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Validation of the use of exogenous gonadotropins (PG600) to increase the efficiency of gilt development programs without affecting lifetime productivity in the breeding herd[1]

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ABSTRACT: The objective of this study was to validate the use of exogenous gonadotropin (PG600) treatment for stimulating estrus in noncyclic gilts and to compare lifetime productivity of gilts recorded as having natural (NAT) versus PG600-induced (PG600) first estrus in a commercial setting. Prepubertal Camborough gilts (*n* = 4,489) were delivered to a gilt development unit (GDU) with the goal of delivering known cyclic breeding-eligible females to the sow farm (SF). A boar exposure area (BEAR) was designed to facilitate stimulation and detection of puberty by providing fence line and direct contact (15 min daily) with mature boars over an intensive 28-d period, starting at approximately d 160 (d 0). At d 14, nonpubertal gilts were mixed in new pen groups. At d 23, noncyclic "opportunity" gilts with no record of vulval development and required to meet breeding targets, were eligible for treatment with PG600 to induce puberty. Overall, 77.6% (*n* = 3,475) of gilts exhibited standing estrus (NAT = 2,654; PG600 = 821) and were eligible for shipping to the SF at approximately 35 d, and 76.6% of gilts that were administered PG600 exhibited the standing reflex within 13 d of treatment. Ultimately, 72.0% of gilts entering the GDU were delivered to the SF as breeding-eligible females. Considering the gilts delivered, a greater proportion of NAT than PG600 gilts were successfully bred ($P < 0.001$) and had better farrowing rates to first service, and overall farrowing rates (including gilts that returned to estrus and were rebred) were greater for NAT compared to PG600 gilts ($P < 0.001$) . Farrowing rates at second and third parity were similar between NAT and PG600 gilts; however, at fourth parity, a greater proportion of NAT gilts farrowed. In comparison, considering only gilts served, there was no difference ($P > 0.05$) in the proportion of NAT and PG600 gilts farrowing a third litter, but a greater proportion of NAT than PG600 gilts farrowed their fourth litter ($P < 0.001$). There was no difference between NAT and PG600 gilts for litter size at parity 1 through 4 or total pigs born over 4 parities ($P > 0.05$). A negative correlation ($P < 0.0001$) was detected between age at puberty and lifetime growth rate at puberty, and growth rate classification affected age and weight at puberty. However, retention rates and total sow productivity to parity 4 were not affected by growth rate classification at puberty.

Key words: age at puberty, gilts, PG600, sow lifetime productivity

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INTRODUCTION

Routine implementation of efficient gilt development unit (**GDU**) programs, which deliver breeding-eligible gilts to the sow farm with a recorded estrus event (heat-no-serve, **HNS**) is still lacking in the North American industry. Furthermore, a failure to select gilts with the greatest reproductive potential and inappropriate management of body condition at breeding are key risk factors for poor sow lifetime productivity (**SLP**). Limiting the time from the start of gilt stimulation to

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a recorded HNS event (30 d starting at 170 d of age) allows producers to identify earlier maturing gilts and, thus, to take advantage of the link between early sexual maturity and improved SLP (Patterson et al., 2010). Second, given the ad libitum feeding systems typical of the North American industry, a relatively aggressive cutoff age by which gilt selection is completed (200 to 210 d) reduces the risk of gilts being overweight (>170 kg) at breeding (Calderón Díaz et al., 2015) and of early culling due to locomotion problems (Williams et al., 2005; Bortolozzo et al., 2009).

The present study was funded by the National Pork Board (**NPB**; Des Moines, IA) Sow Lifetime Productivity initiative and had 2 specific goals: 1) to validate the use of exogenous gonadotropin (PG600) treatment of noncyclic "opportunity" gilts under commercial conditions as a means of routinely meeting gilts selection targets and 2) to compare the lifetime productivity of gilts with natural (**NAT**) versus PG600-induced estrus. However, a further strategic goal of this preliminary study was to establish an effective and standardized protocol for gilt selection that would facilitate planned studies to evaluate: 1) the effects of gilt nutrition and body composition and 2) litter of origin effects on SLP in ongoing projects funded under the NPB initiative. The present paper describes the successful achievement of these objectives.

MATERIALS AND METHODS

The study was conducted in accordance with existing industry Codes of Practices, and farms selected for the study were certified by the Pork Quality Assurance program of the NPB and with approval of the Faculty Animal Policy and Welfare Committee–Livestock of the University of Alberta.

Location and Source of Gilts

This study was conducted in the facilities of Holden Farms Inc. (**HFI**), Northfield, MN between November 2010 and March 2014. Data on the performance of 4,489 prepubertal Camborough (PIC L03 dams ´ PIC L02 sires) gilts (PIC Inc., Hendersonville, TN), born to multiparous sows, were recorded from approximately 160 d of age until culling or rebreeding at fourth parity.

Gilt Development and Preselection

At weaning, gilts considered to have acceptable growth performance and with no obvious anatomical or conformational problems were relocated to a single nursery that received all gilts from the production nucleus farm. Gilts were initially housed in pens of approximately 25 gilts with a floor space allowance of 0.2 m^2 per gilt until 4 to 5 wk of age and 0.25 m2 until 10 to 11 wk of age. At approximately 70 d of age, gilts were relocated to a single gilt grower/finisher barn until approximately 135 d of age and were housed in pens of 25, with a space allowance of 0.7 m2 per gilt. Every 3 wk, starting at approximately 135 d of age, a preselection process identified approximately 288 potential replacement gilts for relocation to a single off-site GDU facility. Typical recorded reasons for "non-selection" included small for age, lameness, structure, and health. Gilts were not weighed as part of the preselection process. On arrival at the GDU (Supplemental Fig. 1), gilts were housed in pen groups of 14 on partially slatted floors and provided at least 1.2 m2 floor space per gilt throughout the gilt development and puberty stimulation phases. All gilts were allowed ad libitum access to water and to diets from a single feeder with 2 feeding spaces in each pen.

Diets fed throughout the gilt development program are presented in Supplemental Table 1 and, as discussed by Calderón Díaz et al. (2015), are considered to be representative of industry norms.

Group Flows Through the Offsite GDU Facility

Each half of the GDU provided adequate penning for successive cohorts of 288 gilts for a 6-wk period. During the first 2 wk of acclimation to the GDU, routine management practices included vaccinations and unique ear tagging of gilts. A boar exposure area (**BEAR**) was located on each side of the GDU and was used for the stimulation and detection of estrus (HNS). The BEAR consisted of a row of 8 stalls in which mature boars were individually and continuously housed. No feeders were present at the front of the stalls, and waterers were located at both ends of each stall, enabling the boar to face either way. Boars were fed once per day using a removable feed bucket. The stimulation pens located on either side of the boar stalls each allowed adequate space (3.4 by 4.9 m) for effective direct contact between a single boar and a group of gilts. At all times during the study, at least 8 mature boars were used in the BEAR, and a gilt-to-boar ratio of no greater than 15:1 per side was maintained during stimulation. New boars replaced older boars on a regular basis to ensure the boars did not get too large and to maintain boar libido.

