Applied Animal Behaviour Science, 18 (1987) 269-286
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

An Examination of Behavioral, Immunological and Productive Traits in Four Management Systems for Sows and Piglets

JOHN J. McGLONE

Department of Animal Science, Texas Tech University, Lubbock, TX 79409 (U.S.A.)

FRANK BLECHA

Department of Anatomy and Physiology, Kansas State University, Manhattan, KS 66506 (U.S.A.)

(Accepted for publication 26 November 1986)

ABSTRACT

McGlone, J.J. and Blecha, F., 1987. An examination of behavioral, immunological and productive traits in four management systems for sows and piglets. *Appl. Anim. Behav. Sci.*, 18: 269-286.

Forty-one sows and litters were utilized in a multi-disciplinary evaluation of four common commercial housing systems for sows and piglets: (1) a standard crate (SC); (2) a modified or turn-around crate (TC); (3) a pen with an indoor and outdoor area (OP); (4) a straw-bedded hut on a lot (HL). HL litters had a higher incidence of still-births than OP litters. Litters raised in HL had higher mortality and weaned fewer and lighter pigs. Litters in TC had lower mortality than SC litters. Sow behavior data (such as sow feeding time) paralleled productivity data (number piglets weaned). Sows who spent more time showing oral behaviors towards bars pre-farrowing had larger litter sizes ($r=0.73, P<0.01$). Sows who were less active (that is, moved while standing) pre-farrowing weaned more piglets ($r=0.55, P<0.05$). Sows who spent more time feeding weaned more pigs ($r=0.57, P<0.05$). Immunological data indicated that piglets in OP had higher white blood cell numbers and piglets in HL had lower antigen-induced blood antibody titers. Since litters in the TC had improved piglet survival compared with SC, a large-scale performance and economic-evaluation trial is in order to further study the system on commercial farms.

INTRODUCTION

Objective assessments of farm animal welfare in common housing systems are needed. Selecting appropriate variables to measure animal well-being is a difficult task. While no author has been able to identify the best single measure, most authors feel a battery of animal measurements and tests should be collected for each environment (Wood-Gush, 1980; Banks, 1982; Baxter, 1983; Craig and Adams, 1984). The assessment of housing systems should include,

0168-1591/87/$03.50

at least, measures of productivity, physiology, health and behavior. Additional evidence may be derived from animal preference tests, although results from these measures are generally considered to be difficult to interpret (Dawkins, 1976; Duncan, 1981).

The lactation environment for domestic swine is particularly difficult to assess. The physical, thermal, physiological and behavioral needs of sows and piglets are diverse. Sows would not thrive in an environment designed precisely to meet piglet's needs (see Holmes and Close, 1977). Consequently, common farrowing systems have at least two micro-environments — one each for sows and piglets. A comprise must be struck between degree of permissible freedom-of-movement and sow clumsiness to avoid crushing and chilling piglets. Few research reports have been published which compare productivity, health and behavior of sows and piglets in United States farrowing systems. The objective of this study was to gather multiple measures of productivity, immune function and behavior for sows and piglets as we evaluated and compared four common farrowing systems. Systems ranged from a fully extensive pasture system to the intensive farrowing crate.

METHODS

The experiment was conducted at the University of Wyoming farm in Laramie, Wyoming (elevation 2277 m above sea level). Adult females were either gilts (first litter) or sows (second or greater litter) from Yorkshire, Duroc or crossbred breeds. Each sow breed or crossbreed type was as equally represented in each treatment group as was possible. Piglets were crossbred.

Pregnant gilts and sows were housed on a dirt lot in groups of 8–12 animals. On Day 109 of gestation, females were washed, treated topically for mange and lice and then moved to a randomly assigned farrowing environment. Environments included a standard farrowing crate (SC), a turn-around crate (TC), an outdoor pen (OP) and a hut situated on a dirt lot (HL). The standard farrowing crate measured 1.5×2.2 m with an inside sow area measuring 2.2×0.6 m. The turn-around crate measured 1.5×2.6 m with an inside sow area measuring 0.6 m at the feeder, and the side rails (2.2 m long) were flared out to be 1.5 m wide near the back of the crate. The outdoor pen had an inside area that measured 1.8×2.5 m and an outside area that measured 1.8×2.5 m. The inside area had two guard rails, behind which piglets could get away from the sow. The two types of farrowing crates were in a heated barn (thermostat set at 18°C) with full-length windows on the south (which equalized photoperiod across treatments). Each crate had a single 250-W heat-lamp and the outdoor pen had a heated pad in the inside area. Floor materials were slatted (plastic-coated expanded metal in the center and slats in the front and rear) for both farrowing crates, and the outdoor pen had a solid wood floor (with a small amount of bedding) inside and wooden slats in the outdoor area. The fourth environment was a hut situated on a large lot measuring 6.2×15.4 m with a single large hut. The hut was heavily bedded (about 0.5 m deep) with straw. An additional straw pile was provided outside the hut (in case sows used bedding while outdoors). The hut had no supplemental heat. This lot was designed for 3 sows and their piglets. Three individual feeding stalls and a waterer were on the lot.

