Expanding the dairy herd in pasture-based systems: The role of sexed semen use in virgin heifers and lactating cows

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ABSTRACT

A model was developed to examine the effects of sexed semen use in virgin heifers and lactating cows on replacement heifer numbers and rate of herd expansion in a seasonal dairy production system. Five separate herds were established according to the type of semen used: conventional frozen-thawed (Conv), sexed fresh semen used in lactating cows for the first 3 wk of the breeding season (SFre1), sexed frozen-thawed semen used in lactating cows for the first 3 wk of the breeding season (SFro1), sexed fresh semen used in lactating cows for the first 6 wk of the breeding season (SFre2), or sexed frozen-thawed semen used in lactating cows for the first 6 wk of the breeding season (SFro2). In the SFro1, SFre1, SFro2, and SFre2 herds, sexed semen was used for the first and second artificial insemination in virgin heifers. Pregnancy rates achieved with sexed fresh and sexed frozen-thawed semen were assumed to be 94 and 75% of those achieved with conventional frozen-thawed semen, respectively. Initial herd size was 100 cows, which was maintained for the first 2 yr of the 15-yr simulation, after which all available replacement heifers were retained to facilitate herd expansion. Two different scenarios of land availability were examined for each of the 5 herds: land available allowed expansion to a maximum herd size of 150 cows (S1), or land available allowed expansion to a maximum herd size of 300 cows (S2). Once maximum herd size was reached, sexed semen use was discontinued and all excess heifer calves were sold at 1 mo old. All capital expenditure associated with expansion was financed with a 15-yr loan. Each of the 10 different options was evaluated in terms of annual farm profit, annual cash flow, and total discounted net profit. The use of fresh sexed semen generated more replacement heifers, leading to faster herd expansion compared with frozen-thawed sexed semen and conventional frozen-thawed semen. Maximum herd size under S1 was reached in yr 5, 5, 4, 5, and 7 for the SFre1, SFro1, SFre2, SFro2, and Conv herds, respec-

tively. Under S2, maximum herd size was reached in yr 8, 10, 7, 9, and 14 for the SFre1, SFro1, SFre2, SFro2, and Conv herds, respectively. Total discounted net profit under S1 for the SFre2 herd was €4,130, €38,869, €47,231, and €52,089 greater compared with the SFre1, SFro1, Conv, and SFro2 herds, respectively. Under S2, discounted net profit for the SFre2 herd was €44,204, €255,524, €280,373, and €325,815 greater compared with the SFre1, SFro1, SFro2, and Conv herds, respectively. The negative effects of the sexed frozen-thawed semen on herd fertility reduced farm profitability and will prevent its widespread use in lactating cows.

Key words: sexed semen, herd expansion, economics, simulation model

INTRODUCTION

Flow cytometry is a proven method of distinguishing populations of X- and Y-chromosome-bearing sperm (Garner et al., 1983), providing dairy producers with the opportunity to increase the number of female calves born in a herd. The fertility of the sexed semen product, however, is reduced compared with conventional semen (Seidel et al., 1999).

Several studies that examined the use of sexed semen in virgin heifers indicate that that pregnancy per AI with frozen-thawed sexed semen is approximately 70 to 80% of that achieved with conventional semen (DeJarnette et al., 2009; Chebel et al., 2010; DeJarnette et al., 2010). A similar reduction in pregnancy per AI with sexed semen compared with conventional frozen-thawed semen was observed in lactating cows (Schenk et al., 2009; DeJarnette et al., 2010; Norman et al., 2010). Preliminary results from New Zealand indicate that using fresh sexed semen in lactating cows results in conception rates that are 90 to 95% of those achieved with conventional frozen-thawed semen (LIC, 2012).

The reduction in conception rates associated with sexed semen use is a major barrier to the adoption of the technology in seasonal, pasture-based systems of dairy production. The relative importance of fertility is increased in seasonal systems, compared with year-round production systems (Veerkamp et al., 2002). Any reduction in herd fertility performance can have consid-

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erable negative effects on farm profitability (Beukes et al., 2010).

Hutchinson et al. (2013) previously demonstrated the potential of using sexed semen in virgin heifers to facilitate faster expansion of seasonal-calving dairy herds compared with conventional semen use. The use of sexed semen as a strategy to increase rates of herd expansion may have an important role in meeting ambitious targets set by the Irish government of a 50% increase in national milk output by 2020 (DAFM, 2010).

The objective of this study was to determine the effect of using sexed semen in both lactating cows and virgin heifers on the rate of expansion in seasonal-calving, pasture-based dairy herds, and to examine effects on the financial feasibility of expansion at the herd level. The effect of using 3 different types of semen product [fresh sexed semen (**SFre**), frozen-thawed sexed semen (**SFro**), and frozen-thawed conventional (**Conv**) semen] on herd expansion and farm profitability were investigated under 2 different scenarios of land availability.