Puberty Stimulation and Estrus Detection

Assessment of Natural Pubertal Estrus. Each day, starting at approximately 160 d of age, groups of gilts were taken to the BEAR and received at least 15 min of direct exposure to a single boar as well as fence-line exposure to additional boars facing that particular stimulation

Table 1. Descriptive statistics of recorded natural (NAT) or PG600-induced (PG600) pubertal estrus in each group (GRP) of potential replacement gilts that entered the boar exposure area (BEAR) and started puberty stimulation (stim)

GRP no.	Total gilts entered	Age at stim.	Month	No. (%) gilts in NAT estrus	No. (%) gilts given PG600	No. (%) gilts given PG600 in estrus	PG600 induced of total (%)	No. (%) of gilts entered in estrus	Age	Weight (kg)	Growth Rate	No. (%) of gilts entered delivered to sow farm	No. (%) of gilts in estrus delivered to sow farm
1	285	167.8	Nov.	194 (68.1)	58 (20.4)	51 (87.9)	17.9	245 (86.0)	186.6	124.3	0.667	206 (72.3)	206 (84.1)
2	281	160.5	Dec.	148 (52.7)	52 (18.5)	40 (76.9)	14.2	188 (66.9)	178.4	120.3	0.677	177 (63.0)	177 (94.1)
3	281	160.5	Dec.	142 (50.5)	63 (22.4)	37 (58.7)	13.2	179 (63.7)	177.4	121.0	0.686	165 (58.7)	165 (92.2)
4	284	166	Jan.	170 (59.9)	72 (25.4)	57 (79.2)	20.1	227 (79.9)	184.5	123.8	0.672	213 (75.0)	213 (93.8)
5	282	157	Feb.	104 (36.9)	137 (48.6)	92 (67.2)	32.6	196 (69.5)	176.6	122.2	0.693	181 (64.6)	181 (95.3)
6	258	169.5	Mar.	170 (65.9)	79 (30.6)	62 (78.5)	24.0	232 (89.9)	187.1	119.4	0.641	194 (80.2)	194 (89.9)
7	283	165.5	Apr.	174 (61.5)	92 (32.5)	72 (78.3)	25.4	246 (86.9)	182.9	125.1	0.683	195 (73.0)	195 (84.8)
8	273	166	Apr.	155 (56.8)	94 (34.4)	65 (69.1)	23.8	220 (80.6)	184.4	123.0	0.668	198 (74.4)	198 (93.0)
9	288	161.8	May	167 (58.0)	82 (28.5)	54 (65.9)	18.8	221 (76.7)	179.0	121.2	0.679	192 (70.6)	192 (93.7)
10	269	164.8	Jun.	155 (57.6)	87 (32.3)	63 (72.4)	23.4	218 (81.0)	181.9	121.1	0.667	210 (78.1)	210 (96.3)
11	273	163.8	Jun.	200 (73.3)	31 (11.4)	23 (74.2)	8.4	223 (81.7)	176.2	117.6	0.668	197 (76.7)	197 (95.2)
12	286	165.5	Jul.	187 (65.4)	25 (8.7)	23 (92.0)	8.0	210 (73.4)	179.2	119.6	0.667	187 (69.3)	187 (96.4)
13	282	164.7	Aug.	172 (61.0)	50 (17.7)	40 (80.0)	14.2	212 (75.2)	180.5	120.7	0.670	188 (70.9)	188 (96.4)
14	277	165.4	Sep.	162 (58.5)	56 (20.2)	47 (83.9)	17.0	209 (75.5)	181.5	120.5	0.664	194 (71.9)	194 (96.0)
15	281	162.4	Sep.	212 (71.5)	57 (20.3)	48 (84.2)	17.1	249 (88.6)	179.4	125.0	0.697	221 (85.0)	221 (97.0)
16	293	164.5	Oct.	179 (52.2)	60 (20.5)	47 (78.3)	16.0	200 (68.3)	182.2	125.4	0.690	197 (67.2)	197 (98.5)
Totals	4,476	–		2,654	1,095	821	–	3,475	–	–	–	3,115	3,115
Mean		164.1		59.4	24.5	76.7	18.4	77.8	181.1	121.9	0.674	72.0	93.5

pen. Boars were used in rotation for direct stimulation of successive groups of gilts and were not permitted to breed a gilt. However, to maintain libido, boars were routinely permitted to mount a gilt in standing estrus and were "hand collected" by a technician. Physical signs of pending estrus in gilts, such as redness, degree of swelling and mucosal discharge from the vulva were recorded daily during the stimulation period using a 5-point scale (see Supplemental Fig. 2) as an aid to the successful detection of pubertal estrus. However, only the observation of a full standing estrus reflex in the presence of a boar scored 5 and was accepted as a record of a natural pubertal estrus. Regrouping of nonestrus gilts at d 14 after the start of stimulation was used as an additional stimulus for triggering a natural pubertal estrus (see Fig. 1).

PG600-Induced Estrus. If the number of gilts attaining a natural estrus by d 23 of the stimulation protocol did not meet selection targets, an i.m. injection of exogenous gonadotropins (PG600; Merck Animal Health, De Soto, KS) was used to stimulate first estrus in available opportunity noncyclic gilts that were needed to meet breeding targets. However, the use of PG600 was strictly managed, and gilts with evidence of previous ovarian activity (see Supplemental Fig. 2) but with no record of a standing estrus, were not treated with PG600. Eligible opportunity gilts were thus considered to be truly prepubertal at the time of PG600 treatment.

Intensive contact with boars in the BEAR continued until d 28, after which groups of noncyclic gilts received daily boar contact until they were either culled or recorded in estrus and shipped to the sow farm on d 35.

The weight of all gilts was recorded at natural or induced pubertal estrus. Weight was determined using either a scale or a purpose-designed and calibrated weight tape (Pasternak et al., 2008).

