Published November 24, 2014

Impact of pig insemination technique and semen preparation on profitability[1]

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ABSTRACT: Artificial insemination technique and semen preparation impact boar utilization efficiency, genetic dissemination, and biosecurity. Intrauterine (IUI) and deep intrauterine (DUI) AI techniques require lower number of spermatozoa per dose compared to conventional (CON) AI. Frozen semen (FRO) has been associated with lower reproductive performance compared to fresh semen (FRE) preparation. The combined effects of 3 AI techniques (CON, IUI, and DUI) and 2 semen preparations (FRE and FRO) on the financial indicators of a pig crossbreeding system were studied. A 3-tier system was simulated in ZPLAN and the genetic improvement in a representative scenario was characterized. The cross of nucleus lines B and A generated 200,000 BA sows at the multiplier level. The BA sows were inseminated (CON, IUI, or DUI) with FRE or FRO from line C boars at the commercial level. Semen preparation and AI technique were represented by distinct sow:boar ratios in the C × BA cross. A range of farrowing rates (60 to 90%) and litter sizes (8 to 14 liveborn pigs) were tested. Genetic improvement per year for number born alive, adjusted 21-d litter weight, days to 113.5 kg, backfat, and ADG were 0.01 pigs per litter, 0.06 kg, –0.09 d, –0.29 mm, and 0.88 g, respectively. On average, the net profit for FRE (FRO) increased (*P*-value < 0.0001) from CON to IUI and DUI by 2.2 (3.2%) and 2.6% (4%), respectively. The differences in profit between techniques were driven by differences in costs. Differences in fixed costs between IUI and DUI relative to CON were –2.4 (–5.2%) and –3.4% (–7.4%), respectively. The differences in total costs between FRE and FRO were lower than –5%. The difference in variable costs between FRE and FRO ranged from –5.3 (CON) to –24.7% (DUI). Overall, insemination technique and semen preparation had a nonlinear effect on profit. The average relative difference in profit between FRE and FRO was less than 3% for the scenarios studied.

Key words: intrauterine insemination, deep uterine insemination, fresh semen, frozen semen, simulation, net profit

J. Anim. Sci. 2014.92:72–84
doi:10.2527/jas2013-6836

INTRODUCTION

The use of frozen–thawed boar semen (**FRO**) in AI could augment the genetic progress, reduce biosecurity hazards, reduce the cost of boar maintenance, and enable the creation of gene banks relative to fresh semen (**FRE**) preparation (Knox, 2011). These advantages could be overshadowed by the lower viable spermatozoa, average farrowing rate (**FR**; between 35 and 85%), and litter size (**LS**) of FRO relative to FRE observed in some studies (Almlid et al., 1987; Eriksson et al., 2002; Roca et al., 2003; Bolarin et al., 2006, 2009; Wongtawan et al., 2006). Other studies have reported nonsignificant differences in LS between FRO and FRE (Eriksson et al., 2002; Roca et al., 2003; Bathgate et al., 2008). Reservations about the fecundity and limited expertise on effective FRO preparation has resulted in widespread use of FRE. Artificial insemination with FRE is used in the 31 major pork producing countries and 11 of them breed more than 90% of the sows with this technique (Riesenbeck, 2011).

Intrauterine (**IUI**) and deep intrauterine (**DUI**) insemination techniques that deposit sperm closer to the oviduct relative to conventional (**CON**) AI augment the fecundity of boar semen (Roca et al., 2006; Vazquez et al., 2008). Most studies have evaluated boar semen preparation or AI techniques and focused on reproductive indicators (Eriksson et al., 2002; Day et al., 2003; Roca et al., 2003). A comprehensive evaluation of the potential interaction between AI technique and semen prepara-

[1]The authors acknowledge the assistance of U. Wünsch and discussions with N.V.L. Serão. This study was supported by USDA AFRI NIFA project no. 2010–85122–20620 and USDA NIFA ILLU project no. 2012–38420–30209.

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Received June 27, 2013.
Accepted November 7, 2013.

tion on the profit of pig production systems is needed. The main objective of this study was to characterize the simultaneous impact of boar semen preparation (FRE and FRO) and insemination technique (CON, IUI, and DUI) used at the commercial level of the production system on financial indicators. Supporting aims include the simulation of a 3-tier system under a comprehensive range of productive and reproductive circumstances, consideration of realistic biological and financial scenarios, characterization of the genetic change on a representative scenario, and evaluation of complementary financial indicators.

MATERIALS AND METHODS

The simultaneous impact of boar semen preparation (FRE and FRO) and AI technology (CON, IUI, and DUI) on the financial indicators of a system were studied. The comparison of the preparation–technique combinations (FRE–CON, FRE–IUI, FRE–DUI, FRO–CON, FRO–IUI, and FRO–DUI) on the financial indicators was implemented using ZPLAN (Willam et al., 2008). This software supports the assessment of financial and genetic progress in a deterministic framework using selection indexes and gene flow methodology.

A 3-tier, 3-way crossbreeding scheme was simulated and the selection objective encompassed 9 traits that were weighted differently across selection groups. The 3-tier classic pyramid system included 1) a nucleus level containing 500 sows for each of the 3 lines, maternal lines A and B selected for reproductive traits and paternal line C selected for growth-carcass traits, 2) a multiplier level that generates F_1 sows from B boars and A sows, and 3) a commercial level that sells pigs obtained from the cross between BA sows and C boars. The mating scheme resulted in a transmission matrix including 16 selection groups (Table 1; Wünsch et al., 1999). Each nucleus line population had 4 selection groups (boars to produce boars, boars to produce sows, sows to produce boars, and sows to produce sows) totaling 12 (3 × 4) groups. Nucleus A and B pigs produced selection groups 13 and 14, respectively. Nucleus C produced selection group 15 boars. Sows and boars from groups 13 and 14 were mated to produce group 16 (F_1 BA sows). The impact of semen preparation and insemination technique was tested on the service of group 16 sows by group 15 boars. Group 16 sows were artificially inseminated (using CON, IUI, or DUI techniques) with boar C group 15 semen (prepared using FRO or FRE) and generated the market pigs that were sold for profit (Table 1).

Selection Criteria

In this study, genetic selection does not interact with semen preparation and insemination technique because the latter ones are applied in the third tier of the system. Nevertheless, genetic selection impacts the overall financial indicators of the system and is hereby described. Two types of traits, growth-carcass (hereby denoted as growth traits) and reproductive traits, were considered in the selection indices. Growth traits included days to 113.5 kg (**D113**), backfat (**BF**), ADG, feed efficiency (**FE**), and lean carcass percent (**LEAN**). The ADG and D113 were included in the index because ADG encompasses the period between 27 and 113 kg weight while D113 encompasses the days between birth and 113 kg weight. Reproductive traits included number of pigs born alive (**NBA**), litter birth weight (**LBW**), adjusted 21-d litter weight (**A21**), and number at 21 d (**N21**). The maternal lines are usually line crosses to exploit the heterosis of the reproductive traits that typically have lower heritability (Bidanel, 2011).

Table 2 lists the traits included in the selection indices and economic values (US$ per unit), phenotypic standard deviations, heritabilities, and genetic and phenotypic correlations (NSIF, 2002). Seven selection indices were created using this information and records from the pig, ancestors (boar, sow, paternal boar, paternal sow, maternal boar, and maternal sow), and half-sibs. The 7 indices were applied to generate replacement boars and sows in each of the 3 nucleus groups and to generate multiplier sows BA inseminated with line C [2 indices (male and female) × 3 nucleus + 1 terminal level = 7].