MATERIALS AND METHODS

Fertility Model

A model was developed using Microsoft Excel (Microsoft Corp., Redmond, WA) to simulate the reproductive performance of a spring-calving dairy herd over a 15-yr period (Hutchinson et al., 2013). The effect of using sexed semen (either fresh or frozen-thawed) or conventional semen in virgin heifers and lactating cows on the number of heifers available for incorporation into the lactating herd was compared.

In the model, 5 separate herds were established according to the reproductive management related to sexed semen use: Conv semen used in all cows and heifers, SFre semen used for the first and second AI in virgin heifers and the first 3 wk of the breeding season in lactating cows (**SFre1**), SFre semen used for the first and second AI in virgin heifers and first 6 wk of the

breeding season in lactating cows (**SFre2**), SFro semen used for the first and second AI in heifers and first 3 wk of the breeding season in lactating cows (**SFro1**), and SFro semen used for the first 2 AI in virgin heifers and first 6 wk of the breeding season in lactating cows (**SFro2**). In all herds, AI was used only for the first 2 inseminations in heifers, and for the first 6 wk of the breeding season in lactating cows, after which all cows and heifers were bred to natural service.

Reproductive Performance of Heifers

The heifer reproductive performance was previously described by Hutchinson et al. (2013). Briefly, the 12-wk breeding season was divided into four 3-wk periods, and calculations were performed on the proportion of heifers not pregnant at the start of each of the four 3-wk periods using the submission rates (**SR**; proportion of heifers intended to be bred that were inseminated within a 3-wk period) and conception rates (**CR**; proportion of heifers conceiving to a given insemination) shown in Table 1. The differences in CR between Conv and sexed (either fresh or frozen) semen are in line with current available information (Chebel et al., 2010; DeJarnette et al., 2010; LIC, 2012). In the analysis, it was assumed that sexed semen was used only for the first and second inseminations in heifers. A difference in CR between the 3 semen types for third and fourth inseminations was implemented to reflect the greater proportions of otherwise fertile heifers that were not pregnant after the first and second inseminations in the sexed-semen treatments compared with the Conv semen treatment (i.e., result of the semen product used).

Heifers were inseminated following spontaneous estrus; use of synchronization for the first insemination was not included in the model. All heifers that did not conceive in a given 3-wk period were eligible for insemination in the next 3-wk period. The heifers that conceived were attributed a conception date that was the median date of that 3-wk period. The mean calving date for the following year was then calculated

Table 1. Reproductive performance of heifers in the model, using conventional frozen-thawed, sexed fresh, or sexed frozen-thawed semen

Item ¹	Semen type		
	Conventional frozen-thawed	Sexed fresh	Sexed frozen-thawed
First and second insemination SR	0.90	0.90	0.90
First and second insemination CR	0.70	0.66	0.53
Third and fourth insemination SR	0.75	0.75	0.75
Third and fourth insemination CR	0.30	0.35	0.45

¹Submission rate (SR) = proportion of heifers intended to be bred that are inseminated within a 21-d period; conception rate (CR) = proportion of heifers pregnant to a given insemination.

as the mean conception date + 282 d. All heifers that conceived were included in the model for the lactating herd of their respective treatments (Conv, SFre, or SFro) the following year.

The model assumes that all replacement heifers had reached puberty and were eligible for breeding by approximately 14 to 16 mo of age, and subsequently calved for the first time at approximately 23 to 25 mo of age. Only heifers born within the first 6 wk of the calving period were retained as dairy replacements.

Reproductive Performance of Lactating Cows

Submission rates, CR, and embryo survival rates in the model vary according to the cows' DIM during the breeding season. The values used for SR, CR, and embryo survival for all 3 semen types are shown in Table 2. The values for Conv semen were derived from 2 large field studies in pasture-based systems that indicated poorer reproductive performance in cows with short intervals from calving to planned start of mating (Herlihy et al., 2011; MacMillan, 2012). Submission rates and embryo survival rates did not differ with semen type used. Conception rates using either SFre or SFro semen (Table 2) were reduced compared with Conv semen; the reductions were calculated based on data from studies using sexed semen in lactating cows in the United States and New Zealand (DeJarnette et al., 2010; Norman et al., 2010; LIC, 2012).

The model for cows was similar to the heifer model and was based on a 12-wk breeding season split into four 3-wk periods. All calculations were performed on a herd basis. Days in milk at each stage of the breeding season was calculated from calving date until the first day of each 3-wk period. The values for SR, CR, and embryo survival (Table 2) were applied at herd level to the proportion of cows not pregnant in each of the four 3-wk periods during the breeding season. All cows that did not conceive in a given 3-wk period were eligible for insemination in the next 3-wk period. Mean calving dates were calculated using the same method

outlined in the heifer reproductive performance model. This mean calving date was then used in the model for the following year to calculate DIM at the date of planned breeding.

