($P < 0.050$). From d 11 to d 18 and from d 18 to weaning, piglet SM consumption as measured by visits/d or duration of SM visits/d increased with consumption classification ($P < 0.050$). On d 54 postweaning, high SM consumers were heavier and had higher ADG from weaning to d54 postweaning than very high SM consumers, with low and medium SM consumers similar in weight and ADG to both high and very high SM consumers ($P < 0.050$).

Effect of birth weight on performance and supplementary milk consumption

By design, mean birth weights for the birth weight groups were significantly different ($P < 0.001$; Table 7). However, by weaning, piglets from groups 3 and 4 were similar in BW, but heavier than those in groups 1 and 2, with group 1 being the lightest ($P < 0.050$). From d 4 to 11, the piglets from birth weight group 1 had the highest v/d and du/d to the SM bowl ($P < 0.050$). However, there was no effect of birth weight group on SM consumption from d 11 to 18 ($P > 0.050$). From d 18 to weaning, piglets from birth weight group 1 had fewer v/d to the SM bowl than piglets from

Table 7
Pig performance pre- and postweaning, visits/d and duration of visits/d to the supplementary milk (SM) bowl during the suckling period, in relation to piglet birth weight group (group 1: <1.00 kg, 2: 1.02–1.50 kg, 3: 1.52–2.00 kg, 4: >2.00 kg).

Performance parameters	Birth weight group[1]				SEM	*P*-value
	1	2	3	4		
n (piglets)	70	248	251	68		
Average birth weight (kg)	0.88^{d}	1.24^{c}	1.65^{b}	2.06^{a}	0.015	<0.001
Average BW weaning (kg)	6.34^{c}	8.05^{b}	9.27^{a}	9.77^{a}	0.215	<0.001
Visits/d (n)						
d 4 to 11	2.35^{a} (10.5)	1.82^{b} (6.2)^{z}	1.71^{b} (5.5)^{z}	1.66^{b} (5.3)^{z}	0.222	0.006
d 11 to 18	2.32 (10.2)	2.09 (8.1)^{y}	2.11 (8.2)^{y}	2.16 (8.6)^{y}	0.117	0.334
d 18 to weaning	2.49^{b} (12.1)	2.61^{ab} (13.5)^{x}	2.75^{a} (15.7)^{x}	2.89^{a} (17.9)^{x}	0.132	0.038
Total duration of visits/d (s)						
d 4 to 11 (s)	5.63^{a} (279)	5.08^{b} (161)^{z}	4.89^{b} (133)^{z}	4.80^{b} (122)^{z}	0.242	0.001
d 11 to 18 (s)	5.56 (259)	5.28 (197)^{y}	5.24 (189)^{y}	5.26 (192)^{y}	0.131	0.129
d 18 to weaning (s)	5.70 (298)	5.81 (334)^{x}	5.92 (373)^{x}	6.05 (424)^{x}	0.136	0.138
Postweaning						
Average BW d 54 (kg)	34.0^{d}	41.0^{c}	44.8^{b}	48.4^{a}	0.720	<0.001
ADG weaning to d 54 (g/d)	502^{d}	609^{c}	655^{b}	712^{a}	11.3	<0.001

Abbreviation: ADG = average daily gain. Different superscripts within a row (a,b,c,d) or column (x,y,z) denote significance differences at $P < 0.05$.
[1] Birth weight group 1: <1.00 kg, 2: 1.02–1.50 kg, 3: 1.52–2.00 kg, 4: >2.00 kg. Visits/d and duration of visits/d analysed using GLM with Poisson distribution and logarithmic link function due to non-normality. Results are presented as transformed value (backtransformed mean).

Table 8
Pig performance pre- and postweaning, visits/d and duration of visits/d to the supplementary milk (SM) bowl during the suckling period, in relation to suckling position at the udder (anterior, A; centre, C; posterior, P; non-suckler, NONE) on d 14 of age.