The relative economic weight for each trait in the selection indices was the product of the economic value by the standard discount expression (**SDE**) to adjust for interest rate across time, expressed relative to the genetic

Table 1. Transmission matrix denoting the relationship between the 16 pig population groups in the simulated 3-tier, 3-line crossbreed production system

		Maternal lines				Paternal line		F_1
		A		B		C		BA
Group		Boars	Sows	Boars	Sows	Boars	Sows	Sows
Nucleus line A	Boars	1	2					
	Sows	3	4					
Nucleus line B	Boars			5	6			
	Sows			7	8			
Nucleus line C	Boars					9	10	
	Sows					11	12	
Multiplier	Sows		13[1]	14[2]				
Commercial						15[3]		16[4]

[1]Sows in group 13 were obtained from the cross among line A boars and sows (groups 1, 2, 3, and 4).

[2]Boars in group 14 were obtained from the cross among line B boars and sows (groups 5, 6, 7, and 8).

[3]Boars in group 15 were obtained from the cross among line C boars and sows (groups 9, 10, 11, and 12).

[4]Sows in group 16 were obtained from the cross among groups 13 sows and group 14 boars. The sows in group 16 are inseminated with fresh or frozen semen from boars in group 15, using conventional, intrauterine, or deep intrauterine techniques to produce pigs for the market.

Table 2. Economic values (EV), h^2, phenotypic standard deviations (σ_p), and genetic (above diagonal) and phenotypic (below diagonal) correlations of the 9 traits included in the selection indices applied to the nucleus and multiplier stages (NSIF, 2002)

	Parameter			Correlation								
Traits[1]	EV, $	h^2	σ_p	NBA	LBW	A21	N21	D113	BF	FE	ADG	LEAN
NBA	13.50	0.10	2.50	*1.00*	0.63	0.12	0.80	0.20	0	0	0	0
LBW	0.45	0.29	7.20	0.80	*1.00*	0.50	0.67	0	0	0	0	0
A21	0.50	0.15	16.00	0.20	0.66	*1.00*	0.60	0	0	0	0	0
N21	6.00	0.06	2.35	0.60	0.70	0.6	*1.00*	0	0	0	0	0
D113	0.12	0.30	13.00	0.10	0	0	0	*1.00*	0	0.60	–0.70	0.10
BF	15.00	0.40	0.20	0	0.10	0	0	–0.18	*1.00*	0.33	0.14	0.70
FE	13.00	0.30	0.25	0	0	0	0	0.50	0.25	*1.00*	–0.70	0.40
ADG	6.00	0.30	0.20	0	0.20	0	0	–0.50	0.20	–0.65	*1.00*	0.20
LEAN	1.10	0.48	1.50	0	0	0	0	0.10	0.70	0.30	0.10	*1.00*

[1]NBA = number born alive (pigs/litter); LBW = litter birth weight (kg); A21 = adjusted 21-d litter weight (kg); N21 = number of pigs per litter at 21 days (pigs/litter); D113 = days for pig to reach 113.5 kg (d); BF = backfat (mm); FE = feed efficiency (kg/kg); LEAN = lean carcass (%).

standard deviation of each trait (Wünsch et al., 1999). One round of selection (selection only based on parental and half-sib information) was used and therefore the effects of inbreeding, lower genetic variation due to selection, and return from breeding product sales were assumed negligible (Willam et al., 2008).

Biological and Technological Input Parameters

The biological, technological, and financial input parameters used in the simulation were based on a literature review (Tables 3 and 4). Sow stayability was kept constant during the period studied and ranged from 1 (nucleus sows) to 3 yr (commercial sows) and involuntary culling annual rate was approximately 32% (Rodriguez-Zas et al., 2003, 2006; Knox et al., 2008, 2013). For comparison purposes and set barn capacity, all scenarios were simulated to result in 225,000 farrowings at the commercial level every 6 mo and a profit horizon of 10 yr (Weller, 1994). This farrowing number adjusted by the 2.25 expected farrowings per year (2.25/2) correspond to 200,000 sows per cycle. For the set farrowing target, the number of sows in the multiplier and commercial levels varied depending on the FR and LS scenario simulated. In addition to the number of sows, the boar utilization varied across scenarios through the sow:boar ratio. The fixed cost per 6 mo (also referred to as semester in this study) of labor for the previously described production system was estimated to be approximately $7.8 million. This cost resulted from multiplying the number of sows (200,000) by the hourly labor wage ($15) by the hours of labor per week (40 h) and by the number of weeks of labor in a semester (26 wk) and dividing this total by the sow:worker ratio (400). The fixed costs also included insurance cost (1% of the building and equipment costs) and maintenance and repair cost (2.5% of the building and equipment costs). Published building and equipment costs were assumed (Dhuyvetter et al., 2009). The following example demonstrates the calculation of the building and equipment costs. Consider a nucleus herd including 1,500 sows. The herd was divided into 2 groups assuming that at any one time 15% of the sows are farrowing and therefore assigned to the farrowing building and the remaining 85% of the sows are in the gestation building. The building and equipment costs per sow were $2,508 and $1,150, respectively, in the farrowing building and $600 and $235, respectively, in the gestation building. Therefore, the total building and equipment costs (220 × 2,508 + 220 × 1,150 + 1,280 × 600 + 1,280 ×235) amount to $1,837,560. Insurance and maintenance costs were applied to the result of the previous calculation.

The variable costs per sow comprised the cost associated with the reproductive technique and other variables costs directly related to performance and pedigree records at the nucleus level. The variable costs associated with reproductive technique included standard catheter cost and labor time and wage listed in Table 4. The variable costs related to performance included $3 per production measurement and $5 per reproduction measurement (Levis et al., 2001; Martinez et al., 2010; Wünsch et al., 1999).

The differences in reproductive efficiency between FRE and FRO and among CON, IUI, and DUI were simulated through differences in the sow:boar ratio (Table 4). For the calculations, an average of 80 to 120 billion sperm cells per collection value was assumed (Bidanel, 2011). Distinct sperm counts for each of the 3 AI techniques evaluated were 3×10^9 sperm per dose for CON, 1×10^9 sperm per dose for IUI, and 0.150×10^9 sperm per dose for DUI, and 2.1 semen doses per estrus, 2.25 farrowings per year, and 50 collections per boar per year were assumed (Table 4; Levis et al., 2001; Roca et al., 2006; Safranski, 2008). This strategy permitted the evaluation of the same range of FR and LS among preparation (FRE and FRO) and AI technology (CON, IUI, and DUI).

