

Author's accepted manuscript (postprint)

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Published in: Applied Animal Behaviour Science

DOI: 10.1016/j.applanim.2019.104837

Available online: 07 Aug 2019

Citation:

Rosvold, E. M., Newberry, R. C. & Andersen, I. L. (2019). Early mother-young interactions in domestic sows - Nest-building material increases maternal investment. Applied Animal Behaviour Science, 219: 104837. doi: 10.1016/j.applanim.2019.104837

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This is an Accepted Manuscript of an article published by Elsevier in Applied Animal Behaviour Science on 07/08/2019, available online: <https://www.sciencedirect.com/science/article/pii/S0168159119301017?via%3Dihub>

1 Early mother-young interactions in domestic sows – nest-building 2 material increases maternal investment

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8 Abstract

9 Nest building is important in sow preparation for motherhood. However, straw or other bulky materials
10 can block drains, and a finer-grained material such as peat is of interest as an alternative. The main aim
11 of this study was to evaluate effects of different nesting materials on maternal behaviour during
12 farrowing and early lactation.

13 Norsvin Landrace x Swedish Yorkshire sows (n=54) were loose-housed in individual farrowing pens
14 with wood-shavings as litter. Mean (\pm SE) parity was 2.9 ± 2.0 (range 1-9), and 16 were primiparous.
15 They were provided with peat (n=18) or straw (n=17) as nesting material from two days before expected
16 farrowing until they farrowed, or received wood shavings litter only (controls, n=18). From video
17 recordings positive (i.e. sniffing, grunting, nudging) and negative (i.e. pushing, threatening barks, biting)
18 communicatory behaviours from sow to piglets during farrowing (≤ 4 h) and on Day 1 post-partum (4 h)
19 were registered by one-zero sampling at 1-min intervals. Nursing behaviour on Day 2 post-partum (6 h)
20 was registered by continuous observation.

21 During farrowing, sows provided with straw or peat as nesting material showed a lower frequency of
22 negative communication towards piglets compared to controls ($P < 0.05$). Sows provided with straw had
23 a higher proportion of sow-initiated nursing bouts and successful nursing bouts (i.e. with milk let-down)
24 terminated by the piglets than sows in the peat and control groups. There were also differences in
25 maternal behaviour across parities 1, 2-3 and ≥ 4 ($P < 0.05$). Sows of parity ≥ 4 exhibited a lower frequency
26 of negative communication during farrowing than younger sows. On Day 1 post-partum, sows of parity
27 2-3 performed a higher frequency of positive communication than sows of other parities. The proportion
28 of sow-initiated nursing bouts was higher in sows of parity ≥ 4 than in primiparous sows, whereas the
29 proportion of successful nursing bouts terminated by piglets was higher for primiparous than older sows.
30 Positive sow-to-piglet communication increased with litter size during farrowing, but declined with litter
31 size on Day 1. Proportion of sow-initiated nursing bouts increased with litter size, whereas the
32 proportion of successful nursing bouts terminated by piglets decreased. The number of piglets without
33 a teat during milk let-down increased with litter size ($P < 0.05$).

34 These findings show that both peat and straw were associated with a lower rate of negative sow-to-piglet
35 communication during farrowing compared to sows given wood shavings alone. Provision of straw,
36 particularly, resulted in nursing behaviour indicative of increased maternal investment.

37 Key words: Nest building, Peat, Loose-housed sows, Maternal behaviour, Communication, Nursing
38 behaviour

39 Highlights:

- 40 • Negative communication to piglets during farrowing was lower in sows provided with straw or
41 peat before farrowing.
- 42 • Straw provided before farrowing enhanced maternal investment-related nursing behaviours.
- 43 • Parity and litter size affected maternal behaviour.
- 44 • The number of piglets without a teat during milk let-down increased with litter size.

45 1. Introduction

46 When preparing for motherhood, domestic sows are highly motivated to build a nest that protects the
47 newborn piglets against climatic factors and predators, and facilitates the establishment of recognition
48 and filial bonding of piglets with their mother (e.g. Wischner et al., 2009). The nest-building behaviour
49 of sows has remained similar to that of their wild relatives (Jensen, 1986; Gustafsson et al., 1999),
50 involving nest-seeking, digging a hollow in the ground by pawing and rooting, collecting vegetation and
51 depositing it in the hollow and arranging the material before lying down (Jensen, 1986; 1993; Mayer et
52 al., 2002).

53 Piglet mortality is still a considerable welfare and economical challenge in pig production, also in loose-
54 housing systems, with herd mortality of live born piglets ranging from 5-28% (Rosvold et al., 2017).
55 Most piglet deaths occur within the first few days after birth (e.g. Marchant et al., 2000; Kielland et al.,
56 2018), with crushing and starvation as the dominant causes (Andersen et al., 2011; Kielland et al., 2018).
57 Studies on loose-housing systems suggest that piglet survival is highly affected by maternal motivation
58 and protectiveness (Melišová et al., 2011), and that the sow's maternal behaviour is positively related
59 to the performance of nest building before farrowing. For instance, nest building has been associated
60 with increased responsiveness to piglet distress calls, increased maternal bonding and positive
61 interactions (Cronin and van Amerongen, 1991; Cronin and Smith, 1992; Herskin et al., 1998), and a
62 positive effect on nursing behaviour (Cronin and Smith, 1992; Herskin et al., 1999; Yun et al., 2014).
63 Moreover, sows that spend a lot of time on nest building before farrowing are generally more careful
64 and protective towards the piglets (Andersen et al., 2005; Yun et al., 2014). Specifically, those with a
65 higher score for nest building were found to have a lower prevalence of crushing (Ocepek and Andersen,
66 2017), more positive communication with and care of the piglets, and lower overall piglet mortality
67 (Ocepek et al., 2017b). Improved maternal behaviour (i.e. carefulness, nursing behaviour) was

68 accompanied by increased levels of endogenous hormones linked to maternal behaviour, including
69 oxytocin and prolactin (Yun et al., 2013; 2014).

70 Communication is important for bonding, and the sow communicates with her piglets through nasal
71 contact (i.e. sniffing and nudging) and grunting (e.g. Jensen and Redbo, 1987). A high level of such
72 communication from sow to piglets facilitates sow-piglet bonding, and attracts the piglets to stay in
73 close proximity to her, giving them warmth, milk and protection (e.g. Melišová et al., 2011). Moreover,
74 Ocepek and Andersen (2018) found that sows communicating with their piglets while being active had
75 lower piglet mortality. However, maternal aggression towards the newborn may also occur (i.e. biting,
76 savaging), with possible fatal consequences for the piglets (e.g. Ahlström et al., 2002; Chen et al., 2008),
77 occurring especially in the early stages of farrowing (Ahlström et al., 2002). A sow`s motivation to care
78 for her offspring will be expressed in how she communicates with them (Ocepek and Andersen, 2017),
79 and aggressive behaviour may be linked to a lack of preceding nest-building activity (Ahlström et al.,
80 2002).