Gilt Movements to the Sow Farms

All females initially entered a single off-site breeding farm and were considered breeding eligible. During the present study, gilts were delivered to this sow farm every 3 wk. On arrival at the sow farm, the prebreeding protocol stipulated that all gilts be acclimated in individual gestation stalls for a minimum of 14 d before breeding. Therefore, their arrival date relative to the date of their recorded HNS event in the GDU influenced the number of days until breeding at second or third estrus, with target breeding weights of 135 to 150 kg. Gilts were full fed by preset automatic feeders and topped up individually using a feed cart depending on consumption and had ab libitum access to water. From d 18 of the estrous cycle, gilts were permitted daily (a.m.) fence-line contact with a mature boar for detection of estrus. After first detection of estrus, gilts were inseminated early p.m. on the same day and a.m. the following morning and then every 24 h for the duration of standing estrus. Each gilts insemination was performed using a standard transcervical AI catheter (Golden Pig; IMV, Maple Grove, MN) and 2.0 ´ 10^9 morphologically normal sperm pooled from Line 327

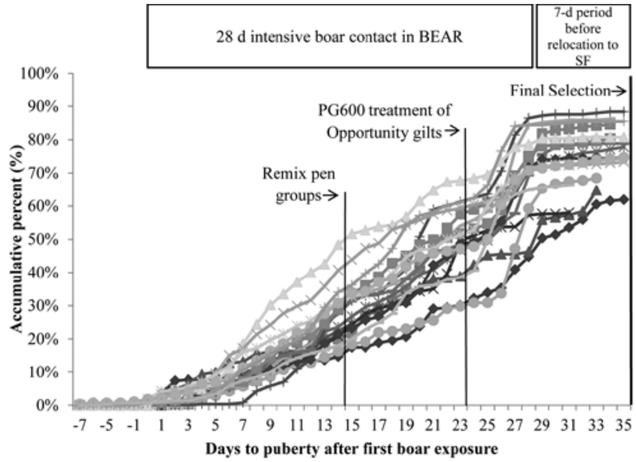

Figure 1. Accumulated percentage of gilts reaching puberty in response to daily contact as a pen group with mature boars in a boar exposure area (BEAR) starting from a pen average of 164.1 ± 3.1 d (mean ± SD) of age. At approximately 14 d after the initiation of puberty stimulation, all noncyclic females were remixed, and new pen groups were formed. At approximately 23 d after the initiation of puberty stimulation, variable numbers of known noncyclic gilts were treated with PG600 to meet breeding targets. The intensive period of boar contact in the BEAR was 28 d followed by a period of 7 d before select gilts were finally relocated to the sow farm (SF). Each line represents a cohort of approximately 288 gilts delivered to the gilt development unit (GDU). Final selection occurred at 35 d after initial exposure to the boar in the BEAR.

boars (PIC Inc., Hendersonville, TN) in 80 mL of extender. Gilts were bred with boars of proven high fertility as part of a standardized AI program at HFI (Patterson et al., 2011). All gilts and sows were allowed fence-line contact with mature boars during insemination. At least 1 to 2 d before farrowing, all gilts were transferred to the designated gilt farrowing barn. After weaning, parity 1 sows were transferred to an offsite breeding farm, and NAT and PG600 gilts were then equally distributed to one of the sites designated for older parity sows. Regardless of the farrowing site, sows were managed according to standard HFI protocols, and farm staff had no knowledge of the origin of the gilts (NAT or PG600).

Statistical Analysis

Individual gilt records included age and weight at puberty, from which growth rate at HNS was calculated. Standard herd performance data were routinely captured using Porcitec (Agritec Software, Barcelona, Spain) from 2010 to 2014 and provided the opportunity to validate any impact of PG600 use on SLP. Extensive auditing and validation of production data occurred, and several assumptions and corrections were made to the database to ensure the quality of the data analyzed. All gilts that had at least 1 d of puberty stimulation were included in the data set, and age at puberty was defined as the first day that gilts exhibited the standing reflex in the presence of a boar (HNS). The gilt stimulation protocol was considered to last 28 d, plus approximately 7 d to include the time necessary to relocate the gilts to the sow farm (see Fig. 1). Therefore, any gilt with a recorded HNS date of greater than 35 d was considered not to have exhibited a natural or PG600-induced estrus according to the established GDU protocol. Only gilts that exhibited a standing reflex within 13 d after PG600 treatment were considered to have positively responded to treatment. Sow lifetime performance data (service, reservice, farrowing, weaning dates, litter size, and culling records) were recorded by farm staff and audited before entry by the HFI data management team. Any gilt or sow with more than 2 rebreeding records (due to returns, abortions, etc.) was "artificially" culled from the data set, and the second service date and outcomes from this second breeding was included as the cull result for these females. Herd protocols stipulated that sows with lactation lengths of less than 15 d were not bred at the first detected estrus after weaning, and data from these sows were excluded from the analysis of weaning-to-estrus intervals (**WEI**). SLP data was recorded on all breeding eligible females until either removal from the sow herd or weaning after farrowing of the fourth litter, and all sows included in the final analysis met these criteria.

All analyses were performed using SAS (version 9.4; SAS Inst. Inc., Cary, NC), with the gilt or sow as the experimental unit for all variables measured. Data were checked for normality and homogeneity of variance by histograms, gplots, and formal statistical tests as part of the MIXED procedure of SAS, and these conditions were met for the data used for analysis. A mixed model (PROC MIXED) was used to analyze the effects of gilt classification (NAT or PG600) on continuous data (age at stimulation; age, weight, and growth rate at puberty; days from puberty to GDU exit; age at service; and estimated estrus at first service). Estrous cycle number at first service was estimated by calculating the number of days from recorded puberty to service and dividing this by the standard length of an estrous cycle (21 d). The model included the fixed effect of classification (NAT and PG600), and gilt group was considered a random effect. A mixed model for repeated measures (parity) was used to analyze total born and WEI. An appropriate covariance structure was selected by comparing the goodness-of-fit measures from runs that fitted different structures. Probabilities of $P < 0.05$ were considered significant. Tests of multiple comparisons of least squares means (LSMEANS) were adjusted according to the Tukey-Kramer method to ensure the overall significance at $P \leq 0.05$. Categorical data (proportion of sows bred, pregnancy rate, farrowing rate, percent served within 7 d) were analyzed separately using the generalized logit function (PROC CATMOD) of SAS. Pearson correlation coefficients (PROC CORR) were used to examine the relationships between the percentage of gilts natu-

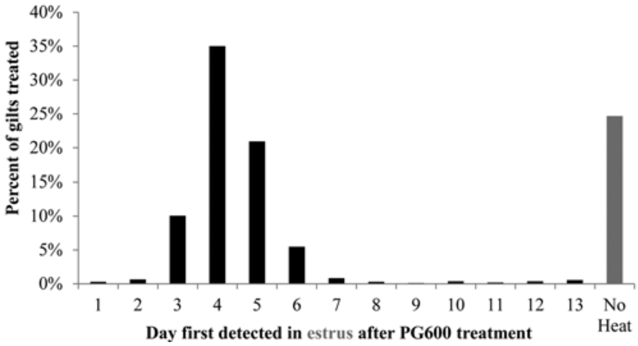

Figure 2. Distribution of the proportion of gilts attaining puberty by days in response to PG600 treatment at approximately 23 d after the initiation of puberty stimulation. Gilts that attained puberty in the presence of a boar are represented by black bars and gilts that did not reach puberty are represented by the gray bar.