Table 3. Biological, technological, and financial input values used in the simulation

Variables	Input
Nucleus size (sows)	500
Involuntary culling	32%
Boar:sow ratio (1st tier)	30
Boar:sow ratio (3rd tier)	Variable (Table 4)
Offspring reared (maternal lines A and B)	9.5
Offspring reared (paternal line C)	8.5
Offspring reared (multiplier sows BA)	10
Productive life of sows (1st pyramid tier)	1 yr
Productive life of sows (2nd pyramid tier)	2 yr
Productive life of sows (3rd pyramid tier)	3 yr
Productive life of boars (1st pyramid tier)	1 yr
Productive life of boars (2nd pyramid tier)	1 yr
Productive life of boars (3rd pyramid tier)	1 yr
Age of sows at the first litter	11 mo
Age of boars at the first litter	12 mo
Investment period	10 yr
Interest ratio for returns	3%
Interest rate for costs	2%
Fixed cost per semester of labor	$7,800,000
Insurances cost	$18,735.60
Maintenance and repair cost	$46,839.00
Cost associated with the reproduction technology	Variable (Table 4)
Cost of boar keeping (fresh semen preparation) per day	$ 0.75

Financial Input Parameters and System Outputs

A summary of the input values used in the simulation was listed in Tables 3 and 4 (Rodriguez-Zas et al., 2003, 2006; Knox et al., 2008, 2013; Dhuyvetter et al., 2009). A FRO:FRE costs ratio equal to 3 was considered based on standard catheter cost, labor cost, and labor time (Levis et al., 2001; Martinez et al., 2010). A demonstration of the computation in Table 4 is provided for FR = 90% and a sow:boar ratio = 258:1 resulting in $12.04 per sow. Assuming 2.1 doses of semen used per estrus and 2.25 farrowings per sow and year, then the number of doses used in a year would be 4.725. Assuming 27 doses were produced per ejaculate and 50 ejaculates per boar and year, then a boar annually produces 1,350 doses. From these numbers, the number of sows needed per boar for a FR = 90% is (1,350/4.725) × 0.9 = 257.14. Therefore, 258 sows per boar would be needed. Assuming 2.25 farrowings per year (1.125 per 6 mo), 225,000/1.125 = 200,000 farrowing sows would be required every 6 mo. These sows, at a FR = 90%, will require 222,222.22 inseminations. Furthermore, assuming the costs of $0.17 per catheter, $10 per insemination labor hour, 4 min per insemination event, and $10 per processed semen, then the total cost would be (0.17 × 222,222.22) + {[(222,222.22 × 4)/60] × 10} + (222,222.22 × 10) = $2,408,148.15. Lastly, 2,408,148.15/222,222.22 = $12.04 per semester and sow.

The impact of preparation and insemination technique on financial outputs was evaluated. Financial outputs included net profit, gross return, and total costs (fixed costs and variables costs; Nitter et al., 1994; Wünsch et al., 1999; Willam et al., 2008). Briefly, profit was return minus cost and return was the monetary value of the sow over the time of investment and therefore was adjusted for the profit horizon using SDE. Total costs included variable and fixed costs that are dependent and independent of the size of the operation, respectively. For example, variable costs related to performance and pedigree recording, and fixed costs included overhead cost to maintain the breeding program (Wünsch et al., 1999).

Analysis of Financial Impact and Sensitivity Analysis

A representative scenario was defined. Artificial insemination using FRE preparation and CON technique is the most common practice in pig industry and was used in an estimated 60% of swine breed herds in the United States in 2000 (Knox, 2000). A large scale survey found that 90% of all the hand-mated sows were artificially inseminated (USDA, 2007). Under these conditions the median LS was approximately 10 liveborn pigs per litter and the average FR in the United States was estimated at 82.7% (Knox et al., 2013; PigCHAMP, 2011). Therefore, the representative scenario in this study was characterized by the FRE–CON combination, a LS of 10 liveborn pigs per litter, and a FR of 85%.

The genetic improvement along the 3-tier system was evaluated for a representative scenario. The genetic progress at the nucleus and multiplier levels was unaffected by semen preparation or insemination technique because these practices were tested solely on the production of market pigs at the commercial level. The study of the impact of the preparation–techniques at the commercial third tier of the system enabled the profiling of the financial trends without confounding with genetic changes throughout the nucleus and multiplier tiers. In the first stage of the study the genetic improvement and financial indicators were estimated for the representative scenario across all tiers. Subsequent stages evaluated the impact of the 6 preparation–technique combinations on the financial indicators.

A sensitivity analysis was implemented based on the evaluation of a grid of FR ranging from 60 to 90% (by 5%) and LS ranging from 8 to 14 liveborn pigs per litter (1 pig increments). Under these boundaries, the worst scenario was characterized by a FR equal to 60% and a LS equal to 8 liveborn pigs per litter and the best scenario was characterized by FR equal to 90% and LS equal to 14 liveborn pigs per litter. An average FR equal to 75% and LS equal to 11 liveborn pigs per litter were considered and variation within symmetric upper and lower bounds

Table 4. Input biological (sow:boar ratio) and financial (cost, $/sow) parameters for the 2 semen preparations and 3 insemination technologies used at the third-tier commercial level of the production system across selected farrowing rates

	Semen preparation[1]					
	FRE			FRO		
	Techniques[2]			Techniques[2]		
Farrowing rate, %	CON AI	IUI AI	DUI AI	CON AI	IUI AI	DUI AI
90	258 (12.04)	772 (13.47)	5,143 (24.44)	115 (34.26)	343 (35.69)	2,286 (46.67)
80	229 (13.55)	686 (15.15)	4,572 (27.50)	102 (38.55)	305 (40.15)	2,032 (52.50)
70	200 (15.48)	600 (17.32)	4,000 (31.43)	89 (44.05)	267 (45.89)	1,778 (60.00)
60	172 (18.06)	515 (20.21)	3,429 (36.67)	77 (51.39)	229 (53.54)	1,524 (70.00)

[1]FRE = fresh semen preparation; FRO = frozen semen preparation.

[2]CON = conventional; IUI = intrauterine; DUI = deep intrauterine.

was evaluated. Realistic upper boundaries were considered to ensure that the study will remain relevant in the short term. Farrowing rate above 85% and LS equal to 14 had been frequently reported for several years (Love et al., 1995; Young et al., 2010; Klindt, 2003).

The financial outputs from the simulation were analyzed using the model

$$y_{ijkl} = \mu + P_i + T_j + PT_{ij} + \beta_1\left(F_{ijk} - \bar{F}\right) + \beta_2\left(F_{ijk} - \bar{F}\right)^2 + \beta_3\left(L_{ijkl} - \bar{L}\right) + \beta_4\left(L_{ijkl} - \bar{L}\right)^2 + \varepsilon_{ijkl},$$

in which y_{ijkl} denoted the value of net profit, gross return, total costs, fixed costs, variable costs, or sows population size, μ is the overall mean, P_i denoted the fixed effect of preparation type with 2 levels (FRE and FRO), T_j denoted the fixed effect of the insemination technique with 3 levels (CON, IUI, and DUI), PT_{ij} denoted the interaction between preparation and insemination technique, β_1 and β_2 denoted the regression coefficients for the covariate FR (F; 60 to 90%) linear and quadratic, respectively, β_3 and β_4 denoted the regression coefficients for the covariate LS (L; 8 to 14 pigs per litter), respectively, and ε_{ijkl} denoted the residual associated with y_{ijkl}. Analysis was implemented using the MIXED procedure of SAS (SAS Institute, Cary, NC). Orthogonal contrasts among the preparation by technique interaction levels were evaluated and Scheffé multiple comparison adjustments were used (Kuehl, 2000). The preparation and technique trends within the interaction were tested using the SLICE option in the GLM procedure (SAS Institute, Cary, NC). The evaluation of the impact of semen preparation on various indicators was expressed in relative difference terms. Relative difference was defined as the difference in the indicator between FRE and FRO relative to the recorded maximum value between FRE and FRO. The use of a relative value enabled the assessment of the impact protected from specific absolute values, and the use of observed maximum value supported a conservative calculation.