81 Nursing behaviour is an important component of maternal behaviour (Cronin and Smith, 1992), and the
82 quality of nursing probably reflects a sow`s motivation for taking care of her young. A sow initiates
83 nursing by lying down, exposing her udder and giving nursing grunts attracting the piglets. The piglets
84 start massaging the udder for 1 to 3 min (pre-massage), which elicits a brief milk let-down (ca. 15 s),
85 and is followed by another udder massage of varying duration (post-massage) depending on the sow`s
86 udder exposure (e.g. Algers and Uvnäs-Moberg, 2007). A nursing bout can however be terminated
87 before milk let-down (unsuccessful nursing) due to insufficient pre-massage related to an insufficient
88 number of piglets at the udder or teat disputes between them (Illmann and Madlfousek, 1995).

89 Straw has been reported to have a positive effect on nest-building behaviour (e.g. Thodberg et al., 1999;
90 Westin et al., 2015). However, many pig houses have pens with a partly slatted floor, and a slurry system
91 for manure removal. Due to a risk of drain blockage when long straw is used, farmers hesitate to use
92 straw and some may also consider that providing straw requires too much work for maintaining pen
93 cleanliness. Peat is a finer grained material with structural similarities to soil, making it suitable for
94 rooting, digging and pawing (Studnitz et al., 2007; Vanheukelom et al., 2011). These behaviours are
95 also elements of nest building.

96 We have found that sows given long-stemmed straw showed more nest-building behaviour, a greater
97 variety of nest-building elements, and fewer stereotypies pre-partum than control sows and sows given
98 peat (Rosvold et al., 2018). They also had shorter farrowing duration and fewer stillborn piglets (Rosvold
99 and Andersen, 2019). The results on nest building in the peat group were intermediate, suggesting that,
100 while straw is more effective in fulfilling the sow`s nest-building motivation, peat has some value as a
101 nest-building material. Parity also affected nest building, with sows of parity ≥ 4 showing more nest-
102 building behaviour and spending more time arranging material than younger sows (Rosvold et al., 2018).

103 There has been limited research on the relationship between nest-building behaviour and maternal care
104 in sows (e.g. Herskin et al., 1998; 1999; Yun et al., 2014). The primary objective of the present work
105 was to investigate the effects of type of nest material provided before farrowing (straw or peat vs. control
106 given wood shavings only) on sow-piglet communication during, and shortly after farrowing, and
107 nursing success after establishment of a stable nursing interval. Because maternal care could be affected
108 by parity, litter size and farrowing batch, we also took these factors into account in our analyses.

109 We predicted that sows provided with straw as nest-building material before farrowing would show
110 more positive (i.e. sniffing, grunting and nudging) and less negative (i.e. pushing, threatening barks and
111 biting) communication with their piglets compared to control sows, and that the peat group would be
112 intermediate compared to the control and straw groups. We also predicted that responses to the provision
113 of nest-building materials before farrowing would be influenced by parity, as the young sows may need
114 more external stimulation due to lack of maternal experience, and because their hormonal status may
115 differ from that of older sows (Yun et al., 2014). Furthermore, we predicted that the quality of nursing
116 bouts would be higher in the straw treatment than in the control treatment, with peat being intermediate.
117 The evaluated indicators of nursing quality included a shorter nursing interval, a higher frequency of
118 nursing bouts, a higher proportion of nursing bouts initiated by the sow, a higher proportion of successful
119 nursing bouts terminated by the piglets, and fewer piglets without a teat during milk let-down.

120 2. Material and methods

121 2.1. Experimental design

122 The study was conducted at Mære Agricultural College in Steinkjer, Norway, in accordance with the
123 Norwegian laws and regulations governing experiments and procedures on live animals. During three
124 farrowing batches, 54 loose-housed sows kept in individual farrowing pens (Fig. 1), were randomly
125 assigned to one of three treatment groups differing in nest material given before farrowing: peat, straw
126 or control, 18 sows in each group. The sows were video recorded from two days pre-partum until three
127 days post-partum to document the sows` pre-partum nest-building behaviour (Rosvold et al., 2018),
128 farrowing and maternal behaviour.

129 2.2. Housing, management and feeding

130 Total area of the farrowing pens was 8.2 m², of which 2.9 m² was slatted floor, and the rest solid floor.
131 The pen contained a creep area for the piglets equipped with heat lamps and floor heating (Fig. 1). Air
132 temperature was recorded by two temperature loggers (Tinytag, Gemini Data Loggers, Chichester, UK)
133 located in different parts of the farrowing room. Due to variation in the outdoor temperature, indoor
134 temperature differed between batches. From one day before the first farrowing until four days after the
135 last farrowing, the average temperature was 20.0°C (range 16.8°-24.7°C) for the first batch (farrowing

136 in May), 23.6°C (19.1°-31.8°C) for the second batch (July), and 20.5°C (17.3°-24.1°C) for the third
137 batch (late August).

138 Intervention during farrowing and early lactation was kept to a minimum, but farrowing assistance was
139 provided if piglets or placenta were retained for at least three hours. Wet straw and litter were replaced
140 with dry litter (wood shavings) after farrowing. The sows were taken out of the pen briefly on the day
141 after farrowing for measurement of body weight and some physical exercise, and all the piglets were
142 subjected to tooth grinding and received iron paste orally (Pluss Jernstarter, 1.5 mL; Felleskjøpet) within
143 the first 24 h after birth. Cross-fostering was carried out between 12-48 h after farrowing if the number
144 of piglets exceeded the number of functional teats and if there were any suitable sows to receive piglets.

145 Sows were fed four times daily on lactation concentrate (FK FORMAT Laktasjon, Felleskjøpet,
146 Steinkjer, NO) from an automatic dispenser, and once daily by the manual distribution of a farrowing
147 concentrate (FK FORMAT Fødsel, Felleskjøpet, Steinkjer, NO), and hay (ca 0.3 kg). For further details
148 on housing and management prior to farrowing, see Rosvold et al. (2018).