Table 2. Reproductive weight and growth rate characteristics (least squares means ± SEM) of gilts with natural (NAT) and PG600-induced (PG600) estrus

Characteristic	NAT (n = 2,654)	PG600 (n = 821)	P-value
Age at stimulation, d	163.6 ± 0.8	163.4 ± 0.8	0.5365
Age at puberty, d	178.4 ± 0.9	189.8 ± 0.9	<0.0001
Days from stimulation to puberty	14.9 ± 0.3	26.4 ± 0.4	<0.0001
Weight at puberty, kg	120.5 ± 0.6	126.3 ± 0.6	<0.0001
Growth rate at puberty, kg/d	0.677 ± 0.004	0.667 ± 0.004	<0.0001
Days from puberty to GDU[1] exit, d	20.9 ± 1.7	9.4 ± 1.7	<0.0001
Age at service, d	222.6 ± 1.3	223.2 ± 1.4	0.1337
Estimated estrus at first service, d	3.1 ± 0.05	2.6 ± 0.05	<0.0001

[1]GDU = gilt development unit.

rally responding to puberty stimulation and the percentage of response to PG600 treatment and between age at puberty and growth rate to puberty.

The effect of growth rate at puberty, irrespective of puberty classification, on subsequent SLP was further evaluated by retrospectively grouping the gilts into 3 growth rate categories: <0.600, 0.600–0.750, and >0.750 kg/d. A mixed model was used to analyze the effects of growth rate on continuous data (age at stimulation; age, weight, and growth rate at puberty; and age at service). The model included the fixed effect of growth rate category, and gilt group was considered a random effect. Categorical data (proportion of sows bred, pregnancy rate, farrowing rate) were analyzed separately using the generalized logit function (PROC CATMOD) of SAS.

RESULTS

Dynamics of Pubertal Estrus Induction

Thirteen of the 4,489 available gilts were culled before the start of puberty stimulation at 164.1 d of age, and age at stimulation was similar between response groups (Table 1). Overall, 77.6% (n = 3,475) of gilts exhibited standing estrus (NAT = 2,654; PG600 = 821) within approximately 35 d of starting the puberty stimulation program (Fig. 1), but the percentage of gilts exhibiting standing estrus within a group varied from 63.7 to 89.9%. The overall percentage of gilts responding to boar stimulation and remixing with a spontaneous "natural" pubertal estrus was 59.4%, and among groups, the "natural" response ranged from 36.9 to 73.3%. As a normal management strategy, the potential shortfall in breeding-eligible gilts with a natural HNS was compensated for by treating a variable number of gilts with PG600 around d 23 (23.0 ± 1.5 SD) after the start of stimulation. Overall, 24.5 ± 9.8% of all gilts received PG600 injections (ranging from 8.7 to 48.6% of gilts among groups), and 76.6% of gilts administered PG600 exhibited the standing reflex within 13 d of treatment (Fig. 2). Among groups, the response to PG600 treatment ranged from 58.7 to 87.8%, and the percentage of gilts induced into a PG600-induced estrus (**PG**) within a group was positively correlated to the percentage of gilts responding to natural (NAT) estrus with an HNS event (PG = 0.56 ´ NAT + 0.044; R^2 = 0.34; P = 0.02).

Not all gilts with a recorded estrus were delivered to the sow farm, and recorded reasons for removal before delivery were as follows: 196 were removed for locomotion problems and poor leg scores, 17 were removed for issues such as health, injury, missing records, and death, and 138 were transferred to an alternate sow farm from which SLP data were unavailable. Ultimately, 72.0% (n = 2,374 NAT; n = 741 PG600) of gilts entering the GDU were delivered to the sow farm as breeding-eligible females with a recorded estrus.

Mean age at puberty and days to puberty were lesser (P < 0.0001) for NAT compared to PG600 gilts (Table 2). PG600 gilts were heavier at puberty detection but grew slower (P < 0.0001) compared to NAT gilts (Table 2). The timing of PG600 injection relative to the GDU exit date dictated that the days from puberty to GDU exit were fewer for PG600 gilts. Figure 3 illustrates the distribution of age at puberty attainment for NAT and PG600-induced HNS responses. PG600 gilts were older at puberty and variance in age was smaller than that of NAT gilts. All gilts without a recorded natural puberty event or those treated with PG600 and not responding within 10 d of treatment were considered "non-select" and protocol dictated that they were not transferred to the sow farm.

Breeding Success, Sow Productivity, and Retention in the Breeding Herd

Due to the shipping of gilts every 3 wk and the required 14-d crate acclimatization period, there was no

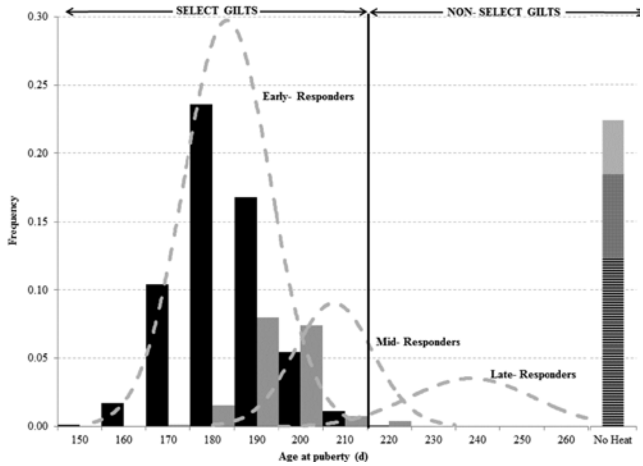

Figure 3. Distribution of age at puberty in gilts with puberty stimulation initiated at 164.1 ± 3.1 d (mean ± SD) of age for NAT (black bars) and PG600-induced (gray bars) gilts. The 3 normal populations representing early-, mid-, and late-responding gilts that were raised under optimal health and housing conditions with daily boar exposure for 100 d from 160 d, as reported by Vallet (2015), are shown by the gray dashed lines. The black line at 210 d of age indicates the proportion of gilts considered "select" gilts (77.6%; n = 3,475) of the gilts entered. Gilts that failed to exhibit their pubertal estrus or failed to respond to PG600 treatment are considered "non-select," and GDU protocol dictated that they were not relocated to the sow farm. "Non-select" gilts were classified into 1 of 3 categories: 1) known noncyclic opportunity gilts that were not treated with PG600 at around 180 d because further gilts were not needed to meet breeding targets (gray band, black horizontal stripes), 2) known noncyclic gilts that were relatively immature and unresponsive to PG600 treatment (dark gray band), and 3) Gilts that showed signs of sexual maturation (scores of 1 to 4) but did not express a standing estrus (light gray band) were not eligible to be treated as opportunity gilts.

difference in age at service (P > 0.05) between NAT and PG600 gilts, but a greater proportion of NAT than PG600 gilts were bred at third estrus (P < 0.001; Table 2, Fig. 4). The distribution of the number of days to the expected second, third, or fourth estrus was consistent with gilts maintaining a 21-d estrous cycle (Fig. 4).