RESULTS AND DISCUSSION

Genetic and Financial Trends Using Fresh Conventional Insemination on a Representative Scenario

In the first stage of the study the genetic improvement and financial indicators were evaluated for the representative scenario characterized by the FRE–CON preparation–technique combination for FR equal to 85% and LS equal to 10 pigs per litter (Table 5). This information offered a characterization of the simulated system unaffected by the semen preparation or AI technique used at the commercial tier.

The genetic gain for the reproductive traits (NBA, LBW, A21, and N21) was similar between the maternal lines A and B selected for reproductive traits and higher than line C. The relative gain of the average of A and B relative to C (calculated as average the (A,B) – C/maximum [average (A,B),C]) for NBA, LBW, A21, and N2 were 85, 82, 99, and 77%, respectively. On the other hand, the genetic gain in the paternal line C selected for growth traits (D113, BF, FE, ADG, and LEAN) was higher than for the average of lines A and B. The relative gain of C relative to the average of A and B or D113, BF, FE, ADG, and LEAN was 141, 75, 93, 134, and 118%, respectively.

The genetic trends observed in the simulated representative scenario (Table 5) were consistent with previously reported (Wünsch et al., 1999). The reported genetic trends for D113, BF, NBA, A21, and number of pigs weaned in Yorkshire, Duroc, Hampshire, and Landrace were –0.40 d, –0.39 mm, 0.018 pigs per litter, 0.114 kg, and 0.004 pigs, respectively (Chen et al., 2002, 2003). The estimated annual genetic trends for ADG, FE, and carcass average BF thickness in French Large White pigs were 3.7 g/d, –0.014 kg/kg, and –0.35 mm, respectively (Tribout et al., 2010). The annual genetic trend for European pig breeding programs for daily gain, lean meat percent, and LS were 20 g/d, 0.5%, and 0.2 pigs per litter, respectively (Merks, 2000).

Table 6 summarizes the discounted economic values and associated relative economic weights per trait and

Table 5. Genetic gain per year for various biological and financial indicators, generation interval, return, cost, and profit for the fresh semen (FRE) preparation and conventional (CON) insemination technique on a representative scenario

Parameter	Unit	Nucleus lines			Total
		Genetic gain per year			
Traits[1]		A	B	C	
NBA	pigs/litter	0.02	0.02	0.003	
LBW	kg	0.13	0.13	0.02	
A21	kg	0.09	0.09	0.001	
N21	pigs/litter	0.01	0.01	0.003	
D113	d	0.54	0.67	–1.49	
BF	mm	–0.17	–0.12	–0.57	
FE	kg/kg	0.0004	0.0002	0.004	
ADG	g	–2.31	–3.08	8.03	
LEAN	%	–0.02	–0.03	0.14	
Mean generation interval	yr	1.17	1.17	1.17	
Monetary genetic gain per year	$	11.36	11.30	3.04	
Return for single trait					
NBA	$	16.80	9.72	0.002	26.52
LBW	$	8.33	4.88	0.03	13.24
A21	$	5.97	3.72	0.01	9.70
N21	$	4.96	2.87	0.02	7.85
D113	$	–0.26	–0.12	1.11	0.73
BF	$	0.45	0.14	2.10	2.69
FE	$	0.04	–0.02	0.60	0.62
ADG	$	–0.23	–0.11	1.11	0.77
LEAN	$	–0.08	–0.06	0.93	0.79
Return total, $/sow	$	35.98	21.02	5.91	62.91
Return, %	%	57.19	33.41	9.39	
Cost total, $/sow	$				20.32
Profit, $/sow	$				42.59

[1]NBA = number born alive; LBW = litter birth weight; A21 = adjusted 21-d litter weight; N21 = number at 21 days; D113 = days for pig to 113.5 kg; BF = backfat; FE = feed efficiency; LEAN = lean carcass.

Table 6. Discounted economic values and relative economic weights of traits used in the selection indices applied to the maternal (A and B) and paternal (C) nucleus lines

	Discounted economic values, $/sow			Relative economic weights , %		
	Nucleus line			Nucleus line		
Traits[1]	A	B	C	A	B	C
NBA	8.792	5.015	0.159	29.389	36.847	0.311
LBW	0.293	0.167	0.005	0.980	1.228	0.010
A21	0.326	0.186	0.006	1.088	1.365	0.012
N21	3.908	2.229	0.071	13.062	16.376	0.138
D113	0.057	0.020	0.173	0.189	0.151	0.339
BF	7.069	2.561	21.630	23.629	18.818	42.389
FE	6.126	2.220	18.746	20.479	16.309	36.737
ADG	2.828	1.025	8.652	9.452	7.527	16.956
LEAN	0.518	0.188	1.586	1.733	1.380	3.109

[1]NBA = number born alive; LBW = litter birth weight; A21 = adjusted 21-d litter weight; N21 = number at 21 days; D113 = days for pig to 113.5 kg; BF = backfat; FE = feed efficiency; LEAN = lean carcass.

nucleus line. These values were applied to the nucleus lines and thus apply all the scenarios simulated. Consistent with the genetic progress, the weight of NBA were higher in the maternal lines A and B with values of 29.3 and 36.8%, respectively. For the paternal line, the relative economic weights were less than 1% for the reproductive traits and ranged from 3.1 to 42.4% for the growth traits (BF, FE, and ADG).

The monetary value of the genetic gain was $11.36, $11.30, and $3.04 for the lines A, B, and C, respectively (Table 5). The difference in genetic gain between lines was due to the higher economic weight assigned to reproductive traits based on the lower expected heritabilities of these traits and impact of additional sold pigs resulting from reproductive trait improvement. The maternal lines A and B contributed the 57.19 and 33.41% and the paternal line C contributed 9.39% of the total return. The highest contribution of line A that produced BA sows was due to the direct selection of the sows and their replacement for the reproductive traits whereas only males were indirectly selected in line B to produce boars of BA sows. In a previous simulation study, the growth and carcass traits contributed more to the return than the reproductive traits and the boar line had higher monetary gain (Wünsch et al., 1999). The differences between studies can be attributed to the single round of selection simulated in the present study compared to the 2-stage selection in the boar line including information from crossbred offspring in the previous study. The single round of selection used in this study used only progenitor and half-sib information to select offspring.

Impact of Semen Preparation and Insemination Techniques on Financial Indicators

The second phase of the study evaluated the impact of FRE–CON, FRE–IUI, FRE–DUI, FRO–CON, FRO–IUI, and FRO–DUI preparation–techniques on the financial indicators. Sensitivity analysis of the different preparation–technique combinations across FR and LS levels permitted the contextualization of the results. The study of the impact of the preparation–techniques at the commercial third tier of the system enabled the profiling of the financial trends without confounding with genetic changes in the first and second tiers.

The *P*-values of the main effects of semen preparation, insemination technique, and their interaction on profit, return, total costs, fixed costs, variable costs, and sow population size were summarized in Table 7. Minimum statistical and financial thresholds were used to identify significant differences on biological and financial indicators across preparation–technique combina-

Table 7. Impact (*P*-value) of semen preparation, insemination technique, farrowing rate, and litter size on the output financial indicators

	Effect[1]						
Indicator[2]	P	T	PT	F	FF	L	LL
Profit	<0.0001	<0.0001	<0.0001	<0.0001	<0.0601	<0.0001	<0.0511
Return	<0.0001	<0.0001	<0.0001	0.0116	0.1568	<0.0001	<0.0601
Total costs	<0.0001	<0.0001	<0.0001	<0.0001	<0.0711	<0.0001	0.9227
Fixed costs	<0.0001	<0.0001	<0.0001	0.0051	0.0666	<0.0001	0.9101
Variable cost	<0.0001	<0.0001	<0.0001	<0.0001	<0.0591	0.4538	0.9849
Population size	<0.0001	<0.0001	<0.0001	0.0067	0.7213	<0.0001	<0.0001

[1]P = semen preparation type (fresh semen or frozen semen); T = insemination technique (conventional, intrauterine, or deep intrauterine); PT = interaction between preparation and technique; F = linear trend on farrowing rate; FF = quadratic trend on farrowing rate; L = linear trend on litter size; LL = quadratic trend on litter size.