The number of cows that underwent embryo loss was calculated as a proportion of the cows that conceived in each 3-wk period, and varied according to DIM at insemination. When embryo loss occurred, these cows were not eligible for reinsemination until 6 wk after the initial successful insemination. Cows were not reinseminated if embryo loss occurred after the end of the 12-wk breeding season or if the initial successful insemination occurred within 6 wk of the end of the 12-wk breeding season.

Mortality and Survival

Mortality in the lactating herd was assumed to be 2%, and voluntary culling in the lactating herd was assumed to be 8% of the cows that remained in the herd following involuntary culling. These figures were applied to each herd at year end for every year of the simulation.

Heifer calf survival to 1 mo of age was assumed to be 96% of successful conceptions (DAFM, 2012), and heifer calf survival to breeding at approximately 14 mo of age was assumed to be 96% of successful calf survival beyond 1 mo of age (DAFM, 2012).

Semen Costs

Semen costs were established by surveying the main cattle breeding companies in Ireland, and reflect current market prices. The price of a straw of Conv semen from a dairy sire was set at €21, and the price of a straw of either SFre or SFro semen from a dairy sire was set at €47. It was assumed that all inseminations were carried out by AI technicians. An insemination fee of €16 per cow for the first service was allocated in each of the herds; there was no insemination fee for repeat

Table 2. Reproductive performance of lactating cows in the model, using conventional frozen-thawed, sexed fresh, or sexed frozen-thawed semen¹

DIM at insemination	Conventional frozen-thawed	Sexed fresh	Sexed frozen-thawed	All semen types	
	Conception rate	Conception rate	Conception rate	Submission rate	Embryo survival
>83	0.60	0.56	0.45	0.90	0.98
63–83	0.55	0.52	0.41	0.85	0.95
42–62	0.48	0.45	0.36	0.78	0.93
21–41	0.37	0.35	0.28	0.67	0.91
<21	0.20	0.19	0.15	0.20	0.90

¹Submission rate = proportion of cows intended to be bred that are inseminated within a 21-d period; conception rate = proportion of cows pregnant to a given insemination.

heats, in accordance with current practice in the cattle breeding industry in Ireland.

Milk Production

Milk production per cow was dependent on parity, and full yield potential was reached at fourth lactation. Milk production was 75, 92, and 98% of fourth-lactation yield for first-, second-, and third-parity cows, respectively, calculated using historical Irish milk production data. Milk production per cow increased by 1% per year, from a starting point of 5,750 kg/cow per year for fourth-lactation animals in yr 1 of the simulation. Milk constituents also increased annually, with milk fat content increasing by 0.5% per year and milk protein content increasing by 0.3% per year, from a starting point of 39.3 g of fat/kg and 33.9 g of protein/kg in the first year of the simulation. The increased levels of milk and milk constituent production represent the annual rate of gain in milk production, and were calculated using historical Irish milk production data (CSO, 2012).

Financing Expansion

The investment required to finance herd expansion is outlined in Table 3. In all herds, it was assumed that the farm had adequate facilities for the 100 cows on the farm in yr 1 and 2 of the simulation. A figure of €1,500 per cow was attributed to all herds in yr 1 of the simulation to represent the cost of facilities currently in place on the farm. Thereafter, it was assumed that for every 1-cow increase in herd size up to 150 cows, there was an investment in facilities of €3,000, and over 150 cows, it was assumed that the investment required would be €2,000 per cow. This difference was included to reflect the nonlinear investment costs associated with expansion and the increased cost associated with lower levels of expansion. The investment was financed with a 15-yr loan and depreciated over a 15-yr period. To take account of the fact that the investment happens in stages on a farm, all investment required up to yr 7 was carried out in yr 1 and the increased investment required between yr 7 and 15 was carried out in yr 7.

Scenarios

Two different scenarios of land availability were examined for each of the 3 herds using different semen types:

Scenario 1: limited land available for expansion and maximum herd size of 150 cows. Herd expansion was limited to a 50% increase in cow numbers. Heifer calves born on farm within the first 6 wk of the calving period were kept as replacements to expand the herd. Sexed

semen was used only up until the point at which maximum herd size was reached, after which Conv semen was used for all inseminations. Herd size was maintained at 150 cows, and all excess heifer calves were sold at 1 mo of age.

Scenario 2: limited land available for expansion and maximum herd size of 300 cows. Herd expansion was limited to a 200% increase in cow numbers. Heifer calves born on farm within the first 6 wk of the calving period were kept as replacements to expand the herd. Sexed semen was used only up until the point at which maximum herd size was reached, after which conventional semen was used for all inseminations. Herd size was maintained at 300 cows, and all excess heifer calves were sold at 1 mo of age.

