PEER REVIEWED

Sexed Semen: Economics of a New Technology

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Abstract

The advent of commercially available sexed semen raises issues about its proper use and economic value on dairy farms. Use of sexed semen solely to produce more female offspring, without regard to genetic merit, is not likely a profitable strategy under most commercial dairy management conditions. Sexed semen may have some value for reducing the rate of dystocia on a dairy, but the impact is small per unit of semen (one dollar or less). Use of sexed semen in virgin heifers may be most fruitful, reserving its use for heifers with the best genetics. This strategy requires good information on the genetic merit of young heifers, and the optimal extent of use depends on many economic variables. The opportunity for economic gain assumes that genetic merit of bulls used for sexed semen breeding is no worse than bulls used for conventional artificial breeding. Economics of using sexed semen technology are considered in this paper.

Keywords: bovine, dairy, breeding, semen sexing

Résumé

La récente disponibilité de semence sexée sur le marché soulève des enjeux concernant sa bonne utilisation et sa valeur économique dans les fermes laitières. L'utilisation de semence sexée dans le seul but d'augmenter le ratio de femelles sans égard au mérite génétique ne sera probablement pas une stratégie profitable dans la plupart des conditions de régie rencontrées dans les fermes laitières commerciales. La semence sexée pourrait avoir une certaine valeur pour réduire le taux de dystocie dans les fermes laitières bien que l'impact par unité de semence soit assez réduit (un dollar ou moins). L'utilisation de semence sexée chez les taures primipares pourrait être des plus bénéfiques lorsqu'on l'utilise principalement chez les animaux avec la meilleure génétique. Cette stratégie nécessite une bonne connaissance du mérite génétique des jeunes taures. L'utilisation optimale dans ce cas dépend de plusieurs variables économiques. La réalisation d'un gain économique présume que le mérite génétique des taureaux utilisés pour la semence sexée ne soit pas pire que celui des taureaux utilisés dans l'insémination artificielle traditionnelle. Dans cet article, nous allons considérer la valeur économique de l'utilisation de la technique de semence sexée.

Introduction

Almost since the advent of breeding by artificial insemination (AI), the dairy industry, producers and researchers have anticipated development of technology to sort or select semen to produce more female offspring. This technology is now a commercial reality, thanks to technological developments that have improved cell sorting capabilities.

The Technology

There have been various developments that allow researchers to separate bovine semen into fractions containing higher than normal concentrations of X-bearing sperm. These technologies include the use of gender specific antibodies, centrifugation, free flow electrophoresis and flow cytometry. Currently, flow cytometry is the only proven method for separating X- and Y-bearing sperm under commercial conditions. This method was first used in the 1980s, but early results produced dead sperm. Johnson *et al* helped refine the use of fluorescence-activated cell sorting technique.[6,7,8,9] The current method of using flow cytometric techniques for sperm sorting was licensed to XY, Inc (www.xyinc.com) for commercial development. This approach uses technologies developed by the United States Department of Agriculture, Colorado State University and DakoCytomation, a company that develops advanced flow cytometers for commercial use.

Briefly, the process involves identification of differences in DNA content.[4,13] X-bearing sperm contain 3.8% more DNA than the Y-bearing counterparts. Sperm is diluted to a very low concentration, then stained with a harmless DNA-specific fluorescent dye. This dilute, dyed sperm sample is then passed through the flow cytometer at approximately 60 mph under pressures of 40-60 psi. Sperm are aligned in a special manner, single-file, and passed through a laser beam. Stained DNA emits fluorescence, and a difference in the amount of fluorescence is detected. For this process to work correctly, sperm heads must be precisely oriented during the cytometric evaluation by using a specially designed beveled nozzle. Without proper orientation, differences in DNA content cannot be accurately determined. The concept of sperm orientation is specifically protected under the Johnson patent, held by the USDA and licensed to XY, Inc.

Depending upon the relative amount of fluorescence (based on relatively small differences in DNA content), positive or negative charges are applied to each droplet that contains a single sperm. Sperm then pass through charged deflector plates where positively charged particles go one direction, negatively charged go in another direction, and uncharged droplets pass straight through. Uncharged particles may contain multiple sperm, uncharged sperm of either sex, or potentially damaged material. The resulting process is able to repeatedly separate sperm with 85-90% purity. Commercialization of sexed semen using this sorting process in the US began with a 2003 license granted to Sexing Technologies, College Station, TX, a company currently partnering with several semen companies in the US and abroad (JM De Jarnette and Dr. Ray Nebel, personal communication, 2005).