149 2.3. Animals

150 The sows were Norsvin Landrace x Swedish Yorkshire crossbreds, inseminated with semen from Duroc
151 boars, and ranging in parity from 1 to 9 (mean \pm SE: 2.9 ± 2.0) of which 16 were gilts. Due to abortion
152 by one sow and failure of video recordings of two sows during farrowing, we obtained videos on the
153 farrowing (Day 0) of 51 sows (n, Material groups: Control: 16, Peat: 18, Straw: 17; n, Parity groups: 1:
154 16, 2-3: 19, ≥ 4 : 16), and on Days 1 and 2 post-partum from 53 sows (n, Material groups: Control: 18,
155 Peat: 18, Straw: 17; n, Parity groups: 1: 16, 2-3: 20, ≥ 4 : 17). Mean parity in the treatment groups control,
156 peat and straw were 2.9 ± 0.5 , 3.0 ± 0.5 and 2.9 ± 0.5 respectively.

157 For each sow, the total number of piglets born was the sum of live born and stillborn piglets. The number
158 of total born piglets (mean \pm SE) were 15.8 ± 1.1 in the control group, 16.8 ± 0.9 in the peat group, and
159 15.2 ± 0.7 in the straw group. Due to cross-fostering in some litters, the litter size on Day 1 post-partum
160 was defined as the number of live born piglets plus piglets fostered into the litter or minus piglets
161 fostered out of the litter. Number of live born piglets was 14.4 ± 0.9 , 15.8 ± 1.0 and 14.7 ± 0.7 in the
162 control, peat and straw groups respectively, and after cross-fostering the number of piglets was $14.4 \pm$
163 0.8 , 15.4 ± 0.9 and 14.8 ± 0.6 in the control, peat and straw groups respectively. Due to piglet mortality,
164 the litter size on Day 2 post-partum was defined as the litter size minus piglets dead on Day 1; $12.8 \pm$
165 0.5 , 13.4 ± 0.7 and 13.4 ± 0.6 in the control, peat and straw groups respectively.

166 2.4. Provision of nest-building material

167 Every morning, all pens were cleaned and supplied with dry wood shavings (0.8 kg, mainly spruce,
168 same amount to all pens irrespective of treatment). In the afternoon, each pen was again cleaned and
169 given new litter (0.8 kg wood shavings) if necessary to replace wet and dirty litter. The wood shavings

170 functioned as litter for hygienic purpose and met requirements for litter in accordance with the
171 Norwegian Regulations on Keeping of Pigs (Lovdata, 2003). Sows in the control treatment did not
172 receive any additional material for nest building.

173 Additional nest-building material was provided on the solid floor to sows in the peat and straw
174 treatments from two days before expected farrowing until farrowing. In the morning, the peat treatment
175 group received 4 kg of peat (90% peat plus formic acid, acetic acid, potassium sorbate and coal; 75%
176 water content, 7.6% crude fiber, and 2.4% ash; Fossli AS, Frosta, NO), and the straw treatment group
177 received 2 kg of straw (long-stemmed barley straw). Because peat was only about half the volume of
178 straw, the weight of peat was doubled to even out the difference (Rosvold et al., 2018). In the afternoon,
179 a refill of 2 kg peat or 1 kg straw was provided respectively. Refills of peat were repeated each morning
180 and afternoon until farrowing, as the peat spread out and disappeared through the slatted floor or was
181 eaten by the sow. Straw was more likely to be retained, and further refills of straw were only given if
182 the sow farrowed later than expected, or dirty straw needed to be replaced. Remaining straw was
183 removed after farrowing.

184 2.5. Behavioural analysis

185 Behavioural data were collected from video recordings made using video cameras (Foscam F19821,
186 1280x720, Shenzhen, PRC) connected to a standard PC, that were suspended above each farrowing pen.
187 Positive and negative forms of communication from sow to piglets, as defined in Table 1, were registered
188 during farrowing and on Day 1 post-partum, using one-zero sampling at 1-min intervals (i.e. if a positive
189 form of communication occurred at least once during one minute, the value was 1). Farrowing was
190 defined as starting with expulsion of the first piglet, and registration continued for 4 h, or until the last
191 piglet was born if the farrowing was finished earlier. On Day 1 post-partum, observations were made
192 for 4 h in separate 1-h periods, each starting when the sow finished a meal or was otherwise active (if
193 she ingested fewer than four meals).

194 Aspects of nursing behaviour, as defined in Table 2, were registered during 6 h of continuous
195 observation in the evening of Day 2 post-partum. This timing was selected because episodic nursing
196 bouts were well established by then and because this was a relatively undisturbed time of day when staff
197 activity was low.

198 Nursing interval was the duration from one nursing bout to the next, regardless of milk let-down.
199 Successful nursing bouts terminated by piglets, were expressed as a proportion of the total successful
200 nursings (i.e. resulting in milk let-down). The number of piglets in a litter without a teat in their mouth
201 during milk let-down was averaged over all observed successful nursing bouts.

202 2.6. Statistical methods

203 The statistical analyses were performed in SAS Version 9.4 (SAS Institute, Inc., Cary, NC). The effects
204 of nest-building material (Control, Peat, Straw), parity (1, 2-3, ≥ 4), batch (1,2,3), litter size, and the
205 interaction between material and parity, were analysed by a generalized model (PROC GENMOD) with
206 Poisson distribution. Nest-building material, parity and batch were class variables and litter size was
207 continuous variable. Pairwise means comparisons were based on differences in least square means, with
208 Tukey adjustment for multiple comparisons. Descriptive statistics were obtained using SPSS Version
209 23 (IBM Corp., Armonk, NY). Wilcoxon signed-rank test was used to examine differences in positive
210 and negative sow-piglet communication between farrowing and Day 1 post-partum.

211 3. Results

212 3.1. Nest-building materials

213 During farrowing, the frequency of positive communication from sow to piglets (mean \pm SE % of scans)
214 was $17.9 \pm 1.5\%$, ranging from 1.3 to 52.9%, and the frequency of negative communication was $2.7 \pm 0.8\%$
215 (range 0.0 to 25.1%). All the sows showed positive communication during farrowing, and 21 sows
216 (41.2%) showed negative communication. Positive communication during farrowing was not affected
217 by nest-building material, whereas there were significant differences between sows in the three nest-
218 building material groups in their frequencies of negative communication (Table 3). Sows in the control
219 group had the highest levels of negative communication, the sows in the peat group the lowest, and sows
220 in the straw group were intermediate (Table 3).

221 On Day 1 post-partum, the frequency of positive communication from sow to piglets (mean \pm SE % of
222 scans) was $26.9 \pm 1.1\%$, ranging from 10.4 to 45.8%, and the frequency of negative communication was
223 $0.3 \pm 0.1\%$, with a range from 0.0 to 6.25%. All the sows showed positive communication on Day 1,
224 while 12 sows (22.6%) showed negative communication. Nest-building materials did not affect the
225 levels of either positive or negative communication on Day 1 (Table 3). A Wilcoxon signed-rank test
226 showed that the level of positive communication was significantly higher on Day 1 compared to
227 farrowing ($Z = -4.325$, $P < 0.001$), and the frequency of negative communication was significantly lower
228 on Day 1 compared to farrowing ($Z = -3.319$, $P < 0.001$).