In both scenarios, the simulation study commenced during the breeding season of spring 2012, with an initial herd size of 100 cows. Herd size was maintained at 100 cows for yr 1 and 2 to reflect the production constraints of the European Union milk quota regimen, which are scheduled to remain in place until 2015.

Economic Analysis

The Moorepark Dairy Systems Model (MDSM; Shalloo et al., 2004), a stochastic budgetary simulation model, was used to simulate a model farm integrating biological data for the different herds generated by each type of semen use, under both scenarios of land availability. The model was used to quantify the economic implications of sexed semen use on farm profitability under different expansion capabilities. The model can simulate any combination of differing calving patterns.

Table 3. Investment required to fund herd expansion in 2 different scenarios of land availability: land available limits maximum herd size to 150 cows (scenario 1) or land available limits maximum herd size to 300 cows (scenario 2)

Herd	Investment required (€)	
	Scenario 1	Scenario 2
Conventional		
yr 1	300,000	317,200
yr 7	—	282,800
Sexed fresh 1		
yr 1	300,000	530,000
yr 7	—	70,000
Sexed fresh 2		
yr 1	300,000	600,000
yr 7	—	—
Sexed frozen 1		
yr 1	300,000	412,000
yr 7	—	188,000
Sexed frozen 2		
yr 1	300,000	440,000
yr 7	—	160,000

In this analysis, differences in calving date were simulated based on outputs from the reproduction model. These differences affected the milk production profile and feed budgets of the different scenarios modeled. The key herd default parameters used in the model farm are shown in Table 3. All male and surplus female calves were sold at 1 mo of age. Replacement females were contract reared, leaving the farm at 1 mo of age. A difference was observed in the overall pregnancy rate of the heifers under the different semen treatments, which meant that the net cost of replacement heifers to the farm differed with type of semen used. The reduced fertility of SFre and SFro semen compared with Conv semen increased heifer rearing costs to €1,152 and €1,180 for SFre and SFro herds compared with €1,145 for the Conv herd. This was because a greater number of heifers needed to be reared to end up with the same number of heifers calving down in the sexed options compared with the Conv option due to the differences in the pregnancy rates of the heifers.

The default owned-farm size was 44.5 ha (Table 4). Land area was treated as an opportunity cost; land was leased out when not required for on-farm feeding of animals in the early years of the simulation, or rented when required due to increased herd size in subsequent years.

The MDSM integrates animal inventory and valuation, milk production, feed requirement, land and labor utilization, and economic analysis. The overall feed requirement was calculated by the MDSM to meet the net energy requirements for maintenance, milk production, and BW change across lactation (Jarrige, 1989) minus energy supplied through concentrate supplementation. Variable costs (fertilizer, contractor charges, medical and veterinarian, silage, and reseeded), fixed costs (machinery maintenance and running costs, farm maintenance, car, telephone, electricity, and insurance) and sales values (milk, cull cow, and calf) were based on current prices (Teagasc, 2008). The herds were compared at a milk price of €0.27 per kilogram, assuming

Table 4. Assumptions used in the model farm

Item	Value
Owned farm size (ha)	44.5
Reference fat (g/L)	36
Price ratio of protein to fat	2
Labor costs (€/labor unit)	22,860
Gross milk price (€/L)	0.27
Reference cull cow price (€)	400
Reference male calf price (€)	75
Reference heifer calf price (€)	350
Concentrate costs (€/t)	220
Opportunity cost of land (€/ha)	250

Figure 1. Herd size (upper panel) and number of heifer calves born in the first 6 wk of the calving period surviving to 1 mo old (lower panel) in herds using fresh sexed (SFre), frozen-thawed sexed (SFro), or frozen-thawed conventional (Conv) semen in virgin heifers and lactating cows under scenario 1 (land available limits maximum herd size to 150 cows). In lactating cows, sexed semen was used for either the first 3 wk of the breeding season (SFre1 and SFro1) or the first 6 wk of the breeding season (SFre2 and SFro2).

33.0 g of protein/kg and 36.0 g of fat/kg, with a relative price ratio of 1:2 for fat:protein.

Annual profit, cash flow, and total discounted profit over the 15-yr period were identified as the key mechanisms in defining the optimum strategy when evaluating the differing semen options over the 15-yr time period. As the different options evaluated resulted in different profitability levels over the 15 yr of the investment, the discounted farm profitability allowed a direct comparison between herds, taking into account the different periods of maximum profitability in each of the options. An annual discount rate of 2.5% was included in this

analysis based on historical inflation. Discounted net profit, combined with the value of the inventory change was used to calculate net worth change over the 15-yr period of the simulation for each herd under scenarios 1 and 2.