Considering gilts delivered, a greater proportion of NAT than PG600 gilts were successfully served (P < 0.001; Table 3). Failure to exhibit estrus after delivery to the sow farm accounted for this difference, as a greater proportion of PG600 (3.7%) than that of NAT (1.9%) gilts was culled for failing to show estrus (P = 0.011). As a proportion of all gilts delivered to the sow farm, pregnancy and farrowing rates to first service and overall farrowing rate (including gilts that returned and were rebred) were greater for NAT than for PG600 gilts (P < 0.001; Table 3). Farrowing rate at second and third parity was similar between NAT and PG600 gilts. However, by fourth parity, a greater proportion of NAT gilts successfully farrowed.

In comparison, considering only gilts served, there was no difference (P > 0.05) in the proportion of NAT and PG600 gilts farrowing a third litter. However, a greater proportion of NAT than PG600 gilts farrowed their fourth litter (P < 0.001). There was no difference between NAT and PG600 gilts for litter size at parity 1 through 4 or

Table 3. Overall retention rates across successive parities (P) within the breeding herd of gilts with a recorded natural (NAT) or PG600-induced (PG600) estrus in the gilt development unit (GDU)

	Classification			
	NAT		PG600	
Nos. delivered to sow farm	2,374		741	
Nos. (%) served of delivered	2,318 (97.6)[a]		709 (95.7)[b]	
	Rates as % gilts delivered		Rates as % gilts bred	
	NAT	PG600	NAT	PG600
P1 pregnancy rate (first serve)	96.3[a]	93.8[b]	98.6	98.0
P1 farrowing rate (first serve)	94.7[a]	92.0[b]	97.0	96.2
P1 farrowing rate (multiple serves)	96.3[a]	94.1[b]	98.6	98.3
Farrowing rate at P2	87.6	85.0	89.7	88.9
Farrowing rate at P3	79.2	76.7	81.1	80.1
Farrowing rate at P4	70.6[a]	65.3[b]	72.3[c]	68.3[d]

[a,b]Within a row, different letters indicate significant differences in retention rate as a percent of breeding eligible gilts delivered to the sow farm (P < 0.05).

[c,d]Within a row, different letters indicate significant differences in retention rate as a percent of breeding eligible gilts served (P < 0.05).

total pigs born over 4 parities (P > 0.05; Table 4). Over their lifetime, more PG600 gilts were culled for locomotion and condition problems (P < 0.001; Fig. 5).

In parity 1, the WEI was shorter and the percentage of sows bred within 7 d was greater in NAT than in PG600 gilts (P < 0.05). There was no difference between NAT and PG600 gilts for the WEI or for the percentage of sows bred within 7 d for parity 2 or parity 3 (P > 0.05). Overall, for both NAT and PG600 gilts, WEI was longer at parity 1 than at parities 2 and 3 (P < 0.05; Table 5).

Associations Between Growth Performance, Puberty Induction, and Lifetime Productivity

A negative correlation (P < 0.0001) was detected between age at puberty and lifetime growth rate at puberty (Fig. 6). Growth rate classification affected age and weight at puberty and a greater growth rate reduced the age of gilts at first service (Table 6). However, retention rates and total sow productivity to parity 4 were not affected by growth rate classification at HNS.

DISCUSSION

Improving sow longevity and herd stability and maximizing lifetime performance in the sow herd represent significant challenges to the swine industry. Effective puberty stimulation and management options for increasing selection efficiency in the GDU are particularly important in maintaining a constant input of high-quality, breeding-

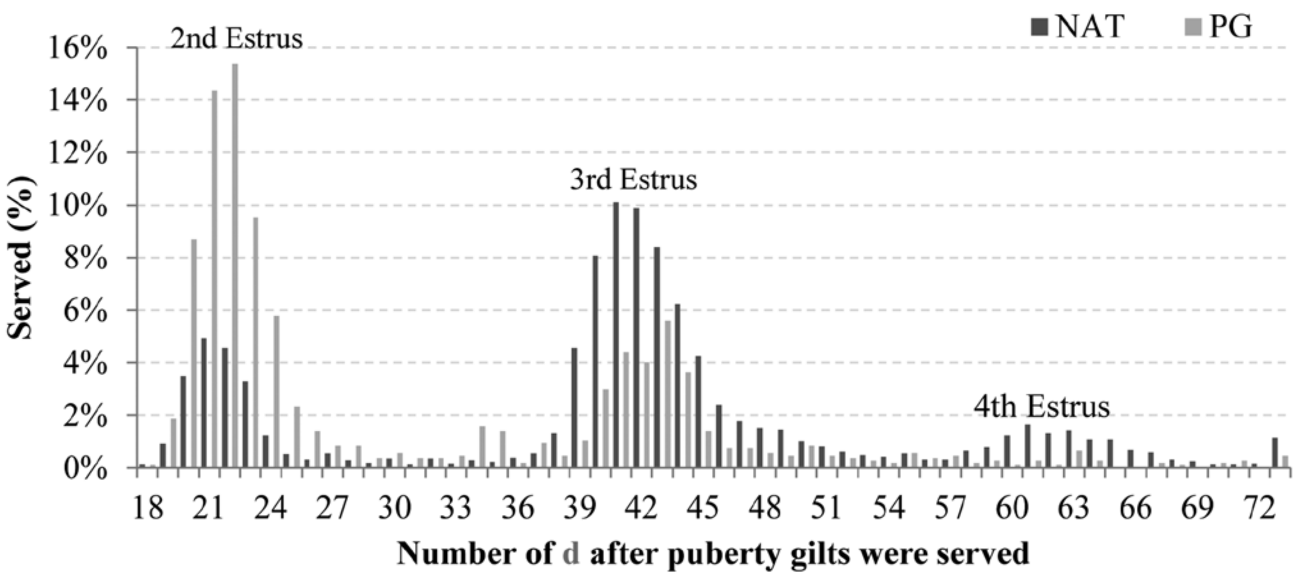

Figure 4. The distribution of estimated estrus at service for natural (NAT) and PG600-induced (PG600) gilts.

eligible gilts to the breeding herd (Foxcroft, 2015). By definition, high-quality, breeding-eligible gilts would have records of a full standing estrus reflex at puberty and acceptable physiological age (at least second estrus) and BW (135 to 150 kg) at first service. As suggested by Spörke (2006), producers should set high targets with respect to anticipated gilt performance; realistic performance targets were suggested to be a weaned to bred gilt ratio of 1.5:1, >86% farrowing rates to first service (highest in the herd), >12.5 total born in the first litter, >70% of gilts initially served farrowing a third litter, no "second parity dip" (>12.5 total born), and >50 pigs weaned per sow lifetime. Subsequently, Kummer (2008) suggested that production benchmarks include 86% of gilts selected to reach first farrowing and no more than 10% of fallout at each subsequent farrowing. Additionally, Stalder et al. (2003) stated that a gilt must remain in the herd for at least 3 parities before the initial investment in her is profitable. The GDU selection program implemented in the present study provided a pool of replacement gilts that largely met or exceeded the above expectations. This system strategically delivered 137% of bred gilt needs to ensure only select gilts, with the greatest potential for improved SLP, entered the sow farm as breeding-eligible gilts and that all non-select gilts were eligible to be shipped as market weight females. From an economic perspective, the cost and labor invested in the GDU program appeared to be justified by the high percentage of gilts served and retained beyond third parity.