229 On Day 2 post-partum, the nursing interval (mean \pm SE) was 42 ± 1 min, with a variation from 21 to 69
230 min, and number of nursing bouts in 6 h was 8.8 ± 0.3 , ranging from 5 to 15. The percentage of nursing
231 bouts initiated by the sow (mean \pm SE%) was $28.1 \pm 3.0\%$, ranging from 0.0 to 85.7%, and the percentage
232 of successful nursing bouts that resulted in milk let-down and terminated by the piglets was $56.1 \pm 5.1\%$,
233 ranging from 0 to 100%. During nursing bouts, the mean number of piglets per litter not having access
234 to a teat during milk let-down was 1.5 ± 0.1 , ranging from 0.0 to 3.7 piglets. Sows provided with straw
235 before farrowing initiated a higher proportion of nursing bouts compared to sows in the other treatment

236 groups (Table 3). Sows in the straw and control groups also had a higher proportion of successful nursing
237 bouts terminated by piglets than sows in the peat group (Table 3). Nursing intervals tended to be longer
238 in the control than peat and straw groups ($P=0.055$), while the number of nursing bouts and number of
239 piglets without access to a teat during milk let-down were not significantly affected by treatment (Table
240 3).

241 3.2. Parity

242 The frequency of negative communication from sow to piglets during farrowing was lower in sows of
243 parity ≥ 4 compared to the other two parity groups (Table 4). On Day 1 post-partum, sows of parity 2-3
244 gave the highest frequency of positive communication to their piglets, whereas primiparous sows gave
245 the lowest. The level of negative communication was not associated with parity on Day 1 (Table 4).

246 The proportion of nursing bouts initiated by the sow was highest for sows of parity ≥ 4 , and lowest for
247 first parity sows, whereas the primiparous sows had the highest proportion of successful nursing bouts
248 terminated by the piglets (Table 4). Nursing interval, number of nursing bouts, and number of piglets
249 without a teat during milk let-down were not associated with parity (Table 4).

250 There were interactions between material and parity regarding both positive and negative
251 communication during farrowing, positive communication on Day 1 post-partum, nursing bouts initiated
252 by the sow and successful nursing bouts ended by the piglets (Table 3, Fig. 2). Sows of parity 2-3 that
253 received peat pre-partum performed the highest frequency of positive communication during farrowing
254 and on Day 1 post-partum. During farrowing, sows in the control group had the highest frequency of
255 negative communication compared to sows with peat or straw in all parities, and especially in parity 2-
256 3 (Fig. 2). The proportion of nursing bouts initiated by the sow was highest among sows of parity ≥ 4
257 provided with peat pre-partum, and among sows in the other two parity groups provided with straw pre-
258 partum. Primiparous sows in control and peat groups had the highest proportion of successful nursing
259 bouts that were terminated by the piglets (Fig. 2).

260 3.3. Litter size

261 During farrowing, the frequencies of positive communication increased and negative communication
262 decreased with litter size (Table 4, Fig. 3). The frequency of positive communication on Day 1 post-
263 partum was also associated with litter size, declining above 14 piglets (Table 4, Fig. 3).

264 The proportions of nursing bouts initiated by the sow increased with litter size, whereas successful
265 nursing bouts terminated by piglets decreased with litter size. The number of piglets without a teat during
266 milk let-down strongly increased with litter size (Table 4, Fig. 3).

267 3.4. Batch

268 There were batch differences in the frequency of negative communication during farrowing (mean \pm SE
269 % of scans); batch 1: $2.0 \pm 1.0\%$, batch 2: $3.3 \pm 1.6\%$, batch 3: $3.0 \pm 1.5\%$ ($\chi^2_{2,39} = 7.9$, $P = 0.020$), and on
270 Day 1 post-partum; batch 1: $0.1 \pm 0.0\%$, batch 2: $0.9 \pm 0.4\%$, batch 3: $0.1 \pm 0.1\%$ ($\chi^2_{2,41} = 18.5$, $P < 0.001$).
271 Length of nursing intervals significantly differed between the batches; batch 1: 47 ± 2 min, batch 2: 37 ± 2
272 min, batch 3: 41 ± 1 min ($\chi^2_{2,41} = 27.2$, $P < 0.001$), as did the proportion of sow-initiated nursing bouts;
273 batch 1: $29.8 \pm 5.0\%$, batch 2: $31.5 \pm 5.4\%$, batch 3: $23.1 \pm 5.5\%$ ($\chi^2_{2,41} = 34.7$, $P < 0.001$). Proportions of
274 successful nursing bouts terminated by the piglets were also different; batch 1: $61.8 \pm 9.3\%$, batch 2:
275 $56.4 \pm 9.8\%$, batch 3: $50.1 \pm 7.8\%$ ($\chi^2_{2,41} = 32.8$, $P < 0.001$). With respect to number of nursing bouts,
276 positive communication during farrowing and on Day 1, and number of piglets without a teat per nursing
277 bout, there were no significant differences between the three farrowing batches.

278 4. Discussion

279 As predicted, sows provided with either straw or peat for nest building before farrowing showed less
280 negative communication towards their piglets during farrowing compared to control sows without nest-
281 building material. Thus, providing straw or peat for nest building appears to be valuable for stimulating
282 maternal care at the time of farrowing, thereby helping piglets to get a good start in life even though the
283 effect of material on negative communication was no longer evident by Day 1. Contrary to our
284 prediction, peat had the greatest effect in reducing negative behaviour towards piglets in total, although
285 not consistently across parity groups. Peat stimulates rooting to a larger extent than straw and it also
286 initiates wallowing, which appears to have cooled the sows, but resulted in a lower overall level and
287 variety of nest-building behaviour than straw (Rosvold et al., 2018). Our current results, therefore,
288 suggest that different mechanisms may underlie benefits from providing straw and peat for stimulating
289 maternal care, and that provision of both might be even more beneficial.