RESULTS

Scenario 1—Land Limited Expansion to Maximum of 150 Cows

The key physical outputs from the 5 herds modeled over the 15-yr simulation period are summarized in Figure 1. The SFre2 herd reached the maximum herd size of 150 in yr 4, 1 yr earlier than the SFre1, SFro1, and SFro2 herds, and 3 yr earlier than the Conv herd, which reached the maximum herd size in yr 7. The SFre herds (both SFre1 and SFre2) produced greater numbers of heifer calves in every year until maximum herd size was reached compared with the SFro1, SFro2, and Conv herds.

Annual profit and cash flow for each of the 5 herds over the 15-yr simulation period are summarized in Table 5. The SFre2 herd and the SFro2 herd realized negative cash flow figures in yr 3 of the simulation (−€2,172 and −€1,637, respectively). All other herds maintained positive cash flows throughout the 15-yr simulation period. The SFre1, SFre2, SFro1, and SFro2 herds all realized negative profit margins in yr 3 of the simulation (−€3,877, −€9,921, −€3,240, and −€9,386, respectively). Profit margins were positive for all other years of the simulation for these herds, and were posi-

tive in every year of the 15-yr simulation period for the Conv herd.

The annual loan repayments (capital repayment plus interest) for the 5 herds are summarized in Table 6. All 5 herds had reached the maximum herd size of 150 cows by yr 7; therefore, the loan structures were the same for all herds; annual repayments were €30,888 and the total cost of expansion was €463,315.

Discounted net profit, inventory change, and net worth change for the 5 herds are summarized in Table 7. As inventory change was the same for all 5 herds, net worth change was directly related to discounted net profit. Net worth change was greater for the SFre2 herd by €4,130, €38,869, €47,231, and €52,089 compared with the SFre1, SFro1, Conv, and SFro2 herds, respectively.

Scenario 2—Land Limited Expansion to Maximum of 300 Cows

The key physical outputs from the 5 herds modeled over the 15-yr simulation period are summarized in Figure 2. The SFre2 herd reached the maximum herd size of 300 cows in yr 7, 1 yr earlier than the SFre1 herd, 2 yr earlier than the SFro2 herd, 3 yr earlier than the SFro1, and 7 yr earlier than the Conv herd, which did not reach the maximum herd size until yr 14 of the simulation. The number of heifer calves generated by each herd followed a similar pattern, with the SFre herds generating the greatest number of heifer calves, followed by the SFro herds, with the Conv herd producing the fewest heifer calves.

Table 5. Annual profit and cash flow from 5 herds using fresh sexed (SFre), frozen-thawed sexed (SFro), or frozen-thawed conventional (Conv) semen in virgin heifers and lactating cows under scenario 1 (land available limits maximum herd size to 150 cows)¹

Year	Conv		SFre1		SFre2		SFro1		SFro2	
	Profit (€)	Cash flow (€)	Profit (€)	Cash flow (€)	Profit (€)	Cash flow (€)	Profit (€)	Cash flow (€)	Profit (€)	Cash flow (€)
1	9,367	18,629	11,573	20,835	11,985	21,247	9,430	18,692	7,347	16,609
2	14,647	23,173	15,933	24,458	16,626	25,152	13,245	21,771	10,520	19,046
3	5,855	13,604	−3,877	3,872	−9,921	−2,172	−3,240	4,509	−9,386	−1,637
4	12,740	19,670	14,036	20,965	20,504	27,433	9,487	16,416	5,766	12,695
5	17,176	23,240	39,575	45,639	42,489	48,553	15,470	21,534	18,584	24,649
6	25,008	30,160	45,252	50,404	45,738	50,891	41,643	46,796	40,400	45,552
7	48,700	43,224	56,526	51,049	56,912	51,436	55,211	49,734	54,807	49,331
8	48,306	51,481	48,673	51,848	48,668	51,842	48,492	51,667	48,270	51,445
9	50,445	52,549	50,484	52,588	50,478	52,582	50,488	52,591	50,333	52,436
10	52,165	53,138	52,531	53,505	52,347	53,321	52,535	53,509	52,454	53,428
11	53,499	53,281	54,447	54,228	54,225	54,007	54,449	54,231	54,370	54,151
12	55,972	54,496	56,522	55,046	56,336	54,860	56,524	55,048	56,444	54,968
13	58,300	55,497	58,667	55,864	58,665	55,862	58,632	55,829	58,554	55,751
14	60,235	56,032	60,859	56,656	60,857	56,654	60,785	56,582	60,783	56,580
15	63,048	57,368	63,601	57,921	63,416	57,736	63,528	57,848	63,525	57,845

¹In lactating cows, sexed semen was used for either the first 3 wk of the breeding season (SFre1 and SFro1) or the first 6 wk of the breeding season (SFre2 and SFro2).