	Suckling position on d 14[1]					
Performance parameters	A	C	P	NONE	SEM	*P*-value
n (piglet)	166	227	164	28		
Average birth weight (kg)	1.54^{a}	1.44^{b}	1.43^{b}	1.32^{b}	0.061	0.001
Average BW at weaning (kg)	9.53^{a}	8.58^{b}	7.86^{c}	6.66^{d}	0.328	<0.001
Visits/d (n)						
d 4 to 11	1.46^{c} (4.3)	1.71^{bc} (5.5)	1.82^{b} (6.2)	3.03^{a} (20.6)	0.121	<0.001
d 11 to 18	1.84^{c} (6.3)	2.02^{bc} (7.6)	2.17^{b} (8.7)	3.21^{a} (24.8)	0.092	<0.001
d 18 to weaning	2.48^{c} (12.0)	2.53^{c} (12.6)	2.80^{b} (16.5)	3.59^{a} (36.1)	0.104	<0.001
Total duration of visits/d (s)						
d 4 to 11 (s)	4.66^{c} (105)	4.93^{bc} (138)	5.02^{b} (151)	6.31^{a} (549)	0.128	<0.001
d 11 to 18 (s)	4.97^{c} (145)	5.17^{bc} (176)	5.33^{b} (206)	6.47^{a} (644)	0.094	<0.001
d 18 to weaning	5.67^{c} (290)	5.71^{c} (302)	5.97^{b} (393)	6.81^{a} (905)	0.107	<0.001
Postweaning						
Average BW d 54 (kg)	44.6^{a}	42.1^{b}	41.9^{b}	39.2^{b}	1.21	<0.001
ADG weaning to d 54 (g/d)	647^{a}	626^{ab}	620^{b}	580^{b}	18.5	0.003

Abbreviation: ADG = average daily gain. Different superscripts within a row denote significance differences at $P < 0.05$.
[1] Suckling position at d 14 where A: anterior, C: centre, P: posterior, NONE: not observed suckling. Visits/d and duration/d analysed using GLM with Poisson distribution and logarithmic link function due to non-normality. Results are presented as transformed value (backtransformed mean).

groups 3 and 4 ($P < 0.050$), with group 2 similar to all. Within birth weight groups, groups 2, 3, and 4 showed an increase in both v/d and du/d over time (antedependence order 1, $P < 0.001$, s.e.m 0.822 and 21.03, respectively), whereas there was no effect of time on SM v/d or du/d of piglets from birth weight group 1.

Both weight at d 54 postweaning and ADG from weaning to d 54 increased with birth weight group ($P < 0.050$).

Effect of suckling position on performance and supplementary milk consumption

Piglets suckling anterior teats were heavier at birth than piglets suckling centre and posterior teats, or non-sucklers ($P < 0.050$, Table 8). Weaning BW decreased from piglets suckling anterior to posterior teats, with non-sucklers being the lightest ($P < 0.050$). Throughout the suckling period, non-sucklers had the highest SM consumption quantified by both visits/d and duration of SM visits/d ($P < 0.001$). From d 4 to weaning, posterior-suckled piglets had higher visits/d and duration of SM visits/d than anterior-suckled piglets ($P < 0.050$), with centre-suckled piglets similar to both. From d 18 to weaning, posterior-suckled piglets also had higher visits/d and duration of SM visits/d than centre-suckled piglets ($P < 0.050$). By d 54 postweaning, pigs that had suckled anterior teats were heaviest, and there was no difference in weight between centre-suckled, posterior-suckled and non-suckled piglets ($P < 0.050$). Pigs that had suckled anterior teats had higher ADG from weaning to d 54 than non-suckled piglets and posterior-suckled piglets ($P < 0.050$), but ADG of pigs that suckled centre teats was intermediate and similar to all others.

Discussion

Teat supply

It was considered appropriate that the study treatments reflected litter size relative to functional teats at the point that SM recording began. As there was very little mortality after this point (1.75% for S and 2.07% for IS litters), the treatments assigned at d 4 were valid for the duration of the study, and more accurately reflected the rearing environment experienced by the piglets, rather than the treatment structure initially obtained by cross-fostering. A limitation of this study is that functional teat number was not assessed post d 0, and it is possible that some previously functional teats may have become non-functional. In S litters, 4.5% of piglets (0.58 pigs/litter) were recorded as non-sucklers at d 14, compared to 6.1% (1 pig/litter) from IS litters. Functional teats at parturition may become non-functional due to lack of stimulation if not suckled (King, 2000; Ocepek et al., 2016; Hurley, 2019); therefore, the occurrence of non-suckling piglets from S litters may be due to low piglet vitality and suckling strength during the first days postfarrowing.

