Animal 16 (2022) 100655

Contents lists available at ScienceDirect

Animal

The international journal of animal biosciences

Development of a new grading system to assess the foster performance of lactating sows

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ARTICLE INFO

Article history:
Received 9 March 2022
Revised 11 September 2022
Accepted 12 September 2022
Available online 10 October 2022

Keywords:
Animal welfare
Cross-fostering
Milk score
Performance analysis
Piglet mortality

ABSTRACT

Increasing litter size has created the need for more sophisticated, accurate, and welfare-oriented systems for assessing the foster performance of lactating sows. The estimation of milk yield alone is not sufficient for meeting these requirements. Therefore, the aim of the current study was to develop a grading system for assessing the foster performance of lactating sows that can be easily applied in commercial farm practice. Data were collected in two German conventional farrow-to-feeder farms with a total sample size of 639 sows (4.05 ± 2.86 parities) and 1 728 litters. Besides general performance data, the piglets were weighed individually within the first 24 hours after birth and at the peak of lactation (day 18.22 ± 2.48). Based on these data, we proposed a new score referring to the milk score (**MS**). This score was compared with the commonly used formula for estimating milk yield (**est. MY**), which solely involves litter weight gain and litter size. The improvement of the developed MS allowed us to distinguish between the birth and foster performances of the lactating sows through considering cross-fostering, litter size, individual piglet weights, and piglet mortality during lactation. Both scores showed a similar progression across parities. It was found that litter size had a significant impact on the performance of lactating sows. A high est. MY was found to be associated with a significantly higher number of piglets per litter (15.79 ± 2.20), lower weight gain per piglet, and increased piglet mortality during lactation compared with sows with high MS, which showed a smaller litter size (13.51 ± 2.18) ($P < 0.05$). The focus on smaller litter size indicates a performance limitation, which seems to be related to the average teat number of 13–15 teats per sow. We recommend the consideration of the number of functional teats, because a litter size above it will not result in a sow having higher foster performance. In conclusion, as an extension of the common est. MY calculation, the MS considers cross-fostering as current farm-management practice when dealing with larger litters. Our recommendations emphasise the importance of an MS which indicates smaller litter size, higher piglet weight gain, and lower piglet mortality during lactation; these factors are related to an improvement in animal welfare for sows and piglets. Moreover, the presented MS could be used to develop a management tool for farmers to assess the foster performance of lactating sows, considering individual farm-management practices.

Implications

With increasing litter size, farmers face new challenges in litter management. For this reason, a new score entitled "milk score" for assessing the foster performance of lactating sows was developed in the present study. It contains additional performance parameters such as piglet birth weight, piglet weight at the peak of lactation, piglet mortality, and cross-fostering. In particular, the milk score focusses on smaller litter size as related to piglet mortality and weight. Furthermore, it may improve several animal welfare aspects caused by large litter sizes.

Introduction

In recent years, a tremendous increase in fertility performance has been achieved in sow herds. Until now, the emphasis has been on increasing litter size, expressed in a higher number of piglets

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https://doi.org/10.1016/j.animal.2022.100655
1751-7311/

born alive (Theil et al., 2012; Rutherford et al., 2013; Vande Pol et al., 2021b). According to Baxter et al. (2013), a larger litter is classified as a litter size of between 14 and 20 piglets, and a medium litter is classified as a litter size of between 7 and 13 piglets.

Previous studies have shown a negative correlation between litter size and piglet birth weight (e.g., Quiniou et al., 2002; Quesnel et al., 2008; Elbert et al., 2021). It is known that the sow has a lower number of functional teats than piglets born alive (Vande Pol et al., 2021a; 2021b). Furthermore, Rutherford et al. (2013) summarised the major biological factors negatively associated with large litter size, such as lower birth weight, intense teat competition, higher stress physiology, and health implications, considering this from an animal welfare perspective for sows and piglets. Overall, the farmers face new challenges as litter size increases. One of the most common practices to overcome this challenge is to manage large litters with cross-fostering, using nurse sows or artificial rearing systems (Rutherford et al., 2013; Baxter et al., 2013).

For piglet-producing farms, a high number of weaned piglets per sow, low piglet mortality, and adequate foster weights are essential for economic success. Thus, milk yield is one of the most relevant parameters for achieving high foster performance among sows, which provide the primary source of nutrition for piglets during the suckling period (Theil et al., 2012; Quesnel et al., 2015; Kobek-Kjeldager et al., 2021). The potential for milk production in lactating sows is mainly determined by the genetic background of the sows (Theil et al., 2012). The two most common methods for determining the milk yield of sows are the weigh-suckle-weigh technique and the deuterium oxide dilution technique (Theil et al., 2012; Quesnel et al., 2015). Applying the weigh-suckle-weigh technique, either the litter or the sow is weighed before and after several consecutive suckling acts. The most precise and accurate method for estimating milk yield is the deuterium oxide dilution technique (Quesnel et al., 2015). The deuterium oxide dilution technique determines milk intake by knowing the proportion of water derived from milk and the extent of dilution of body water after milk intake. For this, piglets are injected with deuterium oxide and blood samples are collected. By separating blood and water in the samples, the deuterium oxide concentration is determined, and the milk intake can be calculated (Prawirodigo et al., 1990). However, recording milk yield with these techniques involves tremendous methodological and technical efforts (Theil et al., 2012; Hansen et al., 2012) and is impractical on conventional farrow-to-feeder farms. For this reason, the most common technique for estimating the milk yield of lactating sows is to weigh piglets several times during the lactation period (Quesnel et al., 2015). This milk yield calculation only considers litter size and piglet weight gain (GfE, 2006; Theil et al., 2002).