All sows were gradually (over 5–7 days post-farrowing) brought up to full feed. They were fed a 14% crude protein commercial sow diet. Water was available to all sows ad libitum.

Thermal data

Air temperature and relative humidity data were recorded continuously. Hygrothermographs, calibrated with a mercury thermometer, were situated inside the farrowing barn and outside. Daily minimum, maximum and median temperature and humidity were obtained from the strip-chart recordings.

Performance measures

Piglets were gathered within 12 h of the unattended parturition. At that time, the number of pigs alive and dead (called still-births, although some piglets may have been born alive then died shortly after birth) were counted and weighed. Piglet's needle teeth were clipped and ears notched for identification. On Day 21 after parturition, piglets were weighed. The following variables were derived from the above information: total piglets born; number born live; number still-births; number weaned (those present at 21 days); percentage mortality (those present at 21 days/number live at birth); piglet weight gain; average piglet weight (at birth and 21 days); the total litter weaning weight (at 21 days).

Immunological measures

Antibody-mediated and cellular immune parameters were measured. At average times of 21 and 7 days before anticipated parturition, sows were injected (subcutaneously) with 1 ml of a 40% solution of three-times-washed sheep red blood cells (SRBC). Within 12 h of birth, colostral milk samples were collected. At 3 days of age, piglets were bled. Packed cell volume (PCV), total white blood cell counts (WBC)[1] and a differential WBC were made from whole blood and blood smears.

Plasma samples from piglet blood were collected and frozen. Colostral sam-

[1]Coulter counter, Model ZBI.

ples and piglet plasma were assayed for agglutination antibody titers to SRBC by previously-reported methods (Blecha and Kelley, 1981).

When piglets were 7 days old, an in vivo measure of cellular immune function was taken (Blecha et al., 1983). One-half ml of 500 μg ml^{-1} solution of phytohemagglutinin (PHA) was injected intradermally on a section of flank skin. An equivalent volume of physiological saline was injected, as a control, in the contralateral flank. Prior to injection and 24 h after injection, a skin-fold thickness measurement was taken. The degree of swelling indicates the ability of some WBC's (lymphocytes and monocytes) to infiltrate the PHA-challenged area.

Behavioral measures

A total of 19 behavioral categories was assessed. With such a broad-based catalog of behaviors, we attempted to sample the major behavioral systems. These behaviors (listed in Table I) were collected on an electronic event recorder[1] which summarized the frequency and duration of each behavior. Measurements were taken (1) when gilts and sows were first moved to their respective environments, and (2) 7 days after parturition. On each day that behavior was recorded, observations were made for three equally-spaced hours during the 24-h period (08.00, 16.00, 24.00 h). The first observation day we sought to collect behavioral data when sows and gilts first entered their new environments and again 8 and 16 h later. On the next observation day (7 days post-partum), we also sampled across the 24-h day in an attempt to identify diurnal cycles in behaviors. Sows were fed prior to 08.00 h in each environment. Consequently, in each environment, the 08.00 h observation time was an active time-period while other times were generally non-active periods. A detailed catalog of sterotypic behaviors was not collected. Cronin and Wiepkema (1984) identified 12 oral/facial stereotyped behaviors, all of which were included in our behavioral categories as "bites, chews, rubs or pushes fences or bars", and "sow pushes or roots ground or floor". We chose to break these oral/facial behaviors into two categories (i.e. directed towards one of two substrates) because Cronin and Wiepkema (1984) found different frequencies of stereotypes for each substrate.

Statistical analyses

For all statistical analyses, the sow or litter was the experimental unit. In the analyses for measures taken on piglets, the litter average was taken. The statistical model examined the effects of four environmental treatments, parity (that is gilts or sows) and the interaction between treatment and parity.

[1]Datamyte, Model 800.

TABLE I

List of measurements taken during this study

Type of data taken			
Climate (from continuous recordings)	Performance (from weights and counts)	Immune or blood (from blood or other tests)	Behavior (from video-tape or live observation)
Minimum daily temperature	Number piglets born Number still-births	Colostral antibody Piglet blood antibody	Sow stands Sow lies down
Maximum daily temperature	Number piglets weaned Percent mortality	Piglet cellular immune test (PHA test)	Sow bites, chews, rubs or pushes fences or bars Sow pushes or roots ground or floor
Minimum daily relative humidity	Average piglets weaning weights Total litter weaning weight	Total white blood cells (WBC) Lymphocytes	Sow standing-moving Sow standing-not moving Sows interact non-aggressively
Maximum daily relative humidty	Days to return to estrus	Mature and banded polymorphonuclear	Sow moves inside hut
		Eosinophils Monocytes Basophils Packed red cell volume	>50% piglets use heat <50% piglets use heat >80% piglets nurse Sow touches piglets Sow moves outside hut
			>80% piglets stop nursing Sow feeding Sow drinking Sow turns body 180° Sow bites or pushes other sow Sow paws ground