The greatest difference in sow performance associated with parity is between gilts and multiparous sows, as gilts typically have lower feed intake (National Research Council, 2012; Lavery et al., 2019) and are still growing and thus tend to rear lighter litters (Carney-Hinkle et al., 2013; Lavery et al., 2019). In this study, the proportion of first parity sows was similar between S and IS; therefore, it is concluded that parity profile had no effect on sow performance; although the proportion of parity grouping 2–4 and grouping 5 and 6 sows tended to differ between S and IS, the difference in performance between these parity groupings is lower than between gilts and multiparous sows (Lavery et al., 2019).

Sows selected as IS tended to have a higher number of piglets born alive than S sows, as litters were allocated to treatment with minimal cross-fostering, aiming to minimise disruption to the innate intra-litter birthweight variation. The litter size born places the sows within the top 10% of UK herds (Agriculture and Horticulture Development Board, 2024). Litter birth weight was heavier for IS sows due to the greater number of piglets born, as average piglet birthweight was similar between treatments. Generally, piglet birth weight shows an inverse relationship with litter size (Quiniou et al., 2002; Beaulieu et al., 2014; Yang et al., 2023), but the difference in litter size between the treatments (2.33 piglets born alive) was probably too low to reflect this.

Mortality of piglets between birth and d 4 was unaffected by teat supply, but was higher (14.6% for S, 17.5% for IS) than UK average figures for preweaning mortality of 12.46% (Agriculture and Horticulture Development Board, 2024). Generally, piglet preweaning mortality is positively associated with litter size (van Rens et al., 2005; Beaulieu et al., 2014; Sanz-Fernández et al., 2024), and the greater litter size born alive achieved in the current study (16.07 for S, 18.40 for IS) compared to average figures (14.8; Agriculture and Horticulture Development Board, 2024) is likely to have contributed to the higher preweaning mortality.

The management strategy of split-suckling litters, employed during the first 24 h after birth, improved access to colostrum where there were supernumerary piglets compared to teats, and so is likely to be the reason for the similarity in mortality between S and IS litters from birth to d 4. Having SM available to litters from birth has also been shown to reduce piglet mortality (Stewart et al., 2010), particularly in large litters (Kobek-Kjeldager et al., 2020a).

There are a few studies where SM has been offered, and sow lactational weight change has been recorded. Both Pustal et al. (2015) and Kobek-Kjeldager et al. (2020a), who offered SM from d2 and d1, respectively, reported a higher sow lactational weight loss than that observed in the current study. This may be explained by the lower feed intake of sows in both previous studies (5.3 kg/d and ~ 6.4 kg/d, respectively) compared to this study (9.44 kg/d for IS and 10.09 kg/d for S sows). The heavier litter weight weaned in the current study would also have required a higher sow lactational feed intake to provide the greater milk yield needed, as the minimal loss in sow weight and backfat indicates very little tissue mobilisation in support of lactation. In agreement with Pustal et al. (2015) and Kobek-Kjeldager et al. (2020a), who reported no effect of weaned litter size on sow lactational weight loss, sow weight change during lactation was similar between S and IS sows.

It is often reported that weight loss in lactation has a negative effect on oocyte quality, resulting in lower litter sizes in the following parity (Thaker and Bilkei, 2005; Prunier et al., 2010; Costermans et al., 2019). The low weight loss observed from the IS sows was insufficient to have an adverse effect on subsequent litter size. A lactational weight loss of above 10% was suggested by Thaker and Bilkei (2005) to be the threshold at which a reduction in litter size would occur, and this was reached by only three gilts in this study (one S, two IS).