With increasing litter size, litter-management interventions have changed. Cross-fostering is a common practice for dealing with increased litter size, but this is not considered in the common milk yield calculation. Thus, calculating a sow's milk yield depends on the cross-fostering practice applied (Baxter et al., 2013; Vande Pol et al., 2021b). According to Sell-Kubiak (2021), a balanced approach should be found that "optimises litter weight, litter size, and uniformity", because this could ensure sows' and piglets' welfare and farm-management concerns. With a similar mindset, the present study aimed to develop a novel grading system for assessing the foster performance of lactating sows, considering current farm and animal welfare conditions.

Material and methods

Farms, housing, and animals

The data collection was conducted at two conventional farrow-to-feeder farms (Farm A and Farm B) in Lower Saxony, Germany, from August 2019 to February 2021. At the time of the study, Farm A and B held herd sizes of 500 and 300 hybrid sows, respectively, from the Bundes Hybrid Zucht Programm (**BHZP**, Ellringen, Germany) (BHZP Landrace × BHZP Edelschwein). Farm A ran a two-week farrowing system with a 21-day lactation period and Farm B ran a five-week farrowing system with a lactation period of 28 days. Seven days before the calculated date of birth, the sows were moved into the farrowing units and fixed into conventional farrowing crates. No routine induction of parturition was practised on either farm. Throughout this manuscript, data are presented as the mean with its SD. On average, the sows were farrowed after a gestation period of 114.62 ± 0.70 days in Farm A and 114.32 ± 1.18 days in Farm B. During the first days after birth, ear tagging, teeth grinding, tail docking, castration of the male piglets, iron supplementation, and vaccination were similarly performed on the piglets on both farms. Both farms provide milk replacer for the piglets during the suckling period. Farm A offers milk replacer from the day of birth, and Farm B offers it from the second day after birth. Both farms increased the amount of milk replacer during the suckling period. In total, the provided amount of supplementary feed for the piglets was in a low range on both farms. Therefore, it was not considered explicitly in the subsequent analysis. All sows and piglets on both farms had water *ad libitum*.

Cross-fostering

For the management of large litters, cross-fostering is a common management practice in piglet production (Baxter et al., 2013). In both farms, litters were cross-fostered by sows from all parities within the first five days after birth by the farmer. The average litter sizes for Farms A and B were 14.32 ± 2.91 and 15.64 ± 2.30 piglets, respectively. It was essential in both farms to balance the litters of the 1st and 2nd parity sows; this is because it is important for the sows that all teats are sufficiently suckled to ensure optimal teat development for subsequent lactations (Farmer et al., 2012). In addition, the emphasis was on adding light piglets to sows from parity 1 and parity 2 because they have the smallest teats compared with multiparous sows. Both farmers ensured that litters were homogeneously balanced according to parity and piglet weights during cross-fostering. In Farm A, the most extensive cross-fostering was performed on 2nd parity sows. For Farm A, a total average of 4.50 ± 4.10 piglets per litter were added and 5.70 ± 4.20 piglets per litter were removed. In Farm B, most cross-fostering was performed on 1st parity sows. An average of 4.20 ± 4.80 piglets were added, and 4.53 ± 4.20 piglets were removed per litter for the entire herd in Farm B.

In this study, the number of teats per sow was counted only in Farm A (n = 697). On average, there were 15.04 ± 0.95 teats per sow. Both farms raise the same sow genetic from BHZP (BHZP Landrace × BHZP Edelschwein). Therefore, the number of teats can also be assumed for the sows from Farm B. The distribution of the number of teats per sow and performance group can be seen in Supplementary Table S1.

Data recording and processing

Overall, 1 728 litters (Farm A: 1 064, Farm B: 664) and 27 130 piglets (Farm A: 16 013, Farm B: 11 117) were used for the analysis. The data gathered from both farms included information about 639 sows from parity 1 to parity 16 after incomplete records were removed. Incomplete records were considered as those that did not contain all the required parameters for the calculations of the present study. Due to an insufficient number of observations, sows from parity 10 to parity 16 were combined into one group (parities "$\geq$10"). The sows were counted 2.07 ± 1.02 times during the experimental period. The average parity number of all sows was

4.05 ± 2.86 (Farm A: 4.15 ± 3.07, Farm B: 3.88 ± 2.47). Sows were categorised according to the following parity classes: Gilts-1 (1st litter), Gilts-2 (2nd litter), Top Performer (3rd–7th litter), and Old Sows (8th–16th litter). The categorisation was performed considering the biological performance change of a sow per parity (according to Milligan et al., 2002).

To differentiate the sows on their performance level, we grouped them in this study as low, medium, and high, according to the following scheme: low $[-\infty, \mu-SD)$; medium $[\mu-SD, \mu+SD)$; high $[\mu+SD,\infty)$. In order to compare the different performance parameters of the study, a min–max normalisation was performed to transform the values ranging from 0 to 1.