TABLE II

Temperature and relative humidity data during the study (May–November 1984)

Item	Number of days	Mean daily value	Standard deviation	Lowest value	Highest value
Indoor environments					
Minimum temperature (°C)	124	20.7	2,42	11.0[1]	23.0
Maximum temperature (°C)	124	27.2	3.15	19.5	33.5
Minimum relative humidity (%)	162	27.7	11.69	7.0	55.0
Maximum relative humidity (%)	162	58.6	19.22	13.0	89.5
Outdoor environments[2]					
Minimum temperature (°C)	123	7.6	5.67	− 9.7	17.0
Maximum temperature (°C)	123	21.4	6.71	0.0	30.0
Minimum relative humidity (%)	69	35.8	14.02	10.0	61.0
Maximum relative humidity (%)	69	85.1	3.26	74.0	91.5

[1]For 2 days the farrowing barn furnace malfunctioned; otherwise the room thermostat was set at 18°C.
[2]Air temperatures below 0°C were recorded on 18 days. The outdoor pasture environment was not used in October and November (machine failure caused loss of some relative humidity data).

Measures of performance were taken on 41 litters, while behavioral and immunological measures were taken on fewer litters (numbers given in tables). A preliminary analysis showed no significant breed effects, so breed was dropped from the final analyses. Correlation coefficients were calculated between each variable measured.

RESULTS

Thermal data

Table II gives the temperature and relative humidity data collected during the study. Although the study was conducted in late spring to early autumn (May–November), the summertime climatic conditions outdoors were relatively cold (since the study was conducted at a moderately high elevation). The median temperature indoors was 24°C and outdoors it was 14°C. Median relative humidity indoors was 43% and outdoors it was 60%. However, the median absolute amount of water in the air indoors was 0.0036 (kg water/kg dry air) and outdoors it was 0.0027 (kg water/kg dry air).

Performance measures

Performance data are given in Table III. Total number of piglets born and number of pigs born live were not significantly ($P > 0.10$) influenced by treat-

TABLE III

Least-squares means per litter for measures of piglet performance as influenced by treatment[1]

Treatment	N^2	Total number born	Number born live	Number still-births	Number weaned	Mortality (%)	Piglet daily weight gain (kg)	Average piglet 21-day weight (kg)	Total litter 21-day weight (kg)
Standard crate (SC)	11	10.4	9.6	$0.74^{a,b}$	7.1^{a}	29.3^{a}	0.17	4.8^{a}	38.4^{a}
Turn-around crate (TC)	11	9.4	8.8	$0.61^{a,b}$	8.0^{a}	9.4^{b}	0.16	4.7^{a}	37.9^{a}
Outdoor heated pen (OP)	10	10.0	9.7	0.30^{a}	7.9^{a}	$18.2^{a,b}$	0.16	4.9^{a}	39.2^{a}
Hut on a lot (HL)	9	9.2	7.6	1.62^{b}	4.0^{b}	51.5^{c}	0.11	3.5^{b}	16.0^{b}
Primiparous	23	8.6^{a}	8.1	0.46	6.7	78.0	0.13	4.2	30.6
Multiparous	18	10.9^{b}	9.8	1.15	6.9	67.9	0.17	4.8	35.5
Square-root of error mean square		2.18	2.29	1.28	2.48	22.04	0.049	1.21	11.64

[1]Means within a column with different superscripts differ, $P<0.05$.
[2]N indicates number of litters per treatment.

ments. Sows giving birth in the hut on a lot had more still-births than sows in the outdoor pen ($P<0.05$). The increased still-births (actually the number of piglets found dead when first observed within 12 h of birth) in the hut on a lot-treatment were probably due to piglets being born live, becoming chilled and then dying. Litters in the most extensive system (HL) also weaned fewer pigs ($P<0.01$), had a higher piglet death rate during lactation ($P<0.01$), had lighter average pig weight at weaning ($P=0.05$) and had lighter total litter weight at weaning ($P<0.01$). The turn-around crate significantly improved mortality rate over the standard crate ($P<0.05$). Although the litters in the turn-around crate and outdoor pen weaned more pigs than litters in the standard crate, this difference did not reach statistical significance. First-litter females (primiparous) had fewer piglets born ($P<0.05$) than older sows (multiparous).

Immune measures

White blood cell (WBC) data are listed in Table IV. Total WBC numbers were higher for piglets raised in the outdoor pen ($P<0.05$) than for litters in the turn-around crate or hut on a lot. When each class of WBC was considered, treatments did not have a significant influence ($P>0.10$). First-litter gilts had higher WBC ($P<0.05$) and mature polymorphonuclear cell ($P<0.01$) numbers.