By design, at d 4, litter size was higher for IS compared to S sows, and the difference was maintained until weaning, with similar mortality between treatments. Although provision vs absence of SM was not tested in the current study, it is unlikely that supernumerary piglets would have survived until weaning without SM provision, as Gourley et al. (2020) reported a negative relationship between piglets:teat and % weaned, and piglets without a teat will die within 2–3 days (Andersen et al., 2011). It appears that SM provision can enable litters to remain intact after d 4, and sows can rear supernumerary piglets without the need for interventions such as artificial rearing or shunt-fostering. As the average piglet weight was similar between S and IS sows at d 4, the greater litter size resulted in heavier litter weight at d 4 for IS sows. The heavier litter weight reared by IS sows was due to weaned litter size being more than two pigs/litter greater compared to S sows, but average piglet weaning weight was lower in IS litters. Lower average piglet weaning weight as litter size increases is consistent with previous research by Milligan et al. (2002), Douglas et al. (2013), and Kobek-Kjeldager et al. (2020a), whereby the nutritional demands of a larger litter size are unable to be met by the sow. The lower growth observed from d 4 to weaning in IS piglets (6.16 kg) compared to S piglets (6.63 kg) indicates that sow milk yield was insufficient to maintain piglet growth where there were more piglets than functional teats, and SM was unable to fully compensate for this lost growth. This observation may be related to the lower efficiency of conversion to piglet weight gain of SM compared to sow milk. Total SM consumed over lactation, SM consumed per kg litter weight weaned, and SM consumed per piglet weaned were all substantially higher in IS litters compared to S litters. The 52.2 kg additional litter SM consumed over lactation by IS compared to S litters over lactation would have a DM content of 7.46 kg (143 g/kg DM), and this supported 9.8 kg of additional litter growth, if there was no additional milk yield from the sow. The additional SM DM consumed divided by the additional litter weight gain equates to an SM DM feed conversion ratio of 0.76, which is higher than the 0.70 that could be predicted assuming sow milk DM of 175 g/kg (Zhang et al., 2018), and using a conversion rate of 4 kg sow milk:1 kg piglet growth (Whittemore et al., 2003). Using the calibration equation linking daily weighed litter SM consumption with daily piglet weight and du/d ($\sum$wti*dui), and calculating individual piglet contribution to litter $\sum$wti*dui, an estimation of SM DM feed conversion ratio for non-sucklers (assumed to have no contribution to their nutrition from the sow) of 0.88 was calculated for the final week preweaning. The higher feed conversion ratio of piglet growth from SM than sows' milk could be linked to SM composition, as the SM specification was lower in fat (21 g/kg mixed SM) than published values for sows' milk (75.5 g/kg as-fed; Zhang et al., 2018), due to the requirement of being water soluble. This lower fat content would result in a lower energy content of SM compared to sows' milk. The SM provided also had a lower protein specification (33 g/kg mixed SM) than published values for sow's milk (49.9 g/kg as-fed; Zhang et al., 2018). Improving the formulation of SM powder is beyond the scope of the current study, but it is an important area for future research.

At d 54 postweaning, the average weight and ADG of pigs from S and IS sows were similar, demonstrating no long-term adverse effects on average pig performance from being reared in a litter where there were insufficient teats. Previously, a positive relationship between weaning weight and subsequent weights has been observed (Pluske et al., 2003; Magowan et al., 2011; Collins et al., 2017), but it is possible that the difference in average pig weaning weight was insufficient to be detected in subsequent performance. These average figures for postweaning performance do not reflect the experience of individual piglets, particularly non-sucklers and very high SM consumers, of which there were a higher proportion from IS than S sows, as discussed in the following sections.

Quantification of supplementary milk consumption

The moderate positive correlation between weighed daily litter SM consumption and the function combining daily piglet weight and duration of SM visits/d (Σwti*dui) demonstrated that this is a practical system to estimate SM consumption. The final week prior to weaning (from d 18 to weaning) was selected as the period for classification of individual level of SM consumption due to the r^2 linking these parameters being highest during this period (r^2 = 0.73 for daily weighed litter SM vs duration of SM visits/d, and r^2 = 0.84 for daily weighed litter SM and Σwti*dui). The significant contribution of piglet weight to the regression indicates that piglets' SM consumption rate increases with piglet weight. Light birth weight piglets typically consume a lower volume of milk per suckle (Douglas et al., 2014a), and Wolter et al. (2002) found that the SM feeding rate of heavy birth weight litters was higher than that of light birth weight litters. Kobek-Kjeldager et al. (2020b) used direct observation of SM consumption and concluded that lower drinking frequency on d 14 and d 21 compared to d 7 indicated that the older (heavier) pigs had a higher consumption rate, although they did not measure the duration of visits. In finishing pigs, there is a positive correlation between pig weight and feeding rate (Hyun et al., 1997). Including piglet weight therefore enables a single equation to be used for estimating daily litter SM consumption for the entire preweaning period. A limitation is the relatively low r^2 observed during the early stages of lactation, when weighed daily litter SM consumption was low. A further limitation was the exclusion of the 5% of visits with a duration of visit longer than 70 s. These visits were discarded from the analysis, as from the video recordings, it was evident that piglets were not drinking the entire time, but they would still have consumed some SM.