The general performance data, such as those for the number of piglets born alive, the number of stillborn piglets, the litter size after cross-fostering, piglet mortality (after birth and during lactation), and the number of weaned piglets, were routinely collected for this study. In addition, each piglet was weighed individually within the first 24 hours after birth (**PW1**). The second weighing (**PW2**) was performed on average at day 18.22 ± 2.48. During the cross-fostering, no additional piglet weighing was performed by the farmer. It was assumed that the farmer's objective for cross-fostering was to attain a uniform weight distribution of piglets among all litters. Piglet mortality was recorded daily. For MS calculation, piglet mortality was categorised into early mortality (≤5 days after birth) and piglet mortality during lactation (>5 days after birth). No additional weighing of dead piglets was performed.

Statistical analysis – development of the milk score

In the current study, a new formula for linking different production parameters (e.g., number of piglets born alive, number of stillborn piglets, number of weaned piglets, piglet mortality during lactation) was developed and compared with the common milk yield calculation method (GfE, 2006). All statistical data analyses were performed using R version 3.6.2 (R Core Team, 2019, Computing, Vienna, Austria) and RStudio (RStudio: Integrated Development for R. RStudio, 2019, PBC, Boston, MA, USA).

Milk yield calculation

Sow milk yield was estimated based on differences in the individual piglet weight gain, PW2 – PW1, summed up for each litter and divided by the corresponding suckling period length (GfE, 2006; Quesnel et al., 2015). Generally, 1 g of BW gain in piglets does not correspond to 1 g of sow milk. The effort required for growing piglets during the suckling period increases, similar to the milk production of a sow (Theil et al., 2002). GfE (2006) recommends 4.1 kg milk per 1 kilogram BW gain in piglets as average factor for milk yield calculation for the entire suckling period.

This method of calculating the est. milk yield is mainly applied in practice, although it may have reduced accuracy (GfE, 2006; Theil et al., 2002). Due to the practical context of this study, we used this method to calculate the estimated milk yield per sow, which will be referred to as "**est. MY**".

Milk score calculation

Using the production performance data and piglet weights, a new formula, entitled the milk score (**MS**), was developed to assess the foster performance of lactating sows.

$$\textit{milk score}\ (s) = \underbrace{\left(\lambda\frac{l_{1s}}{n_{1s}}\right)\left(\sum_{i=1}^{n_{1s}}F(B_i)\right)}_{(a)\ Birth\ performance} + \underbrace{\left((1-\lambda)\frac{l_{2s}}{n_{2s}}\right)\left(\frac{1}{n_{2s}}\sum_{i=1}^{l_{2s}}F\left(\frac{Zw_i - B_i}{t_{Zw,i} - t_{b,i}}\right)\right)}_{(b)\ Foster\ Performance} \quad (1)$$

s Sow
F Scoring function (F:Q → Z)
B_i Birth weight per piglet
l_{1s} Number of living piglets per biological sow
n_{1s} Number of piglets per biological sow
λ Weighting factor ≤ 1
l_{2s} Number of living piglets per foster sow
n_{2s} Number of piglets per foster sow
Zw_i Interim weight per piglet
$t_{b,i}$ Birth weighing day per piglet
$t_{Zw,i}$ Interim weighing day per piglet

Eq. (1) presents the formula of the MS which consists of two parts: (a) birth performance, containing the sum of the piglet birth weight scores per sow multiplied by penalised stillborn piglets; (b) foster performance, which focuses on the daily weight gain of the piglets after cross-fostering, multiplied by penalised piglet mortality during the lactation period. The MS distinguishes between birth and foster performance, thus allowing individual performance evaluation of sows despite cross-fostering. This distinction is necessary because of the farmers having different farm-management practices of adding and removing piglets per litter (see cross-fostering in Material and Methods). In addition to the est. MY calculation, the MS considers the number of piglets per biological and foster sow, the individual piglet weights at PW1 and PW2, and combines this with a scoring function and a weighted piglet mortality. The scoring function F was calculated for each piglet and reflects the position compared with all other piglet weights. Here, birth weight (B_i) and daily weight gain ($\frac{Zw_i - B_i}{t_{Zw,i} - t_{b,i}}$) compared with all piglets of the same farm are scored in eight levels. The following symmetric scoring scheme was applied to calculate the level of a piglet:

$$F(x) = \begin{cases} \pm 1: & x \in [\mu, \mu \pm \sigma) \\ \pm 2: & x \in [\mu \pm \sigma, \mu \pm 2\sigma) \\ \pm 3: & x \in [\mu \pm 2\sigma, \mu \pm 3\sigma) \\ \pm 4: & \text{otherwise} \end{cases}$$

For example, a piglet with slightly higher weight than the average of all the piglet weights will be scored as +1 because its value will be limited by $\mu + \sigma$. If the individual score of a piglet is above $\mu + 3\sigma$, then it will be scored with 3, indicating a high-performing piglet. For each sow, the average of the individual piglet score was calculated. The distribution of piglets' birth weight, ordered by birth weight score, can be seen in Supplementary Fig. S1. Moreover, Supplementary Fig. S2 demonstrates the relative weight gain versus the absolute weight gain per piglet using the foster scores for all piglets. Cross-fostering was considered in the calculation automatically by splitting the formula into parts (a) and (b). Piglets born by a biological sow were considered in (a) and piglets raised by the foster sow were considered in (b). Due to cross-fostering, the piglets in (a) and (b) are not necessarily the same or equal in number. To adjust for piglet mortality, the ratio between the number of living piglets and the number of piglets recorded at the beginning (n_{1S}, n_{2S}) of each period ((a) birth performance; (b) foster performance) was calculated. This ratio was weighted by λ or $1 - \lambda$ to differentiate between stillborn, early, and late piglet mortality. The λ-term characterises the severity of piglet mortality concerning sow investment in milk production for fostering piglets. Thus, after cross-fostering, dead piglets are penalised more than stillborn piglets. Both weighting factors in parts (a) and (b) of the equation have to reach a sum of 1.