TABLE IV

Number of total piglet leukocytes (WBC) and of each leukocyte type per ml whole blood for litters in different treatments (table values are least-squares means)

Treatment	N^1	WBC ml^{-1}	Numbers of leukocytes ml^{-1}					
			Lymphocyte	Mature polymorpho-nuclear	Banded polymorpho-nuclear	Eosinophil	Monocyte	Basophil
Standard crate (SC)	6	9937[a,b]	6395	2255	722	138	529	3.1
Turn-around crate (TC)	7	9642[b]	5627	2495	826	157	477	5.0
Outdoor heated pen (OP)	8	11820[a]	6978	2615	1292	130	842	12.1
Hut on a lot (HL)	7	9208[b]	4941	2585	1152	113	405	3.0
Primiparous	14	11355 *	6302	3194 **	1108	173	560	0.2
Multiparous	15	8986	5669	1781	889	96	567	11.5
Square-root of error mean square		2115	1574	700	457	119	408	13

[1] N indicates number of litters sampled. Means within a column with different superscripts differ, $P<0.05$.
*Primiparous sows' piglets different from multiparous litters, $P<0.05$.
**Primiparous sows' piglets different from multiparous litters, $P<0.01$.

TABLE V

Least-squares means for physiological measures

Treatment	N[1]	PHA measure (mm)	Antibody concentrations ($\log_2$)				N	Packed red blood cell volume
			N	Colostral	N	Piglet blood[2]		
Standard crate (SC)	6	3.63	6	1.17	6	$5.39^{a,b}$	7	32.0
Turn-around crate (TC)	7	3.89	5	2.87	6	6.03^{a}	8	35.1
Outdoor heated pen (OP)	8	3.11	5	2.14	6	$5.38^{a,b}$	8	33.1
Hut on a lot (HL)	6	3.50	3	0.94	4	4.60^{b}	6	36.0
Primiparous	14	3.95	12	1.75	11	6.07^{a}	14	34.9
Multiparous	13	3.11	7	1.81	11	4.62^{b}	15	33.2
Square root of error mean square		0.80		1.82		0.92		3.39

[1]N indicates number of litters per treatment.
[2]Means within a column with different superscripts differ, $P<0.05$.

Additional physiological measures are summarized in Table V. Treatments did not significantly influence ($P>0.10$) PHA skin-test reactions (a measure of cellular immunity), packed red cell volume or colostrum antibody titers to SRBC. Treatments did significantly influence piglet blood SRBC antibody concentrations — piglets in the hut on a lot had lower ($P<0.05$) blood SRBC antibody levels than piglets in the turn-around crate. Piglets from immunized sows also had lower ($P<0.05$) blood SRBC antibody levels than piglets from gilts. Differences in piglet blood SRBC antibody levels reflect an impaired immune system which may have been caused by either environmental stress or by reduced colostrum consumption during the first hours of life (since piglets obtain these antibodies from their mother's milk).

Behavioral measures

Tables VI and VII (frequency and duration data, respectively) list results from behavioral observations. When gilts and sows were first put in the outdoor pen environment, sows and gilts showed (1) greater ($P<0.05$) frequencies of biting, chewing, rubbing or pushing fence materials, (2) greater frequencies and durations of pushing or rooting on the floor, (3) greater frequencies of standing–moving, (4) greater frequencies of turning around, (5)

TABLE VI

Average frequencies (number of occurrences per hour) for each of 19 behaviors. Environments were standard crate ((SC), turn-around crate (TC), outdoor pen (OP) and a hut on a lot (HL). The dash (-) indicates a behavior not appropriately measured in that environment

Behavior	Pre-farrowing observation						Post-farrowing observation					
	SC	TC	OP	HL	SE_p^1	$P<$	SC	TC	OP	HL	SE_p^1	$P<$
Sow stands	1.3	1.6	0.7	1.8	0.50	NS	0.6	1.2	0.7	0.2	0.21	NS
Sow lies down	2.1	2.5	1.7	2.1	0.45	NS	2.1	1.6	1.9	2.0	0.35	NS
Sow bites, chews, rubs or pushes fence or bars	3.4^a	1.3^a	12.3^b	4.5^a	2.67	0.10	1.8	7.0	2.0	2.8	2.4	NS
Sow pushes or roots ground or floor	0.9^a	1.2^a	5.4^b	2.0^a	0.85	0.01	0.8	8.5	1.2	2.8	2.42	NS
Sow standing-not moving	5.9	1.3	15.1	4.7	3.4	NS	1.3	14.1	4.0	4.7	4.30	NS
Sow standing-moving	5.9^a	1.2^a	16.9^b	$7.2^{a,b}$	3.65	0.10	0.2	4.1	3.6	7.2	1.90	NS
Sow turns body 180°	-	1.2^a	5.8^b	1.5^a	1.17	0.05	-	1.2	1.4	0.8	0.38	NS
Sow bites or pushes other sow	-	-	-	0.4	0.23	-	-	-	-	0.25	0.13	-
Sow paws ground	0	0	0	0	0	NS	0.0	0.1	0.1	0	0.05	NS
Sow interacts with other sow (non-aggressive)	-	-	-	2.2	1.02	-	-	-	-	1.7	0.46	-
Sow moves inside hut	-	-	1.1	0.3	0.28	NS	-	-	0.9	0.70	0.14	NS
Sow moves outside hut	-	-	0.5	0.2	0.20	NS	-	-	0.76^a	0.15^b	0.10	0.01
Sow touches piglets	-	-	-	-	-	NS	0.2	0.3	0.6	2.8	0.83	NS
Sow feeding	1.3	1.6	4.2	1.8	0.90	NS	1.1	3.1	2.4	1.2	0.67	NS
Sow drinking	1.0^a	$1.5^{a,b}$	4.7^b	1.7^a	0.97	0.10	0.3^a	1.7^b	1.9^b	0.7^a	0.38	0.05
>80% piglets nurse	-	-	-	-	-	-	0.8	1.3	0.5	0.8	0.42	NS
>80% piglets stop nursing	-	-	-	-	-	-	1.2	1.1	0.5	0.6	0.36	NS
>50% piglets near heat	-	-	-	-	-	-	0.2	0.8	0.4	-	0.27	NS
<50% piglets near heat	-	-	-	-	-	-	0.2	0.7	0.3	-	0.24	NS