290 Negative communication included aggressive pushing with the nose, biting or biting attempts, which
291 could lead to savaging resulting in death, although there were no documented cases of savaging in the
292 present experiment. According to Ahlström et al. (2002), sows that exhibited savaging were more
293 restless during farrowing. In our study, the sows in the control group not only directed more negative
294 communication towards piglets during farrowing, but were also more restless before farrowing than the
295 sows given straw, spending more time walking, standing or sitting, and performing stereotypies in the
296 nest-building phase and less time resting (Rosvold et al., 2018). Ahlström et al. (2002) also suggested
297 that there is a link between restrictive housing, prevention of nest-building behaviour and undesirable
298 behaviour such as savaging, and that individuals expressing such behaviour may be those that are least
299 able to cope with environmental restriction. Sows in crates have been reported to perform more threats,
300 snapping at or biting towards piglets during the first week after farrowing than sows in pens (Cronin and
301 Smith, 1992). Furthermore, Yun et al. (2013; 2014) observed that sows restricted to crates had lower

302 plasma concentrations of oxytocin and prolactin pre-partum compared to sows provided with straw and
303 space to move. Even when loose-housed in pens, Yun et al. (2013; 2014) found lower oxytocin and
304 prolactin levels in sows without straw compared to sows given straw before farrowing, and the sows
305 without straw showed weaker maternal behaviour as indicated by being less careful when lying down,
306 an effect that lasted for several days post-partum. These results support our findings regarding the
307 positive effects of peat and especially straw as nest-building materials.

308 The amount of negative sow communication towards piglets during farrowing was higher in younger
309 than older sows (parity ≥ 4). Our results are in correspondence with earlier studies showing that savaging
310 is more frequent in younger than older sows (e.g. Harris et al., 2003; Chen et al., 2008). Negative sow
311 communication was higher during farrowing than on Day 1 post-partum, possibly due to changes in
312 hormonal status and birth-related pain and discomfort (Algers and Uvnäs-Moberg, 2007; Mainau and
313 Manteca, 2011).

314 Contrary to our prediction, there was no consistent difference in positive communication with piglets
315 between sows provided with different nesting materials. In contrast, nest-building activity has
316 previously been associated with improved maternal behaviour (Andersen et al., 2005; Yun et al., 2014),
317 and recently Ocepek et al. (2017b) revealed a positive correlation between scores for nest-building
318 activity and scores for sow communication and carefulness. One reason for this discrepancy may be that
319 we provided a limited amount of nesting material to the sows whilst, in Andersen et al. (2005) for
320 instance, the sows had free access to straw. We also detected a nest material by parity interaction on
321 positive communication, both during farrowing and on Day 1 that could account for differences in results
322 between studies.

323 Positive sow-to-piglet communication was lower during farrowing than on Day 1 post-partum, possibly
324 because sows are generally passive during farrowing, giving piglets opportunities to find the udder and
325 suckle (Jarvis et al., 1999). Melišová et al. (2011) observed more positive communication on the day
326 after farrowing than two days later. The higher level of positive communication on Day 1 compared to
327 farrowing and Day 3 (Melišová et al., 2011) suggests that even though bonding starts right after birth, it
328 is consolidated on Day 1.

329 During farrowing, positive communication increased with litter size, whereas negative communication
330 decreased to some extent with litter size, although the sows with the highest frequencies had large litters.
331 On Day 1 post-partum, positive communication appeared to decrease above a litter size of 14 piglets.
332 Recently Ocepek and Andersen (2018) found that, in the first two days post-partum, positive sow-to-
333 piglet communication while the sow was resting increased with litter size. More communication while
334 resting was associated with higher piglet mortality, possibly due to the sows being more disturbed and
335 stressed by the piglets at a time they should be resting. In contrast, higher level of communication while

336 active was positive for piglet survival (Ocepek and Andersen, 2018). We did not differentiate whether
337 the sow was resting or active while communicating with the piglets in the current study.

338 As predicted and consistent with previous studies, sows provided with straw pre-partum initiated a
339 higher proportion of nursing bouts than sows in the peat and control group, and had a higher proportion
340 of successful nursing bouts terminated by the piglets compared to sows in the peat and the control group.
341 Herskin et al. (1999) found that sows not provided with nest-building material tended to terminate more
342 nursing bouts before milk let-down compared to those with access to straw, suggesting that nest-building
343 material increases the sow`s willingness to nurse. Increased nest-building activity has been associated
344 with elevated levels of prolactin and oxytocin, which are crucial for milk production and milk let-down,
345 respectively, and with nursing performance during early lactation (Yun et al., 2014). When the sow
346 terminates a nursing bout by making her udder unavailable, the amount of post-massage by the piglets
347 may decline, which possibly could result in poorer milk production due to lower prolactin levels,
348 reduced weight and lower productivity of the mammary glands (Algers et al., 1991; Nielsen et al., 2001;
349 Thodberg and Sørensen, 2006). The proportions of sow-initiated nursing bouts increased with increasing
350 parity, as also observed by Thodberg et al. (2002), whilst the proportion of successful nursings
351 terminated by the piglets was highest among primiparous sows. Farmer et al. (1995) found that
352 primiparous sows performed less lying on the belly after farrowing than older sows, suggesting a greater
353 willingness to expose the udder for the piglets, possibly due to having no previous negative experience
354 of nursing (i.e. piglets fighting at the udder). Moreover, Ocepek et al. (2016) point out that breeding
355 goals have emphasized greater maternal investment earlier in life.

356 Increased litter size was associated with higher proportions of sow-initiated nursing bouts and lower
357 proportions of successful nursing bouts terminated by piglets on Day 2 post-partum. These results do
358 not allow conclusions regarding associations between litter size and maternal investment. As in previous
359 studies (Andersen et al., 2011; Ocepek et al., 2017a), increased litter size resulted in a higher number of
360 piglets without access to a teat during milk let-down.

361 There was a significant difference between farrowing batches in the frequency of negative sow-piglet
362 communication during farrowing and on Day 1, with the numerically highest levels in the second batch
363 being accompanied by a lower frequency of nest-building activity (Rosvold et al., 2018). The higher
364 temperatures experienced at the time of observations on the second batch may explain these results.

365 5. Conclusions

366 We have found that the pre-partum provision of straw and peat as nesting materials was associated with
367 a reduction in negative sow-to-piglet communication, and that straw improved nursing performance.
368 These findings support the argument that the provision of appropriate nest-building material has an
369 important impact on the maternal behaviour of sows.

370 Conflict of interest

371 The authors declare no conflict of interest.

372 Acknowledgements

373 The authors wishes to thank staff at the pig house at Mære Landbruksskole, the students Ingrid Marie
374 Håkenåsen, Camilla Therese Skjelbred, and Geir Næss for practical help and the farrowing pen
375 illustration. The Norwegian Research Council (NFR207804/O99), Norsvin, Animalia, Nortura and
376 Fossli AS financed this project.

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484

485 [Table captions](#)

486 **Table 1.** Ethogram of positive and negative sow communicatory behaviours directed towards piglets as
487 observed during farrowing and on Day 1 post-partum.

488 **Table 2.** Ethogram of nursing behaviour, as observed on Day 2 post-partum.