The rationale for adopting more aggressive programs of gilt selection was clearly demonstrated in the recent NPB-funded study reported by Calderón Díaz et

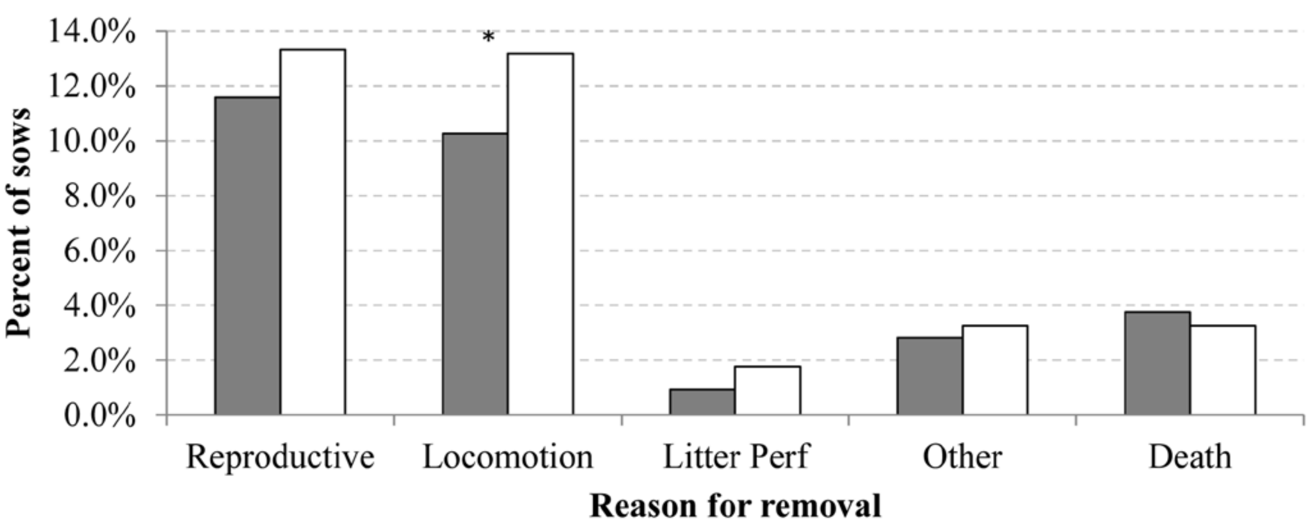

Figure 5. Reason attributed for culling from the herd ($P < 0.05$). Reproductive reasons include anestrus, conception failure, abortion, failure to farrow, and vaginal discharge. Locomotion and condition reasons include lameness, "downer syndrome," and condition. Litter and productivity reasons include retained litters, difficult farrowing, small litter size, and poor milk production. Other reasons include prolapse, injury, general health, and "lost in the system."

Table 4. Total born by parity and total pigs born over 4 parities (least squares means ± SEM) for gilts with natural (NAT) or PG600-induced (PG600) estrus in the gilt development unit (GDU) and remaining in the sow herd

	Classification[1]	
Characteristic	NAT	PG
Parity 1	13.6 ± 0.1[a]	13.6 ± 0.2[a]
No.	2,309	697
Parity 2	13.1 ± 0.1[b]	13.3 ± 0.2[ab]
No.	2,096	630
Parity 3	13.9 ± 0.1[c]	13.9 ± 0.2[ac]
No.	1,896	570
Parity 4	14.2 ± 0.1[c]	14.3 ± 0.2[c]
No.	1,701	486
Total pigs born	55.0 ± 0.4	55.4 ± 0.5

[1]Effect of classification ($P > 0.05$), parity ($P < 0.05$), and treatment ´ parity ($P > 0.05$).

[a–c]Within columns, different letters indicate difference ($P < 0.05$) in total born between parity.

Table 5. Weaning-to-estrus interval (WEI) and percent served within 7 d across successive parities in gilts initially recorded as having natural (NAT) or PG600-induced (PG600) estrus in the gilt development unit (GDU)

	Classification	
Characteristic	NAT	PG600
Parity 1		
Weaning to estrus interval, d	5.9 ± 0.1[a,x]	7.5 ± 0.3[b,x]
Percent served within 7 d	91.6 ± 0.6[a]	83.2 ± 1.5[b]
Parity 2		
Weaning to estrus interval, d	5.0 ± 0.1[y]	5.1 ± 0.2[y]
Percent served within 7 d	92.4 ± 0.6	91.4 ± 1.1
Parity 3		
Weaning to estrus interval, d	4.9 ± 0.1[y]	5.2 ± 0.2[y]
Percent served within 7 d	92.0 ± 0.6	90.4 ± 1.3

[a,b]Within a row, different letters indicate significant difference in WEI or percent served within 7 d between classification ($P < 0.001$).

[x,y]Within columns, different letters indicate significant differences in WEI within classification and between parity ($P < 0.05$).

al. (2015), in which a large cohort of potential replacement gilts was subjected to 100 d of direct boar contact from 160 to 260 d of age, at which time the reproductive status of all gilts was confirmed at slaughter. Average age at puberty was 193 d, and by 260 d more than 90% of the gilts had a recorded HNS event. However, age at puberty ranged from 160 to 265 d, and in later analyses (Vallet, 2015), the distribution of age at puberty was considered to represent 3 distinct populations of gilts (see Fig. 3). The larger majority of early responding gilts attained puberty at an average of 175 d (range of 155 to 195 d), a smaller and later maturing cohort averaged 187 d at puberty (range of 180 to 195 d), and a third very small population of late-responding gilts showing a much more delayed puberty event. These results suggest that efficient selection of naturally cyclic, breeding-eligible gilts should be possible by 200 d of age, and as in the study of Patterson et al. (2010), selection in the present study by 200 d would discriminate these gilts from a smaller cohort of late-maturing females. Comparing the NAT and PG600 response profiles in the present study to the 3 normal distributions of early-, mid-, and late-responding gilts shown in Fig. 3, it can be predicted that intervention with PG600 around 180 d of age effectively induces pubertal estrus in a proportion of the early-responding gilts and in most of the mid-responding population (Vallet, 2015).