[1]Pooled standard error of mean.

TABLE VII

Average durations (min h^{-1}) for each of 19 behaviors (see Table VI for abbreviations)

Behavior	Pre-farrowing observation						Post-farrowing observation					
	SC	TC	OP	HL	SE_p^1	$P<$	SC	TC	OP	HL	SE_p^1	$P<$
Sow stands	6.4[a]	6.8[a]	21.7[b]	10.2[a,b]	3.78	0.10	10.7	10.2	13.7	16.6	5.60	NS
Sow lays down	54.6[a]	53.2[a]	38.2[b]	46.4[a,b]	3.82	0.10	49.3	49.7	48.6	42.2	4.75	NS
Sow bites, chews, rubs or pushes fence or bars	1.7	0.9	2.5	3.4	1.27	NS	0	0.81	1.3	1.3	0.73	NS
Sow pushes or roots ground or floor	0.5[a]	0.5[a]	1.4[b]	0.1[a]	0.22	0.05	0.0	1.4	0.4	1.6	0.62	NS
Sow standing-not moving	1.6	0.9	6.0	5.1	2.26	NS	4.8	3.6	3.6	3.1	2.73	NS
Sow standing-moving	0.6	1.0	1.6	2.9	0.94	NS	0	0.9	0.9	2.5	0.75	NS
Sow turns body 180°	-	0.3	0.4	0.2	0.09	NS	-	0.1	0.1	0.1	0.39	NS
Sow bites or pushes other sow	-	-	-	0	0	-	-	-	-	0.05	0.02	NS
Sow paws ground	0	0	0	0	0	-	0.0	0.0	0.0	0.0	0.00	NS
Sow interacts with other sow (non-aggressive)	-	-	-	1.9	0.76	-	-	-	-	0.6	0.16	-
Sow moves inside hut	-	-	0.2	0.2	0.06	NS	-	-	0.2	7.7	3.35	NS
Sow moves outside hut	-	-	0.4	0.03	0.02	NS	-	-	0.0	0.1	0.02	NS
Sow touches piglets	-	-	-	-	-	-	0.2	0.3	0.6	2.8	0.8	0.10
Sow feeding	1.6[a]	2.1[a]	7.4[b]	0.3[a]	1.50	0.05	4.2	3.9	5.0	5.4	1.79	NS
Sow drinking	0.6	1.2	2.2	0.1	0.76	NS	0.7	0.3	0.8	0.4	0.31	NS
> 80% piglets nurse	-	-	-	-	-	-	10.4[a]	9.5[a]	2.1[b]	4.0[a,b]	2.12	0.10
> 80% piglets stop nursing	-	-	-	-	-	-	49.6[a]	30.4[a,b]	10.0[b]	15.1[b]	6.66	0.01
> 50% piglets near heat	-	-	-	-	-	-	11.3	8.6	2.8	-	3.98	NS
< 50% piglets near heat	-	-	-	-	-	-	13.8	11.3	5.2	-	5.10	NS

[1]Pooled standard error of mean.

TABLE VIII

Least-squares treatment means for gilts (primiparous) and sows (multiparous) showing selected behaviors

Behavior	SC		TC		OP		HL	
	Gilts	Sows	Gilts	Sows	Gilts	Sows	Gilts	Sows
Sow bites, chews, rubs, fence or bars-frequency pre-farrowing	2.00	0.58	-	1.15	7.00	4.89	0.33	4.50
Sow touches piglets-duration (min)	1.30	0.00	-	0.06	0.02	0.23	0.00	2.09

greater frequencies of drinking and (6) greater durations of feeding. The treatment by parity interaction was statistically significant for pre-farrowing frequency of biting, chewing, rubbing or pushing fence material. The treatment averages indicate that sows (who had previous experience with the standard crate) in the standard crate showed less of this behavior, while sows introduced to the other environments (which to them was novel) showed higher rates of this behavior (Table VIII). Unfortunately, behavior data were not available for gilts in the turn-around crate, although we did obtain performance and immune data for gilts in the turn-around crate. If these oral and somatic behaviors indicate an objection or a frustration by the animal relative to that environment, then we must conclude that sows returning to the familiar standard crate and the gilts moved to another dirt lot (similar to the breeding pen where they were housed) were the least frustrated. This effect was not long-term since these behaviors post-farrowing were not influenced by treatment or previous experience ($P > 0.10$).