Using the duration of SM visits/d as a proxy facilitates grouping of piglets into relative levels of individual piglet SM consumption, with the groupings employed being significantly separate from the initial period of d 4 to d 11, and until weaning, allowing investigation of the effect of level of piglet SM consumption on piglet performance in the current study. A limitation of the method employed is that the calibration of duration of visits to weighed SM consumption was performed on a litter basis, rather than individually, and so an assumption was made that du/d would be the most appropriate method for ranking individual piglets based on their SM consumption. It is possible that there is a higher degree of variation in the relationship between duration of visit and weight of SM consumed per visit when considering individual piglets. Validation of the use of duration of SM visits/d as a proxy for individual SM consumption by weighing piglets before and after SM consumption is an area for future research, as quantification of individual piglet SM consumption preweaning would facilitate research into the effect of the level of preweaning SM consumption on piglet physiology.

The method employed in this study enabled continuous recording with no user fatigue, generating a more complete dataset. Diurnal variation in litter hourly SM consumption recorded as a percentage of total daily duration of visits per hour (Fig. 4) was similar to the alternans pattern described by Bus et al. (2023) for feed intake in finishing pigs; therefore, continuous recording eliminated any confounding effect of time of observation, which may occur when directly observing pigs.

Previously, it has been considered that sow milk yield becomes limiting to piglet growth from around d 21 of lactation (Hughes and Varley, 1980), but it can be seen in the current study that weighed daily litter SM consumption, visits/d and duration of SM visits/d began to increase at a greater rate in IS than S from d 12. This is similar to the results of Miller et al. (2012) and Azain et al. (1996), who reported an increase in daily litter SM consumption from d 12 in hot weather, and implies that sow milk yield may be insufficient for piglets' demands earlier in lactation than expected, when conditions are sub-optimal, or piglet demand is greater.

Effect of supplementary milk consumption on performance

Piglets were classified by individual duration of SM visits/d as a proxy for SM consumption during the final week of suckling as this was predicted to be the period where differences were most apparent, but the differences in visits/d and duration of SM visits/d between low, medium, high and very high SM consumers were evident from the first week of recording (d 4 to 11). The lower weaning weight of very high consumers was likely a result of there being a higher proportion of piglets from IS litters, who were lighter on average at weaning, and of non-sucklers, who, as already discussed, may have had a lower energy intake due to the lower fat content of SM compared to sow's milk. Pigs classified as very high consumers were lighter at d 54 postweaning and had lower ADG to d 54 than those classified as high consumers, but were similar to low and medium consumers, indicating that being a very high SM consumer did not adversely affect postweaning performance.

Effect of birth weight on performance and supplementary milk consumption

A positive relationship between birth weight and weaning weight is well established (Quiniou et al., 2002; Paredes et al., 2012; Douglas et al., 2014b) and is supported by the current study. Piglets from all birth weight groups except group 1 showed a large increase in duration of SM visits/d from d 18 to weaning, indicating that the sow's milk yield was most limiting at this point.

Wolter et al. (2002) also found that litters of heavy birth weight (1.8 kg) piglets consumed more SM than litters of light birth weight (1.3 kg) piglets, and Kobek-Kjeldager et al. (2020c) found that heavy birth weight piglets were more likely to consume SM. Conversely, a study by Kobek-Kjeldager et al. (2021) using direct observation on selected days showed no effect of birth weight on visits/d. They concluded that this was due to feeder design; the majority of piglets consumed supplemental feed as multiple piglets could access the feeder at once, leading to more social feeding through learned behaviour. It may also have been affected by the policy of removing the lightest piglets if the litter size was >15. They recorded an average of 10.8 visits/piglet during a 12-h period on d 11, which is greater than the average visits/d recorded for all but the very high users in the current study (high-consuming piglets averaged 4.6 visits/d from d 4 to 11 and 6.7 visits/d from d11 to 18; very high-consuming piglets averaged 9.9 visits/d from d 4 to 11 and 18.8 visits/d from d11 to 18). It is therefore possible that feeder design has an impact on piglet SM consumption. At d 54 postweaning, the difference in pig weight and ADG between birth weight groups followed that observed for piglet weight preweaning. It is well established that lighter piglet weaning weight is associated with a lighter BW throughout the pig's life (Pluske et al., 2003; Magowan et al., 2011; Collins et al., 2017), and the differences in piglet weaning weight due to birth weight group were larger than those due to preweaning teat supply treatment.