Table 6. Annual loan repayments for 5 herds using fresh sexed (SFre), frozen-thawed sexed (SFro), or frozen-thawed conventional (Conv) semen in virgin heifers and lactating cows under scenario 1 (land available limits maximum herd size to 150 cows) or scenario 2 (land available limits maximum herd size to 300 cows)¹

Herd	Scenario 1		Scenario 2		
	yr 1–15 (€)	Total (€)	yr 1–6 (€)	yr 7–15 (€)	Total (€)
Conv	30,888	463,315	32,601	73,279	855,117
SFre1	30,888	463,315	53,802	63,870	897,642
SFre2	30,888	463,315	60,775	60,775	911,630
SFro1	30,888	463,315	42,046	69,088	874,063
SFro2	30,888	463,315	44,835	67,850	879,658

¹In lactating cows, sexed semen was used for either the first 3 wk of the breeding season (SFre1 and SFro1) or the first 6 wk of the breeding season (SFre2 and SFro2).

Figure 3 summarizes the proportions of the herds calving in each calendar month during the 3-mo spring calving period, for the Conv, SFre2, and SFro2 herds, in selected years during the simulation. During the period of sexed semen use (yr 1 to 10—the period of poorest fertility performance in the sexed-semen herds), a smaller proportion of the SFro2 herd calved in February (at the start of the calving period), and greater proportions of the herd calved in March and April, compared with the SFre2 and Conv herds. When sexed-semen use is stopped (yr 7 in the SFre2 herd and yr 10 in the SFro2 herd), the calving pattern begins to return to that of the Conv herd. The calving patterns of the 3 herds were the same in yr 15, when all herds reached the maximum herd size of 300 cows.

Annual profit and cash flow figures for the 5 herds over the 15-yr simulation period are summarized in Table 8. The Conv herd maintained positive profit margins and cash flows for every year of the simulation, apart from a negative cash flow of –€6,445 in yr 7. The SFre1 herd generated negative profit margins in the first 5 yr of the simulation, with the most negative profit margin of –€30,700 realized in yr 3. Cash flows were also negative in yr 1 and yr 3 to 5 in the SFre1 herd, with the most negative cash flow (–€19,042) observed in yr 3. The SFre2 herd gener-

ated negative profit margins in yr 1 to 6, and negative cash flows in yr 1 to 5, with the most negative for each observed in yr 3 (–€44,715 and –€31,867, respectively). Profit was negative in yr 1 to 5 in the SFro1 herd, and cash flows were negative in yr 3 and 7. The most negative profit margin (–€16,558) and cash flow (–€6,906) were experienced in yr 3 for the SFro1 herd. The SFro2 herd generated negative profit margins in yr 1 to 5 and yr 7, the most negative of which was –€25,859 in yr 3. Negative cash flows were generated in yr 3 to 5 and yr 7, with the most negative cash flow in yr 3 (–€15,731).

The annual loan repayments from each of the 5 herds are summarized in Table 6. The different rates of expansion among the 5 herds resulted in varying loan structures and differences in the total cost of expansion. The cost of expansion in the SFre2 herd was greater by €13,988, €31,972, €37,567, and €56,513 compared with the SFre1, SFro2, SFro1, and Conv herds, respectively.

Discounted net profit, inventory change, and net worth change for the 5 herds over the 15-yr simulation period are summarized in Table 7. Discounted net profit (and net worth change) was greater in the SFre2 herd by €44,204, €255,524, €280,373, and €325,815 compared with the SFre1, SFro1, SFro2, and Conv herds, respectively.

Table 7. Discounted net profit, inventory change, and net worth change for 5 herds using fresh sexed (SFre), frozen-thawed sexed (SFro), or frozen-thawed conventional (Conv) semen in virgin heifers and lactating cows under scenario 1 (land available limits maximum herd size to 150 cows) or scenario 2 (land available limits maximum herd size to 300 cows)¹

Herd	Scenario 1			Scenario 2		
	Discounted net profit (€)	Inventory change (€)	Net worth change (€)	Discounted net profit (€)	Inventory change (€)	Net worth change (€)
Conv	458,106	80,305	538,411	403,343	326,945	730,288
SFre1	501,207	80,305	581,512	684,954	326,945	1,011,899
SFre2	505,337	80,305	585,642	729,158	326,945	1,056,103
SFro1	466,468	80,305	546,773	473,634	326,945	800,579
SFro2	453,248	80,305	533,553	448,785	326,945	775,730

¹In lactating cows, sexed semen was used for either the first 3 wk of the breeding season (SFre1 and SFro1) or the first 6 wk of the breeding season (SFre2 and SFro2).