More than 60% of the losses occur within the first 3 days after birth (Kunz and Ernst, 1987; Dyck and Swierstra, 1987; Roehe and Kalm, 2000), making it a risky period for the piglets before cross-fostering (Schröder, 2001; Theil et al., 2014; Nicolaisen et al., 2019). Piglet losses are common during this period and are not related to, e.g., low availability of milk by the biological sow. This implies a low penalty value of 0.4 before cross-fostering. After cross-fostering, the penalty was increased to a value of 0.6 to reflect that each dead piglet during this period represented a more severe loss because milk consumed by such piglets were not accessible to the littermates. Consequently, the later that such an individual piglet dies during the suckling period, the greater the milk loss for littermates. The weighting factors provide the opportunity for further adjustment to farm-specific management.

Additional factors, such as supplemental milk, were not considered in the MS and the subsequent analysis because the supplementary feeding of piglets had a uniform impact on all farm piglets and represents a farm-specific management effect.

Due to the structure of the MS equation, it is only valid for on-farm evaluation to compare individual sows and their performance to distinguish high- and low-performing sows within a herd. The specific farm-management practices of piglet production, e.g., the exact day of cross-fostering, supplemental milk use, or sows feeding are not considered in the structure of the MS.

Results

Table 1 shows the general performance data for the whole dataset of 1 728 litters. The data are presented according to the aforementioned parity classes. The Top Performer category sows recorded the highest number of piglets born alive compared with other sows. Sows in the Gilts-1 and Gilts-2 categories also showed a high number of piglets born alive, but they have the highest piglet mortality on average. This can be attributed to the fact that, due to the cross-fostering practice performed (see cross-fostering in Material and Methods), the litter size after cross-fostering for Gilts-1 and Gilts-2 was the largest. It also becomes more apparent with a higher number of weaned piglets.

It is noticeable that sows in the Old Sows category gained the highest daily weight gain among their piglets, while showing the lowest number of piglets born alive. It is also worth mentioning that piglet mortality during lactation decreases as the sows' parity number increases.

Table 1 shows the progression of the calculated est. MY and MS by parity class. Gilts-1 started with a lower est. MY that increased to Top Performer sows across parities, while a slight decrease was observed in parity 6. From the 8th litter onwards, there was a more noticeable decrease. Overall, the est. MY showed only minor changes between parity classes. The opposite was observed in the MS, which increased drastically in the first parities, reaching a plateau in parity 5 to parity 7, followed by a decrease. However, both parameters demonstrated a similar trend in the data.

The comparison between MS and est. MY values for parity classes 1–≥10 is shown in Fig. 1. The mean and SD demonstrate a similar trajectory across parities of MS as well as est. MY. It shows that the value of the MS is generally higher than the est. MY. The SD is high for both parameters, which is caused by substantial performance differences between the sows in each parity. Compared to the est. MY values, the performance differences from the MS values between each parity can be distinguished more clearly, as these values differ more between the parities (Fig. 1).

Differences between milk score and estimated milk yield

To examine how the est. MY and the MS differ from one another regarding the different performance groups, an alluvial diagram was employed (Fig. 2) (Brunson and Read, 2020). Out of 1 728 observations, there was no change in the performance group for n = 1 029 equalities (59.55%; marked as light grey). Moreover,

Table 1
General performance data of piglet production, piglet weights, sow's estimated milk yield and milk score per parity classes from 1 to ≥10 in two farrow-to-feeder farms.