Effect of suckling position on performance and supplementary milk consumption

Nielsen et al. (2001) and Huting et al. (2017) reported that BW and ADG throughout lactation were highest in piglets suckling anterior teats, and lowest in piglets suckling posterior teats. Conversely, Skok et al. (2007) observed no effect of suckling position on performance, although that may be due to low replication (five posterior vs 34 anterior and 47 centre), as posterior-suckled piglets were numerically 600 g lighter at weaning. Results of the current study agree with Nielsen et al. (2001) and Huting et al. (2017), with piglet BW and ADG reducing from anterior-centre-posterior suckling positions.

The effect of suckling position on piglet SM consumption has not previously been investigated, but it is logical that piglets without a teat should have the highest SM consumption. The difference in duration of SM visits/d between sucklers and non-sucklers was evident from the first period (d4 to d11), demonstrating the requirement for SM to be provided from birth, to prevent early mortality, as concluded in Stewart et al. (2010). Although posterior-suckled piglets had a higher duration of SM visits/d than anterior-suckled piglets throughout lactation, this was unable to compensate for the presumably lower sow milk yield experienced by these piglets. Although non-suckled piglets were lighter at weaning, they were similar in weight and postweaning ADG to centre and posterior-suckled piglets by d 54 postweaning. The numerical difference in weight was approaching 2 kg and the difference in ADG was at least 40 g/d, so the lack of difference may be due to low replication of the non-suckled piglets.

Further research is required to validate the use of an RFID system to record individual SM consumption, including weighing of piglets before and after consumption. Differences in the nutritional value as a feed for piglets between SM and sows' milk may affect piglet performance, and so an investigation of composition and refinement of the formulation is needed. The combined effects of SM and creep feed consumption on piglet performance and physiology should also be examined, as creep feeding is an important aspect of piglet preweaning nutrition.

In conclusion, sows with insufficient functional teats had higher litter weaning weight due to weaning more piglets than sows with sufficient functional teats, but average piglet weaning weight was lower in litters where there were insufficient functional teats. Using an RFID recording system, litter supplementary milk consumption (kg) showed a positive relationship with duration of visits (s) and a function combining duration of visits (s) and piglet weight (kg). Piglets without a teat and those suckling posterior teats had the highest SM consumption (measured using duration of visits as a proxy) throughout the preweaning period.

Ethics approval

This study was approved by the Harper Adams University Research Ethics Committee, project number 0458-207905-PGMPHD.

Data and model availability statement

None of the data were deposited in an official repository. The data that support the findings are available upon reasonable request.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

Author ORCIDs

S. Icely: https://orcid.org/0000-0002-9274-2006.
A.M. Mackenzie: https://orcid.org/0000-0002-1308-8529.
S.C. Mansbridge: https://orcid.org/0000-0003-4246-9782.
A.H. Stewart: https://orcid.org/0000-0003-0309-5343.

CRediT authorship contribution statement

S. Icely: Writing – original draft, Visualisation, Methodology, Investigation, Formal analysis, Data curation, Conceptualisation, Project administration, Validation. **S.C. Mansbridge:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualisation, Formal analysis, Project administration, Validation. **A. M. Mackenzie:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualisation, Formal analysis, Project administration, Validation. **A.H. Stewart:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualisation, Formal analysis, Validation.

Declaration of interest

None.

Acknowledgements

The authors gratefully acknowledge the technical assistance provided by the pig unit staff at Harper Adams University. Harper Adams University is a signatory to the Technician Commitment. This study was part of S Icely's PhD thesis (Icely, 2024).

Financial support statement

This work was supported by the Agriculture and Horticulture Development Board(grant reference 51110101), Primary Diets Ltd (UK) and JSR Genetics Ltd (UK).

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