[2]Profit, return, total cost, fixed cost, and variable cost expressed in $/sow; population size expressed in number of sows.

tions. A stringent *P*-value threshold (*P*-value < 0.005) was used for the multiple testing across financial indicators. The minimum threshold for indicating a financially significant difference was set at 2%, equivalent to the average interest rate of Treasury Notes (U.S. Department of the Treasury, 2013). The interaction between preparation and technique had a significant impact on all the financial indicators considered across the FR and LS levels evaluated. No quadratic association between FR level and the financial indicators was observed. No linear or quadratic association between LS level and variable costs and no quadratic association with the other financial indicators except for sow population size was observed.

The outputs of the simulation, including financial indicator and sow population size estimates (least square means), grouped by preparation–technique were summarized in Table 8. Across the FR and LS levels studied, the indicators differed across preparation–technique combinations. Sow population size exhibited an interesting pattern across preparations and techniques. The numbers of sows in the FRO–DUI, FRE–DUI, and FRE–IUI scenarios were similar. This result can be explained by the effect of the insemination technique on the reproductive efficiency and thus the sow population size. Fewer boars were needed to serve the same amount of sows using IUI and DUI relative to CON and therefore fewer sow replacements were needed to produce these boars, resulting in a lower sow population size. The impact of semen preparation and insemination technique on sow population size was first investigated due to the major role on all financial indicators.

Impact of Semen Preparation and Insemination Technique in Sow Population Size

The relative differences in sow population size across insemination techniques within preparation failed to surpass the 2% threshold (Table 8). Within FRE preparation, the highest sow population size was observed with the CON technique. However, higher FR and LS were associated with less difference between CON and the other techniques; therefore, with FR equal to 90% and LS equal to 14 pigs per litter, fewer sows were needed compared with CON in the worst scenario. Within FRO, the trends across insemination techniques were similar to FRE. In the worst FR–LS reproductive scenario, CON had highest sow population size (1.35% higher than IUI and 1.92% higher than DUI) and in the best FR–LS reproductive scenario, CON had a lowest difference relative to the other techniques (0.94% higher than IUI and 1.33% higher than DUI for

Table 8. Absolute and relative comparison of the output biological and financial indicators across semen preparation and insemination techniques

Indicator	Insemination technique[1]	Semen preparation[2] FRE	FRO	SE	RD,[3] %
Population size (sows)	CON	236,293.88[c]	238,512.25[d]	159.61	–0.93
	IUI	235,106.12[b]	235,853.06[bc]	159.61	–0.32
	DUI	234,587.76[a]	234,710.20[ab]	159.61	–0.05
Profit, $/sow	CON	42.78[b]	41.55[a]	0.02	2.88
	IUI	43.75[e]	42.92[c]	0.02	1.9
	DUI	43.90[f]	43.27[d]	0.02	1.44
Return, $/sow	CON	63.05[b]	62.76[a]	0.003	0.46
	IUI	63.26[d]	63.13[c]	0.003	0.21
	DUI	63.37[f]	63.34[e]	0.003	0.05
Total costs, $/sow	CON	20.28[d]	21.21[e]	0.01	–4.38
	IUI	19.51[a]	20.21[c]	0.01	–3.46
	DUI	19.46[a]	20.07[b]	0.01	–3.04
Variable costs, $/sow	CON	1.92[c]	2.03[e]	0.01	–5.42
	IUI	1.61[a]	2.02[d]	0.01	–20.30
	DUI	1.75[b]	2.32[f]	0.01	–24.57
Fixed costs, $/sow	CON	18.35[d]	19.18[e]	0.01	–4.33
	IUI	17.91[b]	18.19[c]	0.01	–1.54
	DUI	17.72[a]	17.76[a]	0.01	–0.23

[a–f]Means within an indicator (across the 6 preparation–insemination techniques levels) with different superscript differ within row (*P*-values < 0.001).

[1]CON = conventional; IUI = intrauterine; DUI = deep intrauterine.

[2]FRE = fresh semen; FRO = frozen semen.

[3]RD = relative differences in columns between FRE and FRO (FRE – FRO/maximum ([FRE, FRO]).

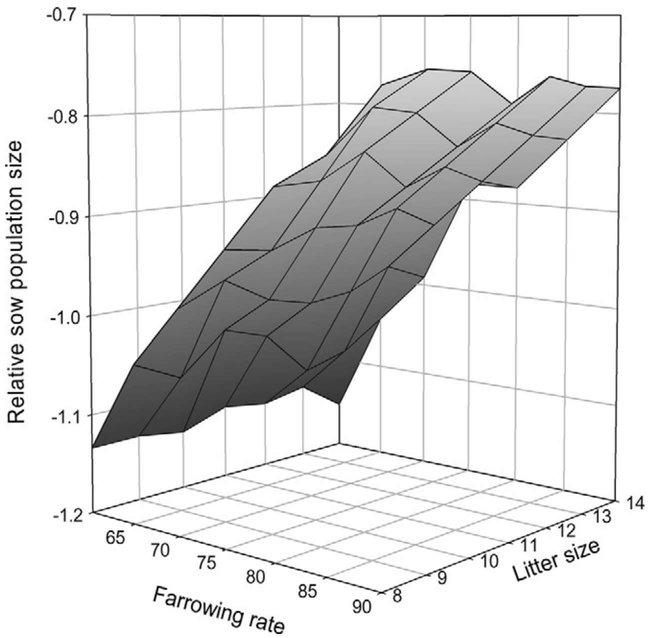

Figure 1. Relative difference between fresh (FRE) and frozen (FRO) semen preparation (FRE – FRO)/maximum ([FRE, FRO]) in sow population size for the conventional insemination technique across farrowing rate (%) and litter size (pigs/litter) levels.

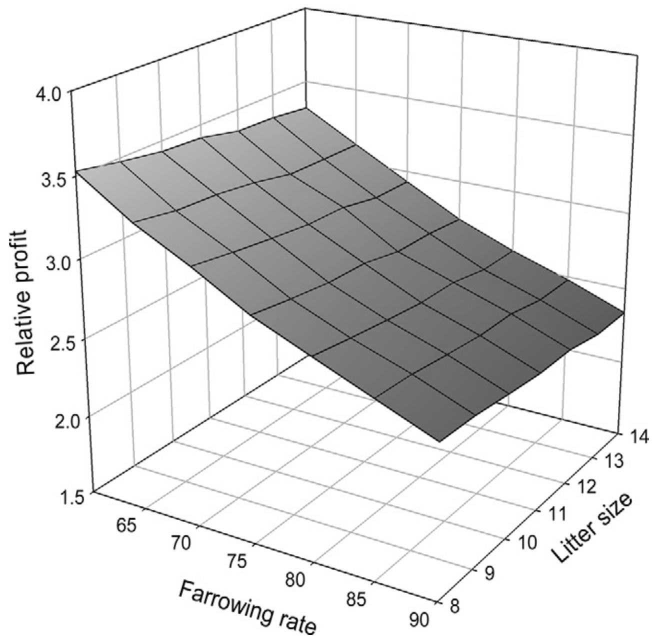

Figure 2. Relative difference between fresh (FRE) and frozen (FRO) semen preparation (FRE – FRO)/maximum ([FRE, FRO]) in net profit for the conventional (CON) insemination technique across farrowing rate (%) and litter size (pigs/litter) levels.