489 **Table 3.** Effects of nest-building material, and interactions between material and parity, on frequency
490 of sow communicatory behaviours towards piglets during farrowing and on Day 1 post-partum and
491 nursing behaviour on Day 2 post-partum (mean \pm SE %).

492 **Table 4.** Associations of parity and litter size with frequency of sow communicatory behaviours towards
493 piglets during farrowing and on Day 1 post-partum, and on nursing behaviour on Day 2 (mean \pm SE %).

494

495 [Figure captions](#)

496 **Fig. 1:** Design of the farrowing pen (Rosvold et al., 2018).

497 **Fig. 2.** Interaction between nesting material and parity on mean (\pm SE) frequency of (a) positive
498 communication from sow (n=51) to piglets during farrowing (% of scans); (b) negative communication
499 from sow (n=51) to piglets during farrowing (% of scans); (c) positive communication from sow (n=53)
500 to piglets on Day 1 post-partum (% of scans); (d) nursing bouts initiated by the sow (n=53) on Day 2
501 post-partum (% of total nursing bouts); (e) successful nursing bouts terminated by piglets on Day 2 post-
502 partum (n= 53, % of total successful nursing bouts).

503 **Fig. 3.** Association between litter size and: (a) positive communication from sow (n=51) to piglets
504 during farrowing (% of scans); (b) negative communication from sow (n=51) to piglets during farrowing

505 (% of scans); (c) positive communication from sow (n=53) to piglets on Day 1 post-partum (% of scans);
506 (d) nursing bouts initiated by the sow (n=53) on Day 2 (% of total nursing bouts); (e) successful nursing
507 bouts terminated by piglets on Day 2 (% of total successful nursing bouts); (f) mean number of piglets
508 per nursing bout per litter (n=53) without a teat during milk let-down on Day 2. Litter size refers to total
509 born (live born + stillborn) piglets during farrowing, and number of piglets (live born \pm cross-fostered)
510 surviving on Days 1 and 2 post-partum.

Table 1. Ethogram of positive and negative sow communicatory behaviours directed towards piglets as observed during farrowing and on Day 1 post-partum.

Communication type	Behaviour	Definition
Positive	Sniff piglet	Sow actively directs her nose towards a piglet. Her snout is <10 cm from the piglet.
	Grunt to piglet	Sow gives short, frequent low-pitched vocalisations with head oriented towards piglets.
	Nudge piglet	Sow actively touches a piglet with her nose, may move snout gently up and down.
Negative	Push piglet	Sow moves a piglet roughly with her nose.
	Threatening barks	Sow directs sharp bark(s) towards piglet(s).
	Bite piglet	Sow bites or snaps towards a piglet.

Table 2. Ethogram of nursing behaviour, as observed on Day 2 post-partum.

Behaviour	Definition
Start of a nursing bout	Time point when >50% of the litter has started to actively massage the udder.
Sow-initiated nursing bout	Sow lies on side, exposing udder and/or starts grunting before piglets start massaging the udder.
Piglet-initiated nursing bout	One or more piglets is massaging the udder before sow exposes the udder and/or starts grunting.
Unsuccessful nursing bout	The nursing bout is terminated before the increase in grunting frequency and/or before the piglets` fast, rapid suckling movement (indicating intake of milk)
Successful nursing bout terminated by sow	Following milk let-down, the sow rolls over or stand up so her udder is not accessible to the piglets, while the piglets still are actively massaging.
Successful nursing bout terminated by piglets	Following milk let-down, piglets fall asleep at the udder or walk away while the sow is lying on her side with her udder exposed.
Without teat	Piglet without teat in mouth during milk let-down.

Table 3. Effects of nest-building material, and interactions between material and parity, on frequency of sow communicatory behaviours towards piglets during farrowing and on Day 1 post-partum and nursing behaviour on Day 2 post-partum (mean \pm SE %).

Activity	Material			Material x parity			
	Control	Peat	Straw	χ^2	P	χ^2	P
<i>Communication during farrowing</i> ^{1,3}							
Positive, %	17.5 \pm 2.9	18.4 \pm 2.5	17.8 \pm 2.3	0.1	0.976	24.4	<0.001
Negative, %	5.3 \pm 2.1 ^a	1.4 \pm 0.6 ^c	1.8 \pm 0.8 ^b	36.9	<0.001	27.0	<0.001
<i>Communication on Day 1</i> ^{2,3}							
Positive, %	26.6 \pm 1.7	26.3 \pm 2.0	27.9 \pm 2.2	1.1	0.582	19.5	<0.001
Negative, %	0.3 \pm 0.2	0.6 \pm 0.4	0.1 \pm 0.1	3.7	0.159	3.0	0.565
<i>Nursing behaviour on Day 2</i> ²							
Nursing interval, min	44 \pm 2	40 \pm 2	41 \pm 2	5.8	0.055	4.6	0.328
Nursing bouts, n	8.3 \pm 0.5	9.4 \pm 0.6	8.8 \pm 0.4	1.1	0.565	0.1	0.999
Sow-initiated nursing bouts, %	23.5 \pm 4.3 ^a	26.6 \pm 5.8 ^a	34.4 \pm 5.5 ^b	44.1	<0.001	72.7	<0.001
Successful nursing bouts terminated by piglets, %	58.8 \pm 8.8 ^a	48.4 \pm 9.7 ^b	61.3 \pm 8.3 ^a	71.1	<0.001	94.3	<0.001
Piglets without teat, n	1.6 \pm 0.2	1.6 \pm 0.2	1.3 \pm 0.2	0.9	0.649	3.2	0.524

¹ Nest-building material χ^2 2.39 ; Material x parity χ^2 4.39

² Nest-building material χ^2 2.41 ; Material x parity χ^2 4.41

³ 1/0 sampling

^{a, b, c} Means with different letters are significantly different (P <0.05).

Table 4. Associations of parity and litter size with frequency of sow communicatory behaviours towards piglets during farrowing and on Day 1 post-partum, and on nursing behaviour on Day 2 (mean \pm SE %).