The post-farrowing behaviors most influenced by treatments were (1) a reduced use of the hut in the most extensive treatment compared with the outside pen, (2) greater frequency of drinking in TC and OP compared with SC and HL, and (3) a greater tendency ($P < 0.10$) for sows in HL to touch their piglets more often. The interaction between parity and treatment was statistically significant ($P < 0.01$) for duration of interaction between sow and piglets. Gilts in SC interacted more with their piglets than sows. However, sows on HL interacted more with piglets. The more experienced sows may have interacted with piglets on HL more because a greater proportion of those piglets died. The sows may have tried to prevent death by encouraging piglets to move.

Correlation analyses

In total there were 106 variables measured in this study. Table IX lists the variables found to be significantly correlated with four measures of productivity. Some high correlations are obvious and do not require discussion (example: number born correlated with number born live).

Only a few immune measures were highly correlated with performance. High correlations were: (1) between piglet mortality and lymphocyte numbers ($r=0.47$, 26 df, $P<0.05$); (2) between total litter weaning weight and number of mature polymorphonuclear cells ($r=-0.45$, 25 df, $P<0.05$); (3) between total piglets born and WBC numbers ($r=-0.47$, 29 df, $P<0.01$); (4) between total piglets born and number of polymorphonuclear cells ($r=-0.72$, 26 df, $P<0.001$).

Many measures of behavior were found to be correlated with measures of productivity. Several behaviors were found to be correlated with total piglets born (example: sow bites bars and total piglets born, $r=0.73$, 19 df, $P<0.001$). Those behaviors found to be correlated with total piglets born could be used to predict productive sows. Future studies would be needed to establish if "abnormal" behaviors (such as bar biting) are actually caused by, or only shown by, the productive sows.

Correlation analysis showed a high negative correlation between sow activity (standing–moving) and number of piglets weaned ($r=0.55$, 16 df, $P<0.05$) and sow feeding and number weaned ($r=0.57$, 19 df, $P<0.01$). These correlations indicate that less active sows weaned more pigs. Also, in support of this premise, sows which stood up less often weaned more total mass of pigs ($r=0.52$, 15 df, $P<0.05$). Other measures of sow behavior were not significantly correlated with the economically important traits of pre-weaning mortality and total litter weaning weight.

DISCUSSION

Low piglet survival is a world-wide problem. English and Morrison (1984) estimate that 12–30% of live-born pigs die before weaning. Genetic selection for enhanced pre-weaning survival was unsuccessful (Lamberson and Johnson, 1984). If piglet survival rates are to improve, the farrowing environment and management procedures must be improved. In our study, management procedures were held constant, and thus observed differences were due primarily to farrowing environments. The hut on a lot treatment may have some merits during very warm summer weather in temperate climates or in a tropical environment. However, during cool or cold weather conditions, the most extensive system would be a failure from productivity and immune perspectives. Although the experiment reported here was conducted largely in the summer, the cold climate (due to high elevation) is probably more typical of spring and autumn weather in other temperate regions. The extremely poor productivity in the most extensive environment was probably due to the relatively cool temperatures and the unattended farrowings required by our experimental protocol.

Behavioral data reflected productivity measures. Correlation analyses showed a predictable relationship between increased sow feeding time and piglet survival (i.e. number weaned). Also, sow inactivity (i.e. lack of energy expenditure) was related to increased number of pigs weaned.

In terms of behavioral indices of frustration such as stereotypic bar biting and fence chewing, sows showed similar levels of these behaviors whether housed on the lot or in the outdoor pen. In fact, experienced sows showed higher levels of these oral–manipulative behaviors when placed on the lot than did gilts or sows placed in the standard farrowing crate. There is good reason to suspect that our catalog of stereotypic behaviors was too broad and our frequency of sampling too sparse to detect differences in individual stereotypic behaviors. Perhaps the detailed work of Cronin and Wiepkema (1984) could be applied to a study of farrowing environments. Such a more complete behavioral catalog and a longer sampling time may prove necessary to detect smaller differences not unveiled in this study.

Immune data indicated a moderate stress response in piglets raised in outdoor pens, although productivity of litters in the outdoor pens was similar to litters in the turn-around crate. The apparent health problem (higher WBC) among litters in the outdoor pens indicates that when disease problems occur, this may be an undesirable housing system. The measure of in vivo cellular immune function proved uninformative.

We hoped to identify measures of immune function which correlated with measures of productivity (Table IX). With this information, future studies could take fewer measurements on a greater number of litters. Colostral and especially piglet plasma antibody titers to a specific antigen (SRBC) provided useful information. Piglet SRBC antibody titers were probably related to piglet consumption of colostrum.