Figure 2. Herd size (upper panel) and number of heifer calves born in the first 6 wk of the calving period surviving to 1 mo old (lower panel) in herds using fresh sexed (SFre), frozen-thawed sexed (SFro), or frozen-thawed conventional (Conv) semen in virgin heifers and lactating cows under scenario 2 (land available limits maximum herd size to 300 cows). In lactating cows, sexed semen was used for either the first 3 wk of the breeding season (SFre1 and SFro1) or the first 6 wk of the breeding season (SFre2 and SFro2).

DISCUSSION

The current study used bioeconomic modeling to examine the potential for using sexed semen (either fresh or frozen-thawed) in both virgin heifers and lactating cows in herd expansion strategies in a seasonal, pasture-based system of dairy production. We have previously demonstrated faster rates of herd expansion and increased farm profitability when sexed semen was used in virgin heifers only (Hutchinson et al., 2013).

The main barrier to the widespread adoption of sexed semen use in seasonal dairy production systems is the reduction in fertility with sexed-semen products. This is highlighted in the current study by the negative

effects that extensive use of SFro semen has on farm profitability. Under scenario 1, the use of SFro semen in all virgin heifers for the first and second AI and all lactating cows for the first 6 wk of the breeding season reduced discounted net profit compared with Conv semen use. The reduction in discounted net profit occurs despite the increased number of heifer calves and faster rates of expansion facilitated by SFro semen use, and underlines the importance of fertility in seasonal dairy production systems (Veerkamp et al., 2002). Our results demonstrate that limiting the use of SFro semen in lactating cows to the first 3 wk of the breeding season (in addition to the first and second AI in virgin heifers) increases the discounted net profit under scenarios 1 and 2 compared with using SFro semen for the first 6 wk of the breeding season in lactating cows. Reduced profitability was observed because of the adverse effects on herd fertility and calving pattern when SFro semen was used for the first 6 wk of the breeding season in lactating cows (Figure 3). Several studies have demonstrated the economic gains that can be achieved by improving reproductive performance in seasonal-calving dairy herds (Veerkamp et al., 2002; Evans et al., 2006; Beukes et al., 2010). A compact calving period in early spring is an essential component of seasonal production systems to ensure maximum utilization of spring pasture growth (Dillon et al., 1995). In addition to reducing costs through reduced rates of involuntary culling, reduced breeding costs and increased genetic gain (Plaizier et al., 1997), excellent fertility in seasonal systems increases the proportion of cows calving earlier in the calving period, enabling greater pasture utilization, longer lactations, increased milk production, and higher profitability (Dillon et al., 1995; Shalloo et al., 2004). The reduction in farm profit in the SFro2 herd is attributed primarily to the increased proportion of cows calving later in the calving period compared with the SFre2 and Conv herds (Figure 3).

The use of estrus synchronization protocols, although not considered in the current study, is widely used in heifers to advance the timing of first AI. In addition, timed AI has been demonstrated to reduce the interval from calving to first AI and increase the proportion of lactating cows pregnant after the first 6 wk of the breeding season (Herlihy et al., 2011). The use of such protocols, in both heifers and lactating cows, may be a means of offsetting the lower conception rates observed with sexed-semen use.

Increasing the proportion of the dairy herd that calves earlier in the year in seasonal systems may increase farm profitability by increasing the value of the milk produced. Geary et al. (2012) investigated the implications of changes in seasonal milk supply profiles on the dairy processing sector in Ireland. An earlier herd mean

Table 8. Annual profit and cash flow from 5 herds using fresh sexed (SFre), frozen-thawed sexed (SFro), or frozen-thawed conventional (Conv) semen in virgin heifers and lactating cows under scenario 2 (land available limits maximum herd size to 300 cows)¹

Year	Conv		SFre1		SFre2		SFro1		SFro2	
	Profit (€)	Cash flow (€)	Profit (€)	Cash flow (€)	Profit (€)	Cash flow (€)	Profit (€)	Cash flow (€)	Profit (€)	Cash flow (€)
1	7,663	17,304	−16,410	−2,079	−24,302	−8,428	−4,197	7,534	−9,662	2,685
2	12,646	21,508	−11,486	1,544	−18,872	−4,470	−108	10,612	−6,129	5,138
3	4,011	12,052	−30,700	−19,042	−44,715	−31,867	−16,558	−6,906	−25,859	−15,731
4	11,991	19,166	−12,195	−1,984	−21,156	−9,947	−3,269	5,258	−10,511	−1,584
5	15,202	21,463	−11,675	−2,992	−20,450	−10,970	−1,535	5,804	−9,260	−1,602
6	23,220	28,516	5,908	12,979	−587	7,069	9,684	15,771	1,909	8,229
7	25,214	−6,445	38,949	13,101	58,716	34,780	24,905	−4,165	20,115	−8,190
8	5,658	64	56,611	42,961	113,725	97,426	4,378	6,395	−1,200	2,557
9	15,526	7,342	113,358	97,455	120,506	102,064	19,040	18,617	13,810	15,172
10	26,357	15,440	119,391	101,111	125,709	105,007	52,497	49,500	86,274	85,108
11	39,685	25,885	124,123	103,335	129,502	106,415	95,833	90,120	98,608	94,775
12	52,788	35,946	128,317	104,883	133,569	107,967	104,503	95,925	106,796	100,151
13	68,257	48,206	132,613	106,388	137,730	109,474	112,257	100,656	111,648	102,034
14	88,763	65,327	137,031	107,862	142,005	110,949	117,362	102,571	116,550	103,805
15	127,078	100,070	142,434	110,158	147,257	113,248	123,096	104,941	121,925	105,877