Activity	Parity			χ^2	P	Litter size	
	1	2-3	≥ 4			χ^2	P
<i>Communication during farrowing</i> ^{1,3}							
Positive, %	18.9 \pm 3.5	17.5 \pm 2.4	17.4 \pm 1.2	3.5	0.177	3.9	0.049
Negative, %	3.4 \pm 1.6 ^a	3.4 \pm 1.5 ^a	1.4 \pm 0.7 ^b	18.7	<0.001	6.0	0.015
<i>Communication on Day 1</i> ^{2,3}							
Positive, %	24.3 \pm 1.5 ^a	29.1 \pm 1.9 ^b	26.9 \pm 2.2 ^{ab}	11.9	0.003	4.4	0.037
Negative, %	0.2 \pm 0.1	0.3 \pm 0.2	0.6 \pm 0.4	1.4	0.497	0.8	0.374
<i>Nursing behaviour on Day 2</i> ²							
Nursing interval, min	42 \pm 2	42 \pm 2	42 \pm 2	1.7	0.430	0.1	0.753
Nursing bouts, n	8.8 \pm 0.6	8.8 \pm 0.5	8.9 \pm 0.5	0.2	0.915	0.1	0.829
Sow-initiated nursing bouts, %	21.4 \pm 3.8 ^a	25.4 \pm 5.0 ^{ab}	37.5 \pm 6.1 ^b	67.4	<0.001	7.1	0.008
Successful nursing bouts terminated by piglets, %	83.6 \pm 5.3 ^a	43.5 \pm 8.7 ^b	45.0 \pm 8.4 ^b	247.4	<0.001	31.8	<0.001
Piglets without teat, n	1.0 \pm 0.2	1.7 \pm 0.2	1.9 \pm 0.3	0.8	0.658	9.5	0.002

¹ Parity χ^2 2.39 ; Litter size χ^2 1.39

² Parity χ^2 2.41 ; Litter size χ^2 1.41

³ 1/0 sampling

^{a, b} Means with different letters are significantly different (P <0.05).

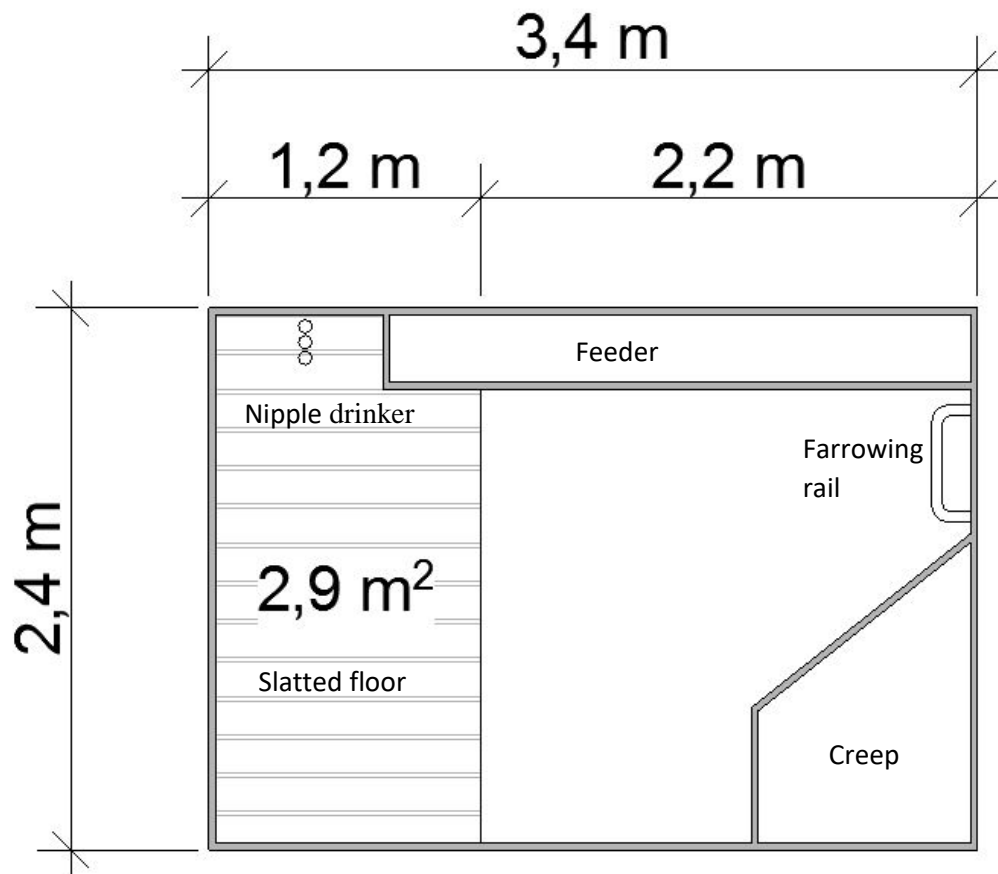


Fig. 1: Design of the farrowing pen (Rosvold et al., 2018).