Item	Unit	Gilts-1	Gilts-2	Top Performer					Old Sows			Total
		1	2	3	4	5	6	7	8	9	10	
		n = 359	n = 290	n = 239	n = 220	n = 167	n = 138	n = 103	n = 67	n = 51	n = 94	n = 1 728
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Piglets born alive	(piglets)	15.67 ± 3.59	15.90 ± 3.32	16.69 ± 3.50	16.80 ± 3.51	16.40 ± 3.44	15.62 ± 3.77	14.31 ± 3.76	14.79 ± 3.74	13.73 ± 3.34	11.81 ± 3.69	15.68 ± 3.73
Stillborn piglets	(piglets)	0.57 ± 1.03	0.87 ± 1.48	0.95 ± 1.37	1.21 ± 1.46	1.19 ± 1.49	1.70 ± 2.09	1.73 ± 2.25	1.69 ± 1.73	2.08 ± 2.01	2.18 ± 2.26	1.15 ± 1.65
Litter size after cross-fostering	(piglets)	16.12 ± 2.61	15.5 ± 2.73	15.22 ± 2.88	14.80 ± 2.50	14.25 ± 2.19	13.43 ± 2.53	13.60 ± 1.90	13.21 ± 2.63	13.41 ± 2.22	12.98 ± 1.93	14.83 ± 2.73
Piglet mortality	(piglets)	2.94 ± 2.50	2.32 ± 2.34	2.03 ± 2.10	1.90 ± 1.99	1.82 ± 1.96	1.57 ± 1.83	1.46 ± 1.55	1.45 ± 1.79	1.90 ± 2.02	1.44 ± 1.57	2.10 ± 2.18
Weaned piglets	(piglets)	13.1 ± 1.57	13.2 ± 2.19	13.19 ± 2.40	12.90 ± 1.94	12.43 ± 1.55	11.86 ± 1.86	12.15 ± 1.31	11.76 ± 1.80	11.51 ± 1.51	11.54 ± 1.54	12.73 ± 1.97
Piglet weight 1[1,2]	(kg)	1.13 ± 0.33	1.28 ± 0.36	1.28 ± 0.36	1.29 ± 0.36	1.33 ± 0.38	1.35 ± 0.36	1.33 ± 0.36	1.31 ± 0.36	1.28 ± 0.37	1.38 ± 0.34	1.27 ± 0.36
Piglet weight 2[1,3]	(kg)	4.68 ± 1.13	4.88 ± 1.22	4.85 ± 1.22	4.92 ± 1.22	5.05 ± 1.25	4.97 ± 1.27	4.95 ± 1.31	4.78 ± 1.30	4.65 ± 1.23	4.95 ± 1.18	4.86 ± 1.22
Day of piglet weight 2[1]	(day)	18.49 ± 2.72	18.26 ± 2.60	18.23 ± 2.65	18.28 ± 2.20	18.28 ± 2.50	17.91 ± 2.30	17.84 ± 2.25	17.60 ± 1.98	17.84 ± 1.98	18.27 ± 2.05	18.22 ± 2.48
Daily weight gain[1]	(kg)	0.190 ± 0.051	0.195 ± 0.055	0.195 ± 0.055	0.196 ± 0.057	0.201 ± 0.057	0.200 ± 0.061	0.201 ± 0.061	0.195 ± 0.062	0.186 ± 0.061	0.193 ± 0.059	0.195 ± 0.056
Estimated milk yield	(kg)	9.69 ± 2.21	10.07 ± 2.51	10.27 ± 2.58	10.41 ± 2.21	10.38 ± 2.24	10.05 ± 2.36	10.33 ± 1.82	10.13 ± 3.03	8.98 ± 2.43	9.10 ± 2.06	10.02 ± 2.37
Milk score	(Score points)	−6.15 ± 9.20	0.35 ± 9.87	0.85 ± 9.60	1.86 ± 9.95	4.14 ± 9.92	4.36 ± 9.39	3.68 ± 8.38	2.84 ± 9.24	0.79 ± 8.01	3.59 ± 6.08	0.43 ± 10.00

[1] Only complete datasets were used for estimation of the general performance parameters.
[2] Piglet birth weight within the first 24 hours after birth.
[3] Second weighing at on average 18.22 days.

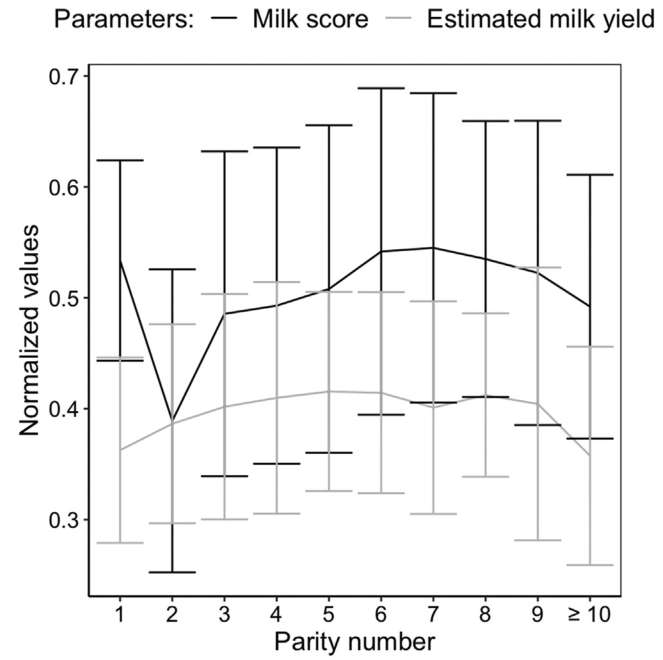

Fig. 1. Comparison of milk score (black) and estimated milk yield (blue) for sows in terms of their min–max normalised mean and SD. Values for both parameters are ordered by parity classes 1–≥10. Both parameters show a similar trajectory with a high range in SD.