the best scenario). Therefore, fewer sows were needed in IUI and DUI than in CON. The relative differences in sow population size between FRE and FRO were –1.13% for CON, –0.38% for IUI, and –0.06% for DUI in the worst reproductive scenario. Also, the relative differences between FRE and FRO in sow population size were –0.77% for CON (Fig. 1), –0.28% for IUI, and –0.06% for DUI in the best reproductive scenario. The lower sow population required by FRE relative to FRO was due to the lower number of doses obtained from an ejaculate for FRO and to the higher number of boar and therefore semen doses required to serve the higher number of sows (Roca et al., 2006). The boar spermatozoa are sensitive to cryopreservation and usually no more than 50% of the spermatozoa in the ejaculate survive the cryopreservation process.

Impact of Semen Preparation and Insemination Technique in Net Profit

The relative difference in net profit (expressed in $ per sow) between FRE and FRO was 2.88% for CON and lower than the 2% financial threshold for IUI and DUI (Table 8). The higher difference in net profit between FRE and FRO under CON was due to the higher population size required to achieve similar outputs. Within FRE (FRO), CON had 2.22% (3.19%) lower profit than IUI and 2.55% (3.98%) lower profit than DUI (Table 8). The relative differences in profit between FRE and FRO were 3.53% for CON, 2.48% for IUI, and 1.85% for DUI in the worst FR–LS reproductive scenarios. Also, the relative differences in profit between FRE and FRO were 2.34% for CON (Fig. 2), 1.55% for IUI, and 1.15% for DUI in the best reproductive scenario.

The net profit increased more than 2% from CON to IUI and to DUI and these increments were slightly less than 2% higher in FRE than in FRO (Table 8). The average net profit across FR and LS scenarios in FRE (FRO) increased from CON to IUI and DUI by 2.22 (3.19%) and 2.55% (3.98%), respectively. The profit per sow and farrowing cycle for FRE across FR and LS scenarios ranged from $40.81 to $44.47 for CON, $41.99 to $45.27 for IUI, and $42.17 to $45.4 for DUI techniques. Likewise, the profit per sow for FRO across FR and LS scenarios ranged from $39.37 to $43.43 for CON, $40.95 to $44.57 for IUI, and $41.39 to $44.88 for DUI techniques. These results demonstrate that the impact of insemination technique on net profit was higher in FRO than in FRE. Both FRE and FRO had the lowest profit in the worst reproductive scenario and the higher profit in the best reproductive scenario.

The DUI technique had the highest net profit regardless of preparation. The profit of DUI relative to CON for FRE (FRO) ranged from 3.23% (4.88%) in the worst reproductive scenario to 2.05% (3.23%) in the best scenario, respectively. In general, IUI resulted in higher profit than CON regardless of preparation. The profit for FRE (FRO) semen preparation associated with IUI relative to CON ranged from 2.81% (3.86%) in the worst reproductive scenario to 1.77%

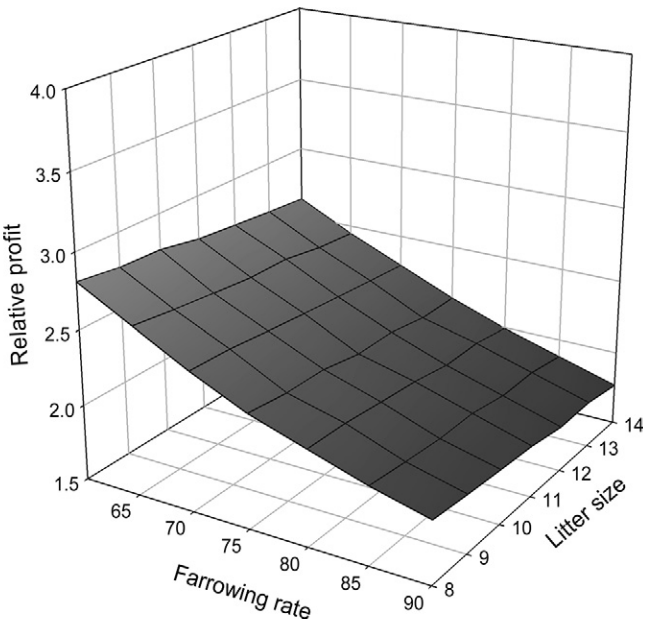

Figure 3. Relative difference between intrauterine (IUI) and conventional (CON) insemination technique (IUI – CON)/maximum ([IUI, CON]) in net profit for fresh semen preparation across farrowing rate (%) and litter size (pigs/litter) levels.

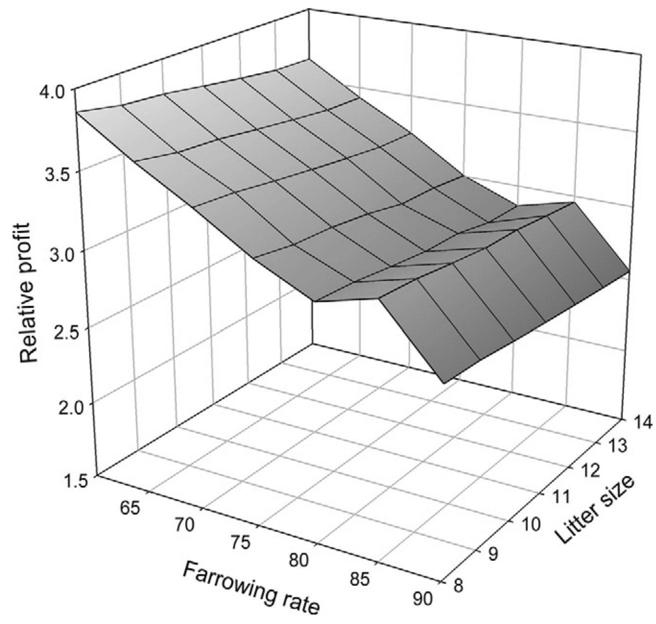

Figure 4. Relative difference between intrauterine (IUI) and conventional (CON) insemination technique (IUI – CON)/maximum ([IUI, CON]) in net profit for frozen semen preparation across farrowing rate (%) and litter size (pigs/litter) levels.

(2.56%) in the best scenario, respectively (Fig. 3 and Fig. 4 for FRE and FRO, respectively). The higher benefit of IUI relative to the CON technique for FRO preparation could be linked to the smaller dose required by the first technique that accommodates the lower spermatozoa counts obtained by FRO relative to the FRE preparation.

Net profit is an indicator that combines 2 other financial indicators, return and total costs (Nitter et al., 1994). A careful study of the differences between preparation and insemination techniques within profit components was undertaken to better understand the overall differences in profit.

Impact of Semen Preparation and Insemination Technique in Gross Return

The relative differences in gross return (expressed in $ per sow) between FRE and FRO within insemination technique were low (less than 1%) and did not surpass the 2% threshold (Table 8). These results suggest that the differences in profit between preparations and techniques were driven by differences in costs. A detailed analysis of total, fixed, and variable costs was undertaken. The average return for FRE (FRO) across FR and LS scenarios increased from CON to IUI and DUI by 0.33 (0.59%) and 0.50% (0.92%), respectively. These findings imply that the impact of insemination technique on return was higher in FRO than in FRE. Both FRE and FRO had the lowest return in the worst scenario and the higher return in the best scenario.