Total WBC data for piglets may indicate disease problems. For unknown reasons, mature polymorphonuclear (PMN) cells were negatively correlated with numbers of piglets weaned. PMN cells' relationship to piglet survival warrants further investigation.

Immune and blood measures in our study could be criticized. Piglet samples were taken at 3 days of age for antibody titer, and WBC data and cell-mediated immune measures were taken at 7 days of age. By 3 days of age, half the baby pig mortality had already occurred and, of course, no samples were taken on the piglets which died early. On the other hand, piglets which died in the first few days probably did not have time to succumb to an immune system defect or deficiency.

Only relatively smaller differences in all measures were identified between the more confining treatments (SC, TC, OP). The performance data were

TABLE IX

List of variables found to be highly correlated with measures of productivity. Abbreviations are: P = pre-farrowing behavior observation; A = post-farrowing; F = frequency; D = duration; r = correlation coefficient; N = number of litters

Total piglets born				Number piglets weaned				Pre-weaning mortality				Total litter weaning weight			
Variable	r	N	$P<$	Variable	r	N	$P<$	Variable	r	N	$P<$	Variable	r	N	$P<$
Number born live	0.84	41	0.001	Mortality	0.85	41	0.001	Litter weaning weight	0.66	39	0.001	Piglet weight gain	0.79	38	0.001
Sow bites bars A, D	0.73	20	0.001	Total litter weaning weight	0.79	39	0.001	Piglet weight gain	0.49	39	0.01	Average piglet weight	0.79	39	0.001
Mature poly-morphonuclear	−0.72	27	0.001	Number born live	0.77	41	0.001	Average piglet weaning weight	0.47	39	0.01	Sow standing P, D	−0.52	16	0.05
Sow standing-not moving P, F	0.59	19	0.01	Total piglets born	0.58	41	0.001	Lymphocytes	0.47	27	0.05	Number born live	0.50	39	0.01
Sow standing-moving P, F	0.58	20	0.01	Sow feeding A, D	0.57	20	0.01	Number still-births	−0.41	41	0.01	Mature poly-morphonuclear	−0.45	26	0.05
Sow feeding A, D	0.67	20	0.01	Sow standing-moving P, D	−0.55	17	0.05	Number born live	0.37	41	0.05				
Number weaned	0.58	41	0.001	Mature poly-morphonuclear	−0.46	27	0.05								
Piglet PCV	−0.57	30	0.01	Piglet weight gain	0.44	39	0.01								
Sow bites bars P, F	0.56	19	0.05	Number still-births	−0.39	41	0.05								
Sow pushes or roots ground or floor A, D	0.55	20	0.05												
Sow stands P, F	0.55	19	0.05												
Sow stands P, D	0.55	17	0.05												
Sow lays down P, F	−0.48	19	0.05												
WBC	−0.47	30	0.01												

similar for the three confined treatments (Table III), except that the percentage mortality was improved in the turn-around crate over the standard crate. Means for other performance measures favored the turn-around crate, but a study with larger numbers of litters is called for to verify if this effect is real. It is likely, however, that the turn-around crate results in at least productivity equal to the standard crate. In order to become adopted on commercial farms, the productivity of sows and litters in the turn-around crate must be clearly better than in the standard crate, since the turn-around crate requires more barn space (the turn-around crate occupies 21% more space than the standard crate).

Previous studies examined sow productivity in different farrowing environments. Fewer piglets were crushed in litters farrowed and housed in crates than in those in pens (Robertson et al., 1966; Devilat et al., 1971). No differences in litter productivity were found between tethered or crated sows (Lynch et al., 1984). Group-housed sows (2–5 per pen) needed less farrowing assistance, had a lower incidence of the mastitis–metritis–agalactia complex, but had similar litter productivity as tethered sows (Hansen and Vestergaard, 1984). However, we are uncertain whether the benefits of loose housing observed by Hansen and Vestergaard (1984) were due to freedom-of-movement or social interactions among sows (perhaps both).

Recent evidence suggests that providing sows more freedom of movement than a standard farrowing crate has enhanced productivity benefits. Collins and Kornegay (1985) reported fewer still-born piglets for sows farrowed in sloped-floor pens compared with conventional farrowing crates. Hansen and Curtis (1981) reported that sows stood up more often in a farrowing crate compared with an open pen. The mouth-based behaviors and the associated stress of crated sows is a suggested cause of the higher number of observed still-births. Our performance and behavior data do not support this hypothesis.

Crated sows, in our study, did not have more still-births than treatments providing greater freedom of movement. In fact, the treatment with the greatest freedom of movement (and the coolest environment) had the highest number of still-births. Infectious agents are an unlikely cause of still-births in our study because sows were housed together as a group during gestation, and hence microbial exposure was equal across treatments.

Sambraus (1985) described various types of mouth-based anomalous behaviors. Sows showing high levels of pre-farrowing mouth-based or stereotypic behaviors (chewing and rubbing fences or bars) had larger litter sizes ($r=0.73$, Table IX). Cariolet and Dantzer (1984) provide additional evidence that hypoactive sows are more common among low parity sows and may be culled due to lower productivity.