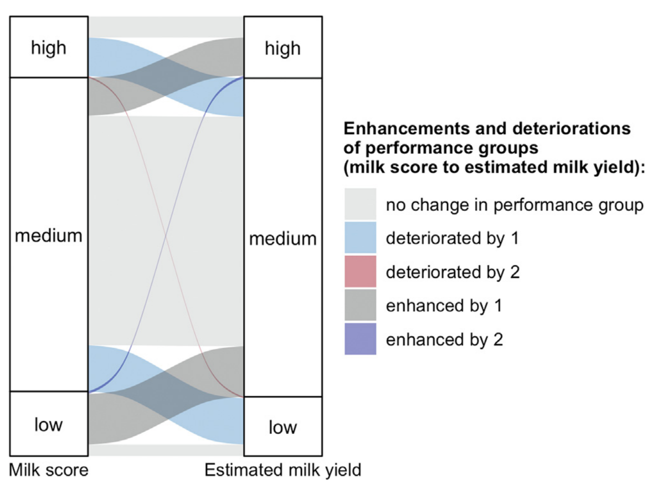

Fig. 2. Alluvial diagram – Enhancements and deteriorations between performance groups of milk score (MS) and estimated milk yield (est. MY) for sows. Performance groups were divided into low [−∞,μ−SD), medium (μ−SD,μ+SD), and high (μ+SD,∞]. Percentage and amount of compared MS and est. MY observation per performance group: no change in performance group (59.55%) (n = 1 029), differences in one performance group (39.53%) (enhanced by 1: n = 349; deteriorated by 1: n = 334), and difference in two performance groups (0.93%) (deteriorated by 2: n = 6; enhanced by 2: n = 10).

there were 699 differences (40.45%; marked as dark blue, light blue, dark grey and light red) between MS and est. MY. Most of these differences (97.71%; marked as dark grey and light blue) led to a change in the performance group into the adjacent class (enhanced or deteriorated by 1), e.g., a sow with a medium est. MY was classified into a high-MS group. Only 2.29% (marked as dark blue and light red) resulted in a change by two performance differences (enhanced or deteriorated by 2), e.g., a sow with a low est. MY was classified into the high-MS group. The dissimilarity between MS and est. MY is of particular interest and might show the impact of management failures caused by the cross-fostering practice of the farmer. The following two examples explain this in more detail.

(1) Sow A:

Sow A in the 2nd parity was classified as a high-MS-performance sow, in contrast to low est. MY performance. In total, the sow gave birth to 16 live-born piglets with an average birth weight of 1.64 kg. After cross-fostering, 15 of her 16 piglets were removed and replaced by 12 piglets from other sows. However, the 12 surrogate piglets had a lower mean birth weight of 0.85 kg. The very low average daily weight gain of 0.093 kg resulted in a low est. MY estimation. Although the added piglets had low weight gain, the sow was rated better in MS than in est. MY calculation. This was because the sow's biological piglets had a high birth weight and there was a low number of piglet losses during the suckling period.

(2) Sow B:

Sow B in the 3rd parity was classified as low-MS- and a medium-est. MY-performance group. The sow had 18 piglets born alive with a mean birth weight of 0.88 kg. No piglets were removed from the litter, but four additional piglets from other sows were added to the litter. The mean daily weight gain of the larger litter was 0.108 kg. Over the suckling period, the sow had a high number of piglet losses (n = 9). In conclusion, sow B was rated as a medium-est. MY-performing sow; however, because of the lower mean birth weights and the high number of suckling piglet losses, the sow was classified into the low-MS-performing group.

Influence of litter size

Fig. 3 shows the differences between the mean number of piglets at piglet weighing 2 (PW2) for the corresponding est. MY- and MS-performance groups. The results show that sows with high est. MY performances had a significantly higher number of piglets per litter (15.79 ± 2.20) compared with those with high-MS performance (13.51 ± 2.18). On the other hand, sows with low est. MY performances had a significantly lower number of piglets per litter (12.30 ± 3.79). The lowest MS-performance group had the highest

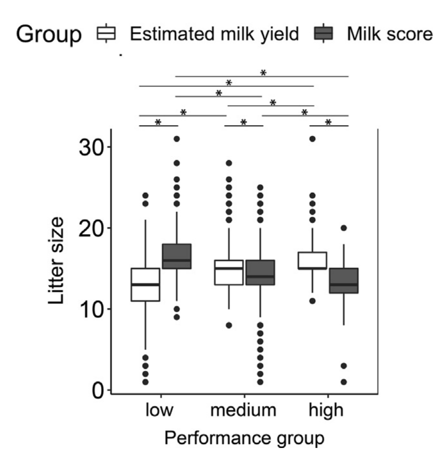

Fig. 3. Group differences of milk score and estimated milk yield for sows' litter size and performance groups at second weighing (on average on day 18). Performance groups were divided into low [−∞,μ-SD), medium (μ−SD,μ+SD), and high (μ+SD,∞]. Within each performance group, the litter size differs significantly at $P < 0.05$ (Wilcoxon-test, P-value adjusted by Benjamini and Hochberg (1995)).

number of piglets per litter on average (16.76 ± 3.20). Moreover, it shows that the groups differed significantly between each other (Supplementary Table S2).

Fig. 4 demonstrates how the daily weight gain, MS, est. MY, and piglet mortality are related to each other as the corresponding number of piglets per litter increases. To scale out size effects and to clarify the courses of different parameters, the data were normalised. Due to the lack of data, litter sizes below 10 and above 20 were omitted. The green line represents the average number of piglets per litter (14.83 ± 2.73). The est. MY performance shows a considerable increase in litter size from 10 to 15, reaching a plateau in subsequent litter sizes. This suggests that the litter size of 15 piglets might represent the maximum performance potential under consideration of the est. MY. Fig. 4 shows a high increase in piglet mortality during lactation above a litter size of 12; consequently, the MS decreases substantially with each additional piglet. The daily weight gain and the MS show a similar trajectory, and from litter size 12 onward, both parameters decreased with each additional piglet.