As discussed by Calderón Díaz et al. (2015), in their study, the growth rates of gilts to 160 d were not limiting for the attainment of puberty in response to daily boar stimulation, but a considerable proportion of the gilts weighed more than 130 kg at HNS and would have been at risk of being above an upper target weight of 150 to 160 kg if they had been bred at second estrus. Bortolozzo et al. (2009) reported that overweight gilts at first breeding (>150 to 170 kg) are at an increased risk of culling due to locomotion problems. In terms of increasing the efficiency of GDU management, stimulating later maturing gilts to reach sexual maturity in response to exogenous gonadotropin treatment would shorten the GDU selection protocol (30 d vs. 100 d), still identify an HNS event in a targeted percentage of gilts in the available replacement pool, and avoid the risk of later maturing and faster growing gilts being above an upper target weight of 130 to 140 kg at puberty. An intervention approach becomes particularly critical when the proportion of gilts showing a natural HNS varies due to environmental, social, or health issues.

As shown in Fig. 3, the non-select gilts in the present study fell into 3 different categories: 1) known noncyclic opportunity gilts that were not treated with PG600 at around 180 d because further gilts were not needed to meet breeding targets (gray band, black horizontal stripes), 2) known noncyclic gilts that were relatively immature and unresponsive to PG600 treatment (dark gray band), and 3) gilts that showed signs of sexual maturation (scores of 1 to 4) but did not express a standing estrus (light gray band) and were not eligible to be treated as opportunity gilts. The small proportion (about 5%) of gilts that would have been reproductively infantile based on the results of Calderón Díaz et al. (2015) would never show a natural or PG600-induced estrus and would be split between categories 2 and 3 above. Collectively, the non-select gilts in the present study include the later maturing part of the population and gilts with abnormal reproductive characteristics. In both cases, their selection as replacement females is not consistent with optimal lifetime productivity. Patterson et al. (2010) reported that gilts known to have reached puberty

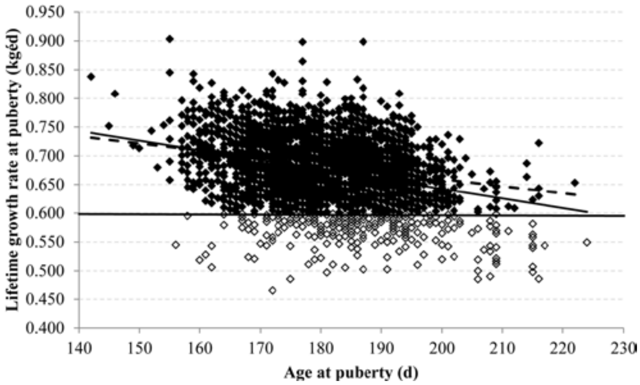

Figure 6. Relationship between average lifetime growth rate at puberty and age at puberty (n = 3,280) in gilts irrespective of classification. The dark horizontal line represents a growth rate of 0.6 kg/d below which the growth rate is reported to increase age at puberty. Age at puberty is negatively associated with lifetime growth rate at puberty (age at puberty = 221.4 − 59.6 [lifetime growth rate]; R^2 = 0.1002; P = 0.0001; solid dark line). If gilts achieving a <0.6 kg/d lifetime growth rate were removed from the analysis (open triangles), age at puberty is less associated with lifetime growth rate at puberty (age at puberty = 219.5 − 56.9 (lifetime growth rate); R_2 = 0.0704; P = 0.0001; broken dark line).

Table 6. Associations between growth performance, puberty induction, and lifetime productivity in gilts initially recorded with growth rates of <0.600, 0.600 to 0.750, or >0.750 kg/d at puberty in the gilt development unit (GDU)

Growth rate group	<0.600	0.600–0.750	>0.750
No.	285	2,729	266
Puberty			
Age, d	186.4 ± 0.9[a]	181.0 ± 0.8[b]	174.8 ± 1.0[c]
Growth rate, kg/d	0.571 ± 0.003[a]	0.675 ± 0.002[b]	0.775 ± 0.003[c]
Weight, kg	106.9 ± 0.7[a]	122.1 ± 0.5[b]	135.4 ± 0.7[c]
Service			
Age, d	228.1 ± 1.4[a]	222.5 ± 1.3[b]	219.0 ± 1.4[c]
Retention rate of delivered			
Served, %	96.7 ± 1.1	97.3 ± 0.3	96.5 ± 1.1
Farrow to first service, %	93.4 ± 1.6	94.2 ± 0.5	92.6 ± 1.6
Farrow parity 2, %	88.1 ± 2.1	87.1 ± 0.7	84.9 ± 2.2
Farrow parity 3, %	76.5 ± 2.7	79.0 ± 0.8	77.2 ± 2.6
Farrow parity 4, %	70.0 ± 2.9	69.7 ± 0.9	67.6 ± 2.9
Total born			
Parity 1	13.7 ± 0.2	13.6 ± 0.1	13.7 ± 0.2
Parity 2	12.9 ± 0.2	13.2 ± 0.1	13.3 ± 0.2
Parity 3	13.9 ± 0.2	13.9 ± 0.1	13.6 ± 0.3
Parity 4	14.2 ± 0.2	14.2 ± 0.1	14.1 ± 0.3

[a–c]Within a row, different letters indicate significant difference in growth rate group (P < 0.05).

within 40 d after the start of boar exposure provided an advantage in terms of the percentage of animals served, retention rate, and reduced physical body size at mating, compared to those that were nonpubertal when moved to the sow farm. Earlier, Sterning et al. (1998) reported that later maturing gilts (oldest one-third) had longer WEI as sows compared to gilts expressing an early puberty (youngest one-third). It has also been reported that the maximal strength of the standing reflex was positively correlated with the proportion of gilts that farrowed (Knauer et al., 2012), although relationships between the strength of the standing reflex and age at puberty were not reported. In future studies, it will be beneficial to determine relationships between age at puberty and the strength of the standing reflex using the standardized GDU protocol reported here and to link these traits back to the sow and litter from which the gilt originated.