¹In lactating cows, sexed semen was used for either the first 3 wk of the breeding season (SFre1 and SFro1) or the first 6 wk of the breeding season (SFre2 and SFro2).

calving date resulted in increased proportions of milk being produced at the beginning and end of the season, which reduced the pressure on processing facilities during the peak midseason. This resulted in an increase in the net value of milk, and an increase in the milk price paid to the farmer. The earlier calving date also increased the capacity to process high-value products, increasing revenues for both farmers and processors in Ireland (Geary et al., 2012).

Consistent with our previous work (Hutchinson et al., 2013), the use of SFre semen generated greater

numbers of replacement heifers, increased the rate of herd expansion, and increased the discounted net profit compared with both Conv and SFro semen. The rapid expansion, however, placed significant financial pressure on the farm business in the first 5 yr of the simulation. Compared with our previous work (Hutchinson et al., 2013), the increased rate of expansion facilitated by sexed-semen use in virgin heifers and lactating cows in the current study resulted in more negative profit margins and cash flows that were sustained over a longer period of time. The negative cash flows and profit mar-

Figure 3. Proportions of the herd calving in calendar months of the year during the spring calving period in herds using fresh sexed (SFre), frozen-thawed sexed (SFro), or frozen-thawed conventional (Conv) semen in virgin heifers for 2 AI and in lactating cows for the first 6 wk of the breeding season under scenario 2 (land available limits maximum herd size to 300 cows).

gins realized by the SFr1 and SFr2 herds in the first 5 yr of the simulation would be unsustainable without additional sources of funding, and would require a comprehensive cash flow budget before embarking upon expansion. Although not considered in the current study, we previously used milk price sensitivity analysis to illustrate the increased vulnerability of the farm business when rapid expansion facilitated by the use of sexed semen (on virgin heifers only) coincides with low milk prices (Hutchinson et al., 2013). Exposure to low milk prices during the much faster expansion facilitated by the use of SFr semen in lactating cows and virgin heifers in the current study will exacerbate the vulnerable position of the farm business. If low milk prices were sustained for several years, the business would become nonviable.

In our previous study (Hutchinson et al., 2013), we outlined the main issues surrounding the use of sexed semen in herd-expansion scenarios. One such issue not previously considered is the pressure that rapid expansion places on the labor force. To increase herd size from 100 to 300 cows in 5 yr (SFr2 herd), requires that skilled labor is readily available to the expanding business. Labor shortages, or the employment of under-skilled staff, may jeopardize the success of the business. For example, a reduction in heat detection efficiency during the breeding period will have negative implications for the reproductive performance of the herd (MacMillan, 2012). The SFro herds in the current study demonstrate the deleterious effects of reduced reproductive performance on farm profitability. The sourcing of skilled labor should, therefore, form a key component of any expansion plan, and must be considered before initiating any herd expansion strategy.

The focus of the present study and that of our previous work (Hutchinson et al., 2013) was to examine the potential use of sexed semen in herd-expansion strategies. Potential also appears to exist for the use of sexed semen in nonexpanding herds. Such scenarios may include (1) using sexed semen to produce increased numbers of dairy heifer calves for sale, (2) using sexed semen to produce the dairy replacements required for the herd from fewer breedings, or (3) a shorter period of dairy AI use, allowing more extensive use of beef sires (Y-sorted beef semen, Conv beef semen, or natural service) and hence greater revenues from the sale of beef calves (Seidel, 2003). Further work is required to determine the feasibility and economic consequences of such strategies.

CONCLUSIONS

The current study demonstrates the potential for SFr semen use to be extended to lactating cows in

addition to virgin heifers to facilitate faster, more profitable expansion of seasonal, pasture-based dairy herds. The faster expansion, however, resulted in negative cash flows during the period of most rapid expansion, placing the viability of the farm business at risk. We have also demonstrated the detrimental effect that the reduced fertility of SFro semen may have on farm profitability if extended to use in lactating cows. Advancements in sorting technology to improve the fertility of the SFro semen product are required for widespread use in lactating cows to become financially viable.

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