Discussion

The MY of a sow is estimated at any chosen time point based on piglet weight gain. Multiple studies have proven this as an adequate approach by demonstrating that the most important determinant of the sow's est. MY is the number of suckling piglets (e.g., Auldist and King, 1995; Auldist et al. 1998). After normalisation of the data, it became clear that the MS and est. MY have a similar trajectory across parities (Fig. 1), which can be attributed to the fact that parts of the est. MY are the basis for the MS equation. This is also evident in the alluvial diagram where most of the values of the different performance groups were classified identically (Fig. 2). The differences can be explained by the extension of the MS equation. The MS equation distinguishes between birth and foster performance for each piglet, calculating a score for each

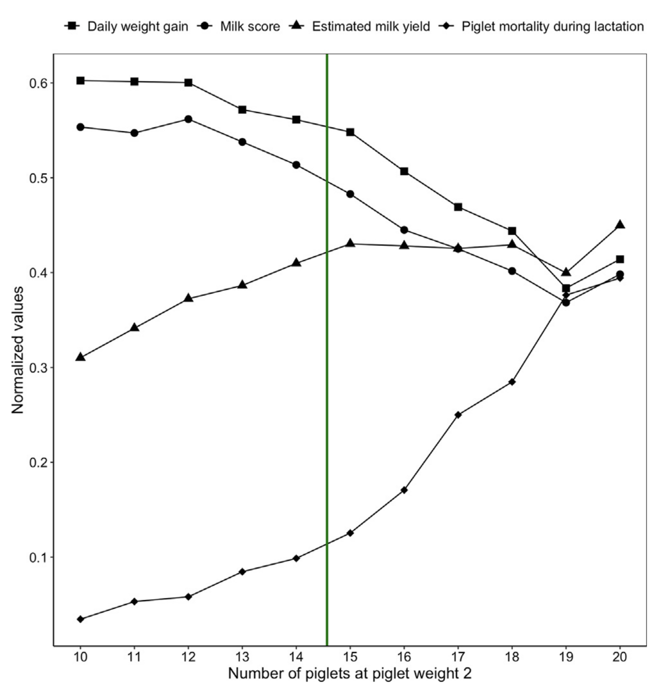

Fig. 4. Min-max normalised progression to compare daily weight gain, milk score (MS), estimated milk yield (est. MY), and piglet mortality during lactation by litter size of 10–20 piglets after second weighing at on average on day 18.22 (piglet weight 2). The green vertical line marks the average litter size of 14.57 piglets.

sow, which is superior to the est. MY. The example sows, sow A and sow B, show that litter size, piglet weights, piglet mortality, and cross-fostering have an impact on the assessment of a sow's foster performance. The consideration of cross-fostering is especially crucial because the sow has no influence on the farmers' cross-fostering practice. Without considering this, it could lead to an unrealistic performance assessment of the sow. Consequently, the developed MS is better adapted to current farm conditions, resulting in a more realistic assessment of the sow's performance.

In increasing the litter size in pig-breeding programmes, one issue is the availability of functional teats per sow, as a crucial factor for piglet weight gain and litter development (Chalkia et al., 2013; Kobek-Kjeldager et al., 2021). On average, commercial sows have 13 to 15 functional teats, but they give birth to more piglets (Vande Pol et al., 2021a). Genetic selection for the number of teats seems to be plausible to ensure the nutrition of larger litters, but this is not necessarily associated with increased milk production from the sow. Furthermore, it is well known that teats differ in the amount of assessable milk (King, 2000; Hurley, 2001; Chalkia et al., 2013). Additionally, many other factors such as nutrition, environment, breed, parity, teat functionality, and stage of lactation influence the total milk production of sows (Dyck et al., 1987, King, 2000; Hurley, 2001; Chalkia et al., 2013). Hence, more teats per sow do not necessarily mean more available milk for the piglets.

As can be seen in Fig. 3, sows from a high-MS-performance group have, on average, a significantly ($P < 0.05$) lower litter size than sows from the high-est. MY-performance group. It can be concluded that high-performing sows have lower litter sizes on average in the MS assessment. This implies that the MS selects for a smaller litter size compared with current farrowing practices. Furthermore, the results indicate that sows in the high-performance group have 13 piglets per litter on average, which is 2 less than the average number of 15 teats per sow. This is also demonstrated in the results of Supplementary Table S1. On average, sows in the high- and medium-performance groups have fewer piglets than teats (Supplementary Table S1). This suggests that the number of teats is not the sole determinant of piglet nutrition. Instead, the crucial factor is the number of functional teats; however, this was not specifically determined in the present study. This leads to the assumption that a litter size above the average number of teats per sow after cross-fostering will result in a reduced daily weight gain and higher piglet mortality (Fig. 4), as pointed out by Vande Pol et al. (2021b). Consequently, it is recommended that the number of functional teats for cross-fostering is considered, because it may result in reduced piglet mortality and higher daily weight gains for the piglets. Moreover, the MS could be used as a tool for the farmer to assess the foster performance of the sows in a more accurate way without counting the number of functional teats, because the MS is directly selective for smaller litter size.