As expected, running individual sperm through a flow cytometer in single file, even at speeds of 3,000 to 5,000 sperm per second, takes some time, and the process reduces the final sperm count of undamaged, progressively motile sperm of the desired sex as compared to the original starting sample. As a result of time, potential for sperm damage, and much less than 100% efficiency, only about 10-15% of the original sperm cells entering the machine are recovered as marketable, sexed product. Thus, commercially available straws contain only about two million sperm, as compared to 20 million in traditional semen straws.

Fertility of the final product, as determined by conception risk in virgin heifers, is reduced by approximately 30%, largely due to the reduced sperm count of sexed semen. Use of sexed semen generally results in lower conception rates than conventional AI semen. In virgin heifers, 55 to 60% conception rates have been reported when using conventional semen, compared to 35 to 40% when using sexed semen.[13] Because of limited supply of sexed semen, higher cost and significantly lower conception rates, sexed semen has thus far been mostly used in special niches in the dairy industry, such as embryo transfer, special matings for producing very high merit offspring, or limited use in virgin heifers.

When using conventional semen, only 35-38% of conceptions (at 40 days pregnant) result in a fertile female offspring that reach first lactation. There are approximately 45% fertile female pregnancies, but that number is reduced by abortion, stillbirth, calf and heifer mortality, as well as failure of some heifers to conceive and calve. Therefore, availability of replacement heifers has been a production constraint for many dairy farms. If more heifers were readily available, farms could increase their herd replacement rate to some degree. This relative shortage of available heifers has played a key role in the unusually high market prices (prices in excess of the cost of production) of replacement heifers in the past several years in the US.

Since January 2001, the quarterly national price of replacement heifers has ranged from $1,300 to $1,870, with an average of $1,561. The lower end of the price range likely represents the floor price set by the cost of rearing a replacement heifer; the higher end of the price range reflects unmet demand driven by the value of filling empty slots on dairy farms.[10]

If use of sexed semen becomes more widely adopted, managers of dairy herds could breed to produce more replacements, to source replacement heifers from their best cows, or both. Use of sexed semen to breed enough of the herd's cows could result in sufficient female heifers for replacements. When using sexed semen that can produce approximately 85% female offspring (female sexed semen), approximately 65% of all cows bred would ultimately produce a two-year-old pregnant replacement heifer (10% reproductive culls, 85% fertile female conceptions, 9% abortion and stillbirths, 4% pre-weaning calf mortality, 2% mortality/failure to conceive after weaning). If 60% of all cows were bred with sexed semen, those breedings could supply more replacements than the current national rate (0.60 x 0.65 = 39%). In this case, as many as 40% of all breedings would be unnecessary to produce replacement heifers, although they would still be necessary to return cows to another lactation.

One strategy for using sexed semen would be to breed top genetic-merit cows (or nulliparous heifers) in a herd with sexed semen, middle genetic-merit cows (or heifers) using conventional AI and bottom merit cows (heifers) using some inexpensive means, without intending to raise females born from bottom-end breedings.

For many dairymen, considerations for using sexed semen will extend beyond the simple biology of the technology and direct economic considerations. The option of increasing the number of growing heifers is not just a question of long-term profit, but also of day-to-day operations. Many farms lack facilities, feed, labor, or capital needed to rear many more heifers. For those that contract heifer rearing off-site, however, these may not be significant barriers. The payoff for investment in sexed semen breedings occurs farther into the future; cash flow constraints at the time of breeding may limit the amount of investment in sexed semen. Environmental regulations and permitting restrictions could mean that increased numbers of heifers on the farm would require reducing the number of adult cows. In most circumstances, this would be undesirable. Finally, by investing in more sexed semen breedings that produce more heifers in a given year, the dairyman might convert cash profit into long-term assets, postponing taxes and converting ordinary income into capital gains in the long term.

Supply and Price of Replacement Heifers

There are about nine million adult dairy cows in the US today.[11] That number is slowly declining as the dairy industry consolidates into fewer herds that produce more average milk per cow. Each year, fewer than four million cows are replaced by first-lactation replacement heifers. Current prices for heifers are at a historical high because demand for heifers, particularly by large herd expansions, has driven the price far beyond the simple cost of rearing a replacement heifer. Currently, female heifer calves born in the US are a limiting resource for the dairy industry, limited by the rate at which female calves are born from breedings with conventional semen and survive to calving. While the shortfall in US heifer production was partially buffered by heifers imported in the past from Canada, Bovine Spongiform Encephalopathy (BSE) has ended that supply and contributed to the very high current heifer prices. The loss of the Canadian market has removed about 75,000 replacement heifers from the yearly supply.[3]

Once use of female sexed semen is adopted across a large enough portion of the dairy industry, there will be an adequate supply of female dairy calves to meet demand for replacements. In all likelihood, modest use of female sexed semen will increase the supply of replacement heifers enough to satisfy current demand, but the impact will not happen quickly. It will take a minimum of three years from the first significant introduction of the technology for sexed semen-derived heifers to arrive as replacements, about one year for breeding and gestation, plus two years for growth. In addition, adoption will inevitably be gradual, due to initial supply limits on female sexed semen, and because of normal constraints to adoption of any new technology. Because most dairy farms breed year round, no more than one-twelfth of a herd are available to be bred in any given month. As a result, the actual upturn in supply of replacement heifers will probably occur gradually over a period of three to four years, or even longer, after initial introduction of female sexed semen.