The use of a BEAR was effective in the stimulation and detection of puberty in gilts in the present study. The BEAR maximized the components of the "boar effect" known to be effective in the stimulation of puberty (Siswadi and Hughes, 1995). There was full physical contact between the boar and the pen of gilts, a gilt to boar ratio of <15:1, and fence-line contact with additional boars during the daily stimulation periods. When inadequate estrus detection technology is employed, there is a high incidence of failure to detect puberty, and sexually mature gilts may be unknowingly culled (Stancic et al., 2011). Additionally, for gilts not recorded as HNS by d 14 after the start of stimulation with boars, a remixing "stress" was induced by repenning noncyclic gilts in the GDU and, thus, mimicking the "transport stress" effect reported in earlier literature (Einarsson et al., 2008). However, even with this optimized stimulation protocol in place, large differences in the accumulated percentage of naturally induced estrus were observed in the successive cohorts of gilts studied. Between-group variation in percentage of gilts exhibiting puberty can be due to a number of factors including age, growth rate, season, health, and unknown litter of origin effects. Based on previous experience in commercial GDU systems, this variation was expected.

Given the variation in the natural HNS response, PG600 treatment of a variable number of opportunity gilts was an integral part of the GDU program implemented in the present study and was an effective tool for inducing pubertal estrus in these gilts. Overall, 73.1% of gilts exhibited the standing reflex within 10 d of PG600 treatment, and normal subsequent cyclicity was observed. These results are consistent with past research, where PG600 was effective in inducing 60 to 70% of females into estrus and 70 to 80% to cycle within 6 d of treatment, as reviewed by Knox et al. (2015). Bartlett et al. (2009) reported that the days to puberty detection decreased, and the proportion of gilts expressing estrus increased when PG600 was used in conjunction with boar contact to induce a HNS event. The success of PG600 in inducing ovulation and estrus can be improved if PG600 treatment is targeted at nonpubertal gilts (Martinat-Botté et al., 2011). In the current study, the use of extensive daily records of reproductive status ensured that PG600 was only given to known noncyclic females in conjunction with ongoing daily direct boar contact in the BEAR. Delaying PG600 treatment to d 23 of the stimulation protocol avoids the possibility that gilts achieving their pubertal estrus before the start of the stimulation program would not be recorded in second estrus before intervening with PG600 treatment. Further, by preventing the treatment of gilts with previous records of initial vulval development, soliciting, and proceptive behaviors toward the boar (scores of 1 to 4 in the system shown in Supplemental Fig. 2) but with an absence of full standing estrus, the treatment of gilts that are cycling but showing "silent" estrus is avoided. The established relationship between the proportion of all gilts in a cohort responding with natural HNS and the proportion of PG600-treated gilts showing a hormone-induced HNS event suggests that the same underlying physiological mechanisms are affecting the sensitivity of the hypothalamo-hypophysial-ovarian (**HHO**) axis to both endogenous endocrine responses triggered by boar pheromones and social stress and to exogenous gonadotropin treatment. From a practical perspective, this association suggests that the present GDU protocol could be further refined by adjusting the number of gilts treated with PG600 to reflect the natural HNS response measured in a particular cohort of gilts entering the GDU.

The large-scale study of Calderón Díaz et al. (2015) suggested that gilts with lifetime growth rates of <0.6 kg/d were at risk of having increased age at first estrus, which is consistent with the growth limitation of 0.55 kg/d suggested by the more intensive study of Beltranena et al. (1993). The present study was conducted in a commercial setting, and a range of factors, including the litter of origin and the health status of gilts during development, would have affected growth rate measured at pubertal estrus. Approximately 7.5% of gilts had growth rates of <0.6 kg/d, and the data in Fig. 6 again suggest that a low growth rate would have affected the proportion of gilts able to express an early HNS event. However, the overall weight and growth rate data for the successive cohorts of gilts recruited into this study (see Table 1) suggest that growth rate was not a major factor explaining group-to-group differences in the HNS response. Indeed, the analysis presented in Table 6 suggests that as long as gilts had a recorded HNS event within the constraints of the 35-d protocol implemented, and were bred by third estrus, their subsequent lifetime performance in the herd was not compromised.

The GDU protocol implemented in the present study dictates that gilts must have at least 1 recorded estrus in the GDU before being considered breeding eligible and being delivered to the sow farm. The effectiveness of this gilt selection protocol is reflected in the fact that 97.6 and 95.8% of NAT and PG600 gilts, respectively, delivered were served, and 96.3 and 93.9%, respectively, farrowed to a first service, considerably exceeding the performance targets suggested by Spörke (2006) and Kummer (2008). Although significantly more NAT than PG600 gilts were served and more PG600 gilts were removed for reproductive reasons and failure to show a subsequent estrus at the sow farm, the overall lifetime performance of even the PG600 gilts also exceeded the benchmarks suggested by Spörke (2006) and Kummer (2008). The strict PG600 induction protocol applied also appears to have avoided the reported risk that PG600-treated gilts may fail to maintain normal subsequent estrus cyclicity (Paterson, 1982; Bartlett et al., 2009) and conflicting results suggesting an increased risk of cystic follicles due to PG600 treatment (Tilton et al., 1995; Knox et al., 2000).

The observation that PG600 gilts had a longer WEI after weaning their first litter and that a smaller percentage of these weaned parity 1 sows were in estrus within 7 d after weaning, is consistent with the earlier report of Sterning et al. (1998), given that PG600 gilts were also slower growing and later maturing than NAT gilts in the present study. This seems to reflect intrinsic differences in the rate of sexual maturation and sensitivity of the HHO axis to exogenous gonadotropic stimulation at induced puberty and associated differences in the HHO response to the endocrine changes triggered by weaning the first litter. If these are repeatable traits, it will again be important in ongoing studies to link these traits back to the sow and litter of origin. Furthermore, in commercial practice, these differences suggest that special attention should be paid to optimizing the stimulation and estrus checking protocols in first parity sows after PG600 induction of pubertal estrus.

Overall, we conclude that PG600 is an essential tool for implementing standardized GDU protocols that efficiently deliver predictable numbers of high-quality breeding-eligible gilts to the sow herd. The minimal differences in lifetime productivity between NAT and PG600 gilts was offset by the minimal number of gilt nonproductive days accumulated and the excellent overall retention of gilts in the breeding herd. From the perspective of ongoing NPB-sponsored trials on factors affecting SLP, the present experiment established the key components of a standardized GDU selection protocol that can be applied in multiple locations under commercial conditions. Despite the excellent results reported here in the existing HFI system, further gains in GDU efficiency and prebreeding management are achievable through the weekly shipping of breeding-eligible gilts to the sow farm. Although this change could increase health risks due to the weekly entry of new gilts, it will shorten the entry-to-service interval and will result in more gilts being bred at second estrus and a greater proportion of gilts being bred within the target weight range of 135 to 150 kg. More consistent induction of a natural HNS event is also considered possible and will involve the modified management of gilts during an extended prestimulation period in the GDU, linked to an older average age at the start of the stimulation protocol. Both modifications to the existing protocol have been implemented, and responses to these changes are being quantified as part of an ongoing study of litter of origin effects on SLP.

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