Impact of Semen Preparation and Insemination Technique on Total Costs

The relative differences in total costs (expressed in $ per sow) between FRE and FRO surpassed the 2% financial threshold in all three CON, IUI, and DUI techniques (Table 8). The relative differences in total costs between FRE and FRO were –4.98% for CON (Fig. 5), –4.09% for IUI, and –3.55% for DUI in the worst FR–LS reproductive scenario. Also, the relative differences in total costs between FRE and FRO were –3.84% for CON (Fig. 5), –3.02% for IUI, and –2.62% for DUI in the best reproductive scenario.

The average total costs in FRE (FRO) across FR and LS scenarios decreased from CON to IUI and DUI by 3.8 (4.71%) and 4.04% (5.37%), respectively. The total cost for FRE ($ per sow) across FR and LS scenarios ranged from $21.35 to $19.27 for CON, $20.42 to $18.64 for IUI, and $20.36 to $18.6 for DUI techniques. Likewise, the total cost for FRO ($ per sow) across FR and LS scenarios ranged from $22.47 to $20.04 for CON, $21.29 to $19.22 for IUI, and $21.11 to $19.1 for DUI techniques. Across insemination techniques, the cost of FRE was lower than FRO. Both FRE and FRO had the highest total costs in the worst reproductive scenario and the lowest total costs in the best reproductive scenario. The higher total costs associated with the lower FR were due to the higher number of inseminations per pregnancy needed to have similar number of output market pigs. This in turn leads to a higher required investment in materials, labor, and semen.

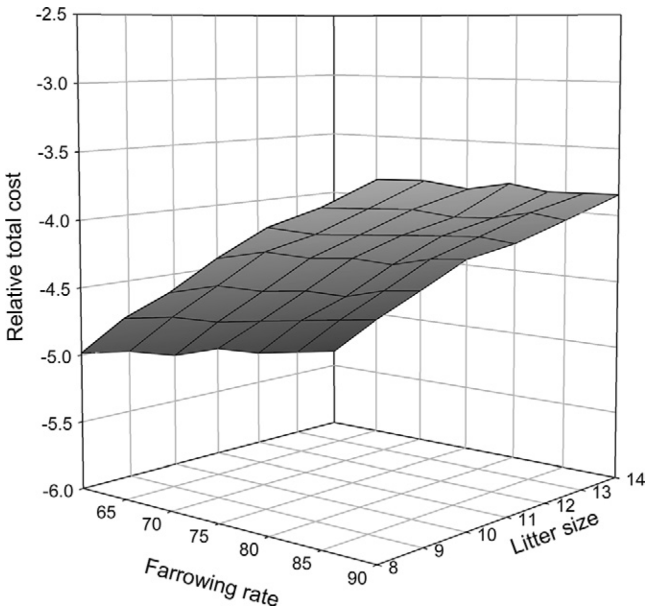

Figure 5. Relative difference between fresh (FRE) and frozen (FRO) semen preparation (FRE – FRO)/maximum ([FRE, FRO]) in total costs for the conventional insemination technique across farrowing rate (%) and litter size (pigs/litter) levels.

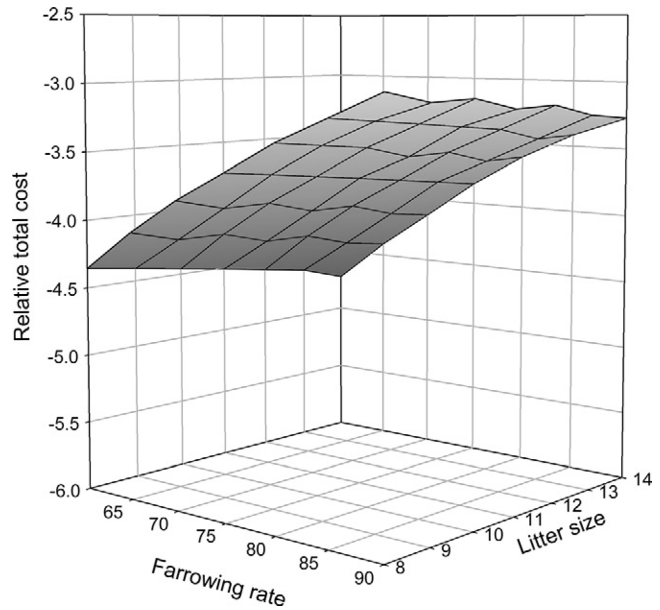

Figure 6. Relative difference between intrauterine (IUI) and conventional (CON) insemination technique (IUI – CON)/maximum ([IUI, CON]) in total costs for fresh semen preparation across farrowing rate (%) and litter size (pigs/litter) levels.

The DUI technique had the lowest total costs regardless of preparation. The total costs of DUI relative to CON using FRE (FRO) was –4.64% (–6.05%) in the worst reproductive scenario and –3.48% (–4.69%) in the best reproductive scenario, respectively. The total costs of IUI were lower than CON regardless of preparation. The total cost of IUI relative to CON using FRE was –4.36% (Fig. 6) and using FRO was –5.25% (Fig. 7) in the worst reproductive scenario and –3.27% (Fig. 6) and using FRO was –4.09% (Fig. 7) in the best reproductive scenario, respectively.

The majority of the indicators studied follow a constant trend. The local oscillations observed in some trends such as the one depicted in Fig. 1 are the result of the individual simulation of the corresponding particular scenario. An unexpected drop (approximately 7%) in the total cost difference between IUI and CON was observed at 85% FR (Fig. 7). The overall trend of lower total costs in IUI relative to CON was maintained; however, the tendency for lower differences in costs between the techniques with higher FR was not observed at 85% FR. The reason for this small oscillation was a slightly higher change in the denominator (total cost for CON) than the numerator (total cost difference between IUI and CON) that caused the relative indicator to dip.

The fixed costs were linearly correlated to the number of individuals in the breeding program and variable costs were defined in each selection group (Sitzenstock et al., 2013). Therefore, both fixed and variable costs were expected to be distinctly affected by preparation and insemination technologies considered. Also, the higher differences in return and total costs between FRE and FRO in CON relative to IUI and DUI can be understood by profiling the fixed and variable costs. An investigation on the impact of preparation and insemination technique on the 2 components of the total, variable, and fixed costs was undertaken.

Impact of Semen Preparation and Insemination Technique in the Variable Costs

The relative differences in variable costs (expressed in $ per sow) between FRE and FRO within insemination technique were –5.42% for CON, –20.30% for IUI, and –24.57% for DUI and were more extreme than the 2% financial threshold (Table 8). The relative differences in variable costs between FRE and FRO preparations were –5.88% for CON, –23.87% for IUI, and –27.63% for DUI in the worst reproductive scenarios. Also, the relative differences in variable costs between FRE and FRO were –4.73% for CON, –18.94% for IUI, and –22.07% for DUI in the best reproductive scenario. The substantial increase in variable cost differences between FRE and FRO from CON to IUI and DUI is due to the requirements of the techniques in catheter costs, labor costs, and labor time. These differences in variable costs do not translate into total costs due to the relative higher impact of fixed costs.