According to Rutherford et al. (2013), an increase in litter size leads to a decrease in animal welfare for sows and piglets. The increase in litter size is related to lower birth weights and higher piglet mortality. It is proven that the number of piglets born alive is negatively correlated with the birth weights of the piglets (e.g., Quiniou et al., 2002; Quesnel et al., 2008; Elbert et al., 2021). Several studies have shown that piglets' birth weight is a crucial factor directly influencing the survival rate, milk intake and weight development during the suckling period; all of which are associated with a variety of negative early life experiences and negative long-term consequences for the piglets (Milligan et al., 2002; Quiniou et al., 2002; Panzardi et al., 2013; Rutherford et al., 2013). For example, increased stress reactivity and increased susceptibility to disease are associated with low piglet BW (Rutherford et al., 2013). According to Rutherford et al. (2013), piglets with a low BW that survive the peri-natal period are more likely to be less robust throughout life than their heavier littermates. This is in accordance with the results of Panzardi et al. (2013) and Huting et al. (2017), showing that lower birth weight results in a reduced growth performance until weaning, causing these piglets to always be among the lighter ones during lactation.

For the sows, a larger litter size means a longer parturition. This is associated with more pain and an increased demand for milk synthesis when sows are unable to maintain a high feed and water intake (Herskin et al., 2011; Mainau and Manteca, 2011). The sows begin to lose their body condition, increasing their risk of developing injuries such as shoulder sores (Herskin et al., 2011). The negative effects mentioned in this paragraph caused by an increased litter size are only some examples that are related to this problem; the evaluation of animal welfare involves more aspects than those discussed here. According to Fraser et al. (1997), the three essential concepts for the evaluation of animal welfare are "basic health and functioning", "natural living", and "affective states"; however, for the present study, we were only able to evaluate animal welfare from the perspective of "basic health and functioning".

Since the milk score may be used as an assessment criterium which focusses on smaller litter size, higher birth weights, and fewer piglet losses, the welfare disadvantages caused by a large litter size could be reduced in the long term. This would help to improve piglet vitality, survival, and growth, and it would lead to an increase in animal welfare for both sows and piglets.

However, there are several aspects which might help to improve the MS which are currently limited by the availability of data or the feasibility of implementing additional measurements in conventional pig-production farms.

Piglet weighing during cross-fostering might improve the calculation of the foster performance in the MS due to better weight gain calculations for the suckling piglets. Refining the penalty term towards a daily penalty model could improve the way that piglet mortality is penalised on different days, allowing more accurate consideration of the loss of available milk for other littermates. In the recent model, a loss shortly after cross-fostering has similar importance to a loss at day 16. More available data will help us to develop such models.

The MS is easily applicable and might be used in daily farm practice, helping farmers to handle their own herd and assess sow performance in more detail. Compared with est. MY, the MS values are more spread out in different parities (see Table 1), which allows improved assessment of individual performance per sow in each parity.

By construction, the MS rate sows specifically within a herd or a farm; thus, biological performance differences between the parities and different farm-management practices, such as piglet nutrition, genetics, and different cross-fostering strategies, can be disregarded. MS values are calculated according to farm-specific performance and management practices. The MS could be applied in piglet-production farms to support farmers in assessing the foster performance of the herd. Furthermore, this information could be used for the assessment of culling decisions at the end of lactation. The farmer would obtain a supportive analysis of their specific herd's performance, with the consideration of their individual farm-management practices.

Currently, the MS measurement method is based solely on the piglet-production performance data. However, additional parameters such as health status (e.g., mastitis), body condition, and feeding conditions also have an impact on the sow's performance (Quesnel et al., 2015; Friendship and O'Sullivan, 2015). According to Fraser et al. (1997), several aspects such as physical fitness, good health, normal growth, and normal behaviour have to be considered for adequate animal welfare assessments. Consequently, the MS provides a good basis for the assessment of the performance of lactating sows, which could be extended with the implementation of other parameters for a more realistic assessment under practical farm conditions.

Conclusion

As a novel assessment tool for determining the foster performance of lactating sows, the MS improves the conventional estimated milk yield approach by the inclusion of parameters such as cross-fostering and piglet mortality at different stages during the suckling period. Applying the milk score in conventional pig-production farms might lead to farmers favouring a smaller litter size, which could reduce piglet mortality and increase birth and foster weights; these are factors which improve animal welfare for sows and piglets. Thus, the milk score could be a suitable basis for the current on-farm performance assessment for lactating sows, which contributes to a more productive and more animal-welfare-oriented piglet-production system.

Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.animal.2022.100655.

Ethics approval

The animal housing and data collection took place in accordance with German regulations. No relevant interventions according to the German Animal Welfare Act had been carried out on live animals (Approval by the Animal Welfare Officer of the Georg-August-University of Göttingen, Foundation, Göttingen, reference: E9-20).

Data and model availability statement

None of the data were deposited in the official repository. Data will be available upon request (contact lea-sophie.trost@uni-goettingen.de or sebastian.zeidler@uni-goettingen.de).

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Declaration of interest

None.

Acknowledgements

The authors thank the participating farmers for data collection.

Financial support statement

This research was funded by EIP-Agri (European Innovation Partnership "Agricultural Productivity and Sustainability"), European Agricultural Fund for Rural Development (grant number: 276034540350521). We acknowledge support from the Open Access Publication Funds of the Göttingen University.

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