Previous work has found that second and third parity sows who showed high levels of stereotypies also had larger litters (Cronin, 1985). Sows of advanced parity who showed higher levels of stereotypes had smaller litters (Cronin,

TABLE X

Some negative and positive factors influencing the efficacy of each environment

Environment	Negative factors	Positive factors
Standard crate	High mortality	Low labor
Turn-around crate	Larger space required, slightly more labor	Highest productivity
Outdoor pen	High WBC numbers (poorer health)	Low investment
Hut on a lot	Poor productivity	Very low investment

1985). Since our study utilized primarily low parity number sows and gilts, our finding of a significant correlation between litter size and oral behaviors supports Cronin's (1985) data.

When evaluating the well-being of sows and piglets, current theories suggest that a proper evaluation of housing systems should take a multi-disciplinary approach. This study, although multi-disciplinary, did not show a simple relationship among all performance, immune and behavior measures. Rather, each environment has different negative and positive factors (see Table X). No one housing system was superior in every measure.

ACKNOWLEDGEMENTS

This work was made possible by a research grant from Humane Information Services. This research was conducted while J.J. McGlone was on faculty at the University of Wyoming and assisted by Cris Arnold-Meeks and Tom Heald. We thank Danielle Topliff and John Drezek for technical assistance. Texas Tech University College of Agriculture paper No. T-5-192 and Kansas Agricultural Experiment Station contribution No. 86-54-J.

REFERENCES

Banks, E.M., 1982. Behavioral research to answer questions about animal welfare. J. Anim. Sci., 54: 434–446.

Baxter, M.R., 1983. Ethology in environmental design for animal production. Appl. Anim. Ethol., 9: 207–220.

Blecha, F. and Kelly, K.W., 1981. Effects of cold and weaning stressors on the antibody-mediated immune response of pigs. J. Anim. Sci., 53: 439–447.

Blecha, F., Pollman, D.S. and Nichols, D.A., 1983. Weaning pigs at an early age decreases cellular immunity. J. Anim. Sci., 56: 396–400.

Cariolet, R. and Dantzer, R., 1984. Motor activity of pregnant tethered sows. Ann. Rech. Vet., 5: 257–261.

Collins, E.R. and Kornegay, E.T., 1985. Sloped-floor farrowing pens may reduce stillborn rate. Feedstuffs, 1 April, pp. 14-15.
Craig, J.V. and Adams, A.W., 1984. Behaviour and well-being of hens (*Gallus domesticus*) in alternative housing environments. World Poult. Sci. Assoc., 40: 221-240.
Cronin, G.M., 1985. The development and significance of abnormal stereotyped behaviours in tethered sows. Ph.D. Thesis, Agricultural University of Wageningen.
Cronin, G.M. and Wiepkema, P.P., 1984. An analysis of stereotyped behavior in tethered sows. Ann. Rech. Vet., 15: 263-270.
Dawkins, M., 1976. Towards an objective method of assessing welfare in domestic fowl. Appl. Anim. Ethol., 2: 245-254.
Devilat, J., Camps, J. and Skoknic, J., 1971. Farrowing crate and conventional pen for sows. J. Anim. Sci., 33: 208 (abstract).
Duncan, I., 1981. Animal rights-animal welfare: a scientists assessment. Poult. Sci., 60: 489-499.
English, P.R. and Morrison, V., 1984. Causes and prevention of piglet mortality. Pig News Inf., 5: 369-376.
Hansen, K.E. and Curtis, S.E., 1981. Prepartal activity of sows in stall or pen. J. Anim. Sci., 51: 456-460.
Hansen, L.L. and Vestergaard, K., 1984. Tethered versus loose sows: ethological observations and measures of productivity. II. Production results. Ann. Rech. Vet., 15: 185-191.
Holmes, C.W. and Close, W.H., 1977. The influence of climatic variables on energy metabolism and associated aspects of productivity in the pig. In: W. Haresign, H. Swan and D. Lewis (Editors), Nutrition and the Climatic Environment. Butterworth, London.
Lamberson, W.R. and Johnson, R.K., 1984. Preweaning survival in swine: heritability of direct and maternal effect. J. Anim. Sci., 59: 346-349.
Lynch, P.B., O'Grady, J.F. and Kearny, P.A., 1984. Effect of housing system on sow productivity. Ann. Rech. Vet., 15: 181-184.
Robertson, J.B., Laird, R., Forsyth, J.K.S., Thomson, J.M. and Walker-Love, T., 1966. A comparison of two indoor farrowing systems for sows. Anim. Prod., 8: 171-181.
Sambraus, H.H, 1985. Mouth-based anomalous syndromes. In: A.F. Fraser (Editor), Ethology of Farm Animals. Elsevier, Amsterdam.
Wood-Gush, D.G.M., 1980. Housing systems and animal welfare research requirements — a review. Anim. Reg. Stud., 2: 275-281.