The average variable costs in FRE across FR and LS scenarios decreased from CON to IUI and DUI by 16.38 and 9.15%, respectively. However, the average variable costs in FRO decreased from CON to IUI by

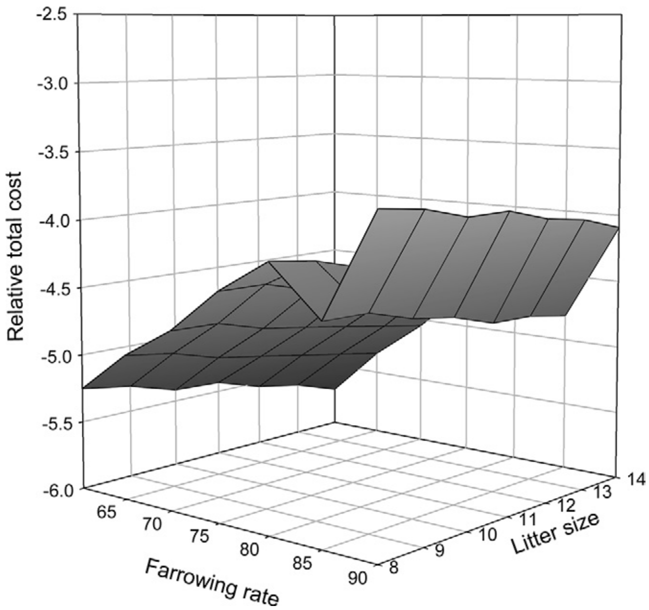

Figure 7. Relative difference between intrauterine (IUI) and conventional (CON) insemination technique (IUI – CON)/maximum ([IUI, CON]) in total costs for frozen semen preparation across farrowing rate (%) and litter size (pigs/litter) levels.

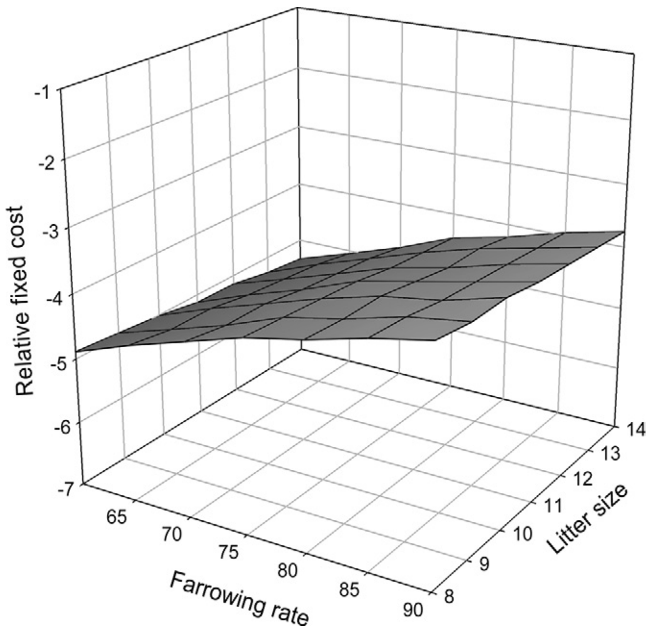

Figure 8. Relative difference between fresh (FRE) and frozen (FRO) semen preparation (FRE – FRO)/maximum ([FRE, FRO]) in fixed costs for the conventional insemination technique across farrowing rate (%) and litter size (pigs/litter) levels.

0.44% and changed the trend and increased by 12.42% for DUI related to CON. The IUI technique was associated with the lowest variable costs, despite that the lowest population size was observed in DUI. However the higher catheter costs, labor costs, and labor time of DUI compared with IUI increased the variable costs for DUI compared to IUI. In FRE, the variable costs of DUI did not reach the values of CON because the reduction in variable costs had 2 sources: the reduction in sow population size and the reduction in the boar maintenance costs. Thus, despite the higher catheter costs, labor costs, and labor time compared with CON, the variable costs decreased. The difference between IUI and CON in FRO was only $0.01. The weaker trend stems from the reduction in variable costs solely due to a reduction in sow population size. This reduction was insufficient to compensate the increased cost associated with the IUI and DUI techniques relative to CON.

The variable costs ($ per sow) for FRE across FR and LS scenarios ranged from $2.08 to $1.81 for CON, $1.69 to $1.54 for IUI, and $1.86 to $1.66 for DUI techniques. The variable costs for FRO ($ per sow) across FR and LS scenarios ranged from $2.22 to $1.90 for CON, $2.21 to 1.90 for IUI, and $2.57 to $2.13 for DUI techniques. Both FRE and FRO had the highest variable costs in the worst reproductive scenario and the lowest costs in the best reproductive scenario. The synergistic effect of preparation and technique costs was responsible for the different variable costs trends between FRE and FRO.

Impact of Semen Preparation and Insemination Technique on Fixed Costs

The relative differences in fixed costs (expressed in $ per sow) between FRE and FRO within insemination technique was –4.33% for CON and more extreme than the 2% financial threshold for IUI and DUI (Table 8). The relative differences in fixed costs between FRE and FRO were –4.89% for CON (Fig. 8), –1.78% for IUI, and –0.27% for DUI in the worst reproductive scenarios. Also, the relative differences in fixed costs between FRE and FRO were –3.75% for CON, –1.33% for IUI, and –0.18% for DUI in the best reproductive scenario.

The average fixed costs across FR and LS scenarios for FRE (FRO) decreased from CON to IUI by 2.4% (5.16%) and from CON to DUI by 3.43% (7.4%). The fixed cost ($ per sow) for FRE across FR and LS scenarios ranged from $19.27 to $17.46 for CON, $18.73 to $17.09 for IUI, and $18.50 to $16.94 for DUI techniques. Likewise, the fixed cost ($ per sow) for FRO across FR and LS scenarios ranged from $20.26 to $18.14 for CON, $19.07 to $17.32 for IUI, and $18.55 to $16.97 for DUI techniques. The impact of insemination technique on fixed costs was higher in FRO than in FRE because of the higher costs associated with spermatozoa loss of the former preparation. A reduction of fixed costs could be achieved by augmenting the efficiency of the technique through a higher number of doses per boar (Glossop, 2003).

Regardless of the insemination technique, FRO returns per sow were on average $63.23 (compared to $63.08 for FRE) and FRO had higher fixed (2.1%) and variable (16.98%) costs than FRE. Therefore, FRO was 3.6% more costly and had 2.07% less net profit than FRE. Developments in the preparation and technologies could further diminish these differences. The present study considered tangible returns and costs in the comparison of the financial indicators of FRE and FRO when applied to the commercial level of a production system. Further studies will benefit from considering other benefits of FRO relative to FRE associated with biosecurity hazard, management logistics of boar maintenance, creation of a genetic bank, and use of FRO in the nucleus and multiplier levels that could lead to accelerated genetic improvement. The former considerations at a global plane and the latter considerations at an individual systems production level could offset some of the financial differences between FRO and FRE identified in this study.

In conclusion, insemination and semen preparation techniques have a nonadditive effect on profit, return, total costs, fixed costs, variable costs, and sow population size. At a similar farrowing number in the commercial level, both IUI and DUI insemination techniques allowed a reduction in sow population size and an increase in the efficiency of boar use with the consequent reduction in fixed costs. The main differences between FRE and FRO in the profits were driven by differences in variable costs. The relatively small differences between FRE and FRO in sow population size (lower than –2% on average), return (lower than 1% on average), and profit (lower than 3% on average) must be weighted in consideration of the benefits of FRO in terms of efficiency of boar semen, dissemination of genetics, and biosecurity.

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