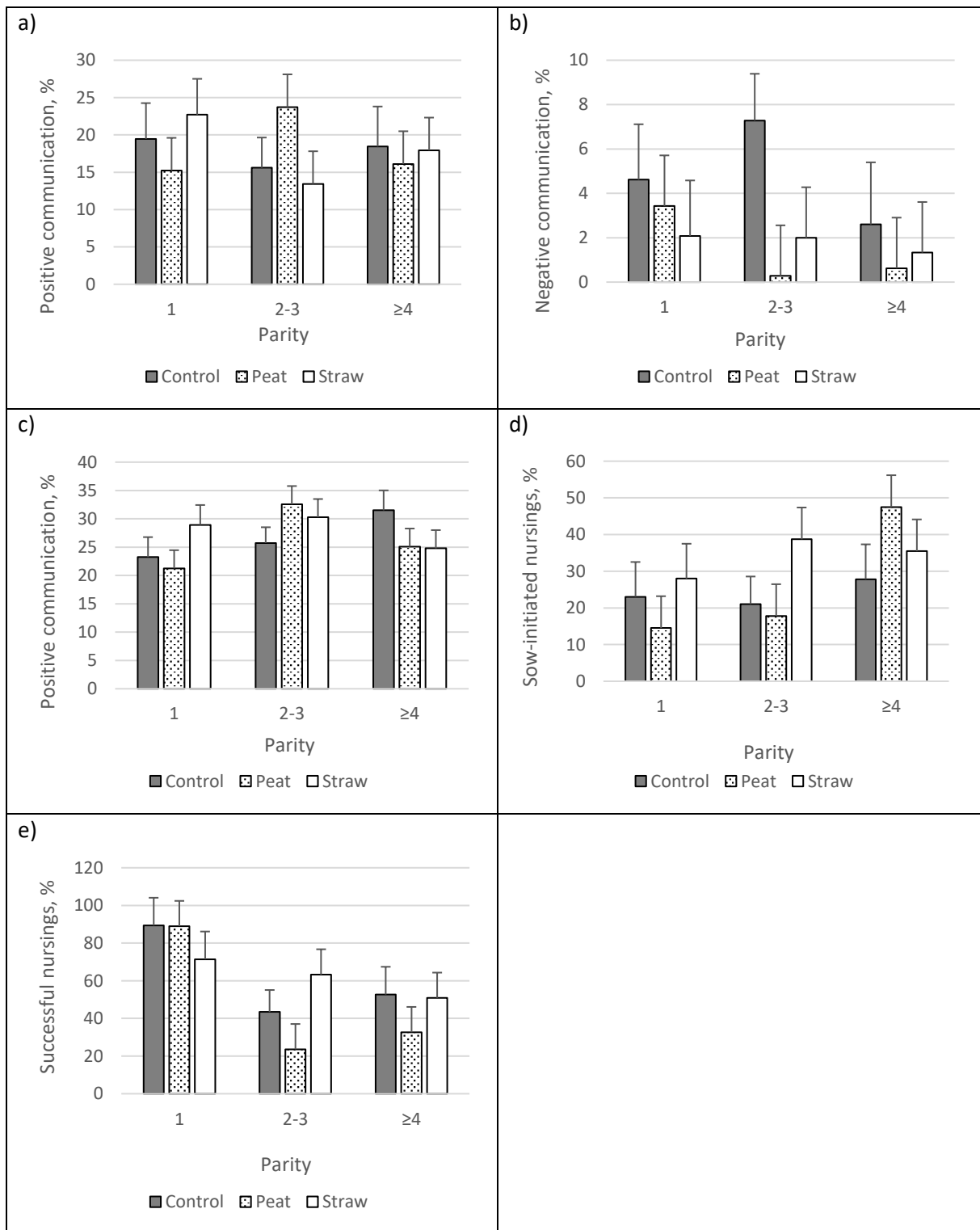


Fig. 2. Interaction between nesting material and parity on mean (\pm SE) frequency of (a) positive communication from sow (n=51) to piglets during farrowing (% of scans); (b) negative communication from sow (n=51) to piglets during farrowing (% of scans); (c) positive communication from sow (n=53) to piglets on Day 1 post-partum (% of scans); (d) nursing bouts initiated by the sow (n=53) on Day 2 post-partum (% of total nursing bouts); (e) successful nursing bouts terminated by piglets on Day 2 post-partum (n= 53, % of total successful nursing bouts).

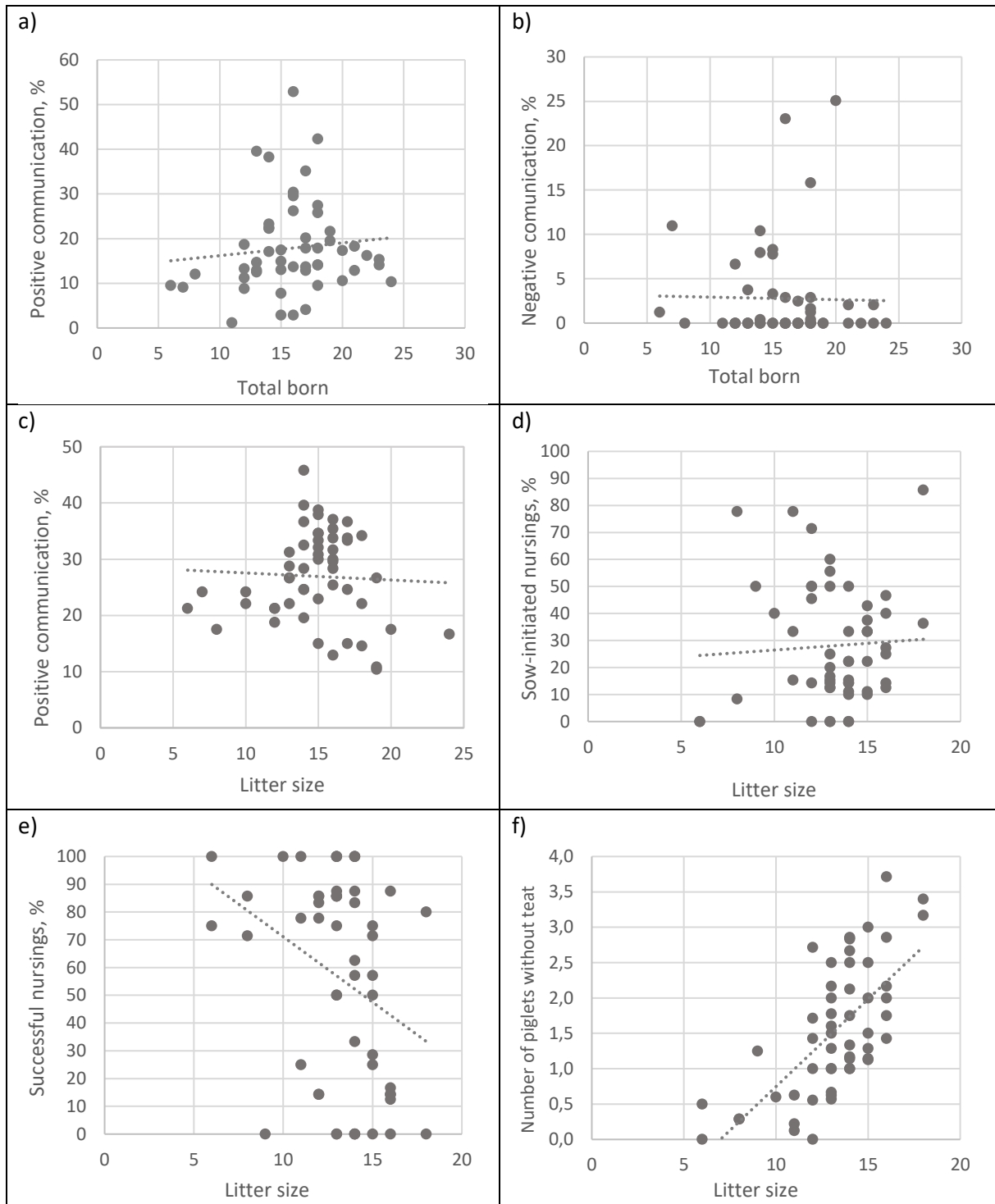


Fig. 3. Association between litter size and: (a) positive communication from sow (n=51) to piglets during farrowing (% of scans); (b) negative communication from sow (n=51) to piglets during farrowing (% of scans); (c) positive communication from sow (n=53) to piglets on Day 1 post-partum (% of scans); (d) nursing bouts initiated by the sow (n=53) on Day 2 (% of total nursing bouts); (e) successful nursing bouts terminated by piglets on Day 2 (% of total successful nursing bouts); (f) mean number of piglets per nursing bout per litter (n=53) without a teat during milk let-down on Day 2. Litter size refers to total born (live born + stillborn) piglets during farrowing, and number of piglets (live born ± cross-fostered) surviving on Days 1 and 2 post-partum.