As the supply of replacement heifers rises and meets demand, the price of heifers will decline to an equilibrium price driven by the cost of the newborn female dairy calf, cost of rearing and profit for the heifer raiser. We expect that over time the price of an average replacement heifer will be $1,300 to $1,500. This is consistent with published studies on the cost of rearing heifers, anecdotal reports from heifer-raising operations, and data on heifer prices in this decade that showed national average prices as low as $1,300, and prices below $1,500, for 40% of quarters since January 2001. Once the price of replacements approaches the cost of rearing, breeding for more heifers than the herd's replacement needs would only make sense if the dairy farm can earn a price premium, such as for superior genetics or health, or could raise heifers for significantly less cost than the average producer. Instead, it may be appropriate to breed poorer cows in the herd for other purposes, perhaps to produce crossbred beef calves.

Early adopters of sexed semen technology may reap a brief profit advantage as they sell excess heifers in a market where the price is still high from the temporary limitations in supply. This opportunity will likely be short-lived and has other limitations discussed below.

Herd Replacement Rates

As noted above, an increase in supply of replacement heifers following the introduction of sexed semen will likely reduce the price of replacements. When replacement heifers cost less, there will probably be an early phase when more cows are culled in response to the larger supply of heifers. With more available heifers, herds can likely cull more cows that do not justify their presence in a "slot" on the dairy farm. This could result in higher turnover rates, an economic advantage for the farm. The long-term equilibrium culling rate will be driven by economics. Preliminary modeled estimates, run at $1,300 for a replacement heifer, suggest culling rates will probably be similar to today's rates, even if more heifers were made available because of female sexed semen (Dr. Albert de Vries, personal communication). Given this, the overall current demand for heifers in North America will look much like it does today.

Over the long term, there will probably not be a significant increase in the nation's herd turnover rate beyond what has been observed in the industry several years ago when heifer prices were at a more moderate level. Optimum herd turnover rates will still be fundamentally driven by the complex mix of milk price, cost of replacement heifers, cull-cow prices and other factors specific to a particular herd at a given time. The need to properly care for cows and preserve their value in the herd will not change.

Biosecurity

Sourcing replacements from within the herd helps the producer avoid risk of introducing or increasing the prevalence of infectious diseases that could accompany outside replacements. In addition, heifers raised under control of the home dairy farm can be vaccinated according to the farm's protocols. Finally, home-raised heifers exposed to pathogens in the farm's environment will more likely have some degree of immunity to the herd pathogens at the time of first calving. If the market for replacement heifers becomes more competitive, some of these biosecurity advantages may also be captured by dairy farms that purchase replacements, since competing heifer suppliers may differentiate themselves by supplying better quality heifers and paying added attention to heifer immune and disease status.

Fewer Dystocias

Dystocia in cattle has several negative impacts. Dematawewa reported dystocia occurred in 19% of first-parity animals (dystocia score of 3 or higher on a 5 point scale), and 6.8% in later parities.[5] Overall dystocia rates were 13.9%. Losses following dystocia included lost milk, fat and protein yield during the following lactation. In addition, increased days open, inseminations, and cow and calf deaths were associated with dystocia. Using data from that study, the average cost of dystocia (score 3 or greater) was $147 per case. Van Tassel *et al* reported dystocia incidence rates for parity 1 cows at 10.9%, parity 2 cows at 5.5%, and parities >2 at 5.15%, parities >1 at 5.3% and an overall incidence of 7.7%.[12] In two large studies on dystocia (19,793 and 31,367 calvings), Cady reported a dystocia rate (calving score of 4 or 5 on a 5 point scale) of 7.4% for female calves and 17.4% for male calves in primiparous heifers, and 2.4% for female calves and 5.3% for male calves for multiparous cows. Data from these studies are adapted for Table 1.[1,2]

Since use of sexed semen will produce proportionally more female calves, and because female calves have lower birth weight than males, use of sexed semen may reduce the rate and cost of dystocia on dairy farms. While possibly true, the overall impact of a change in dystocia rates is likely to be small. The effect, if any, would occur only in cows bred with female sexed semen. If some cows were bred to beef sires or perhaps male beef sexed semen to produce more beef bull calves, some of the effect may be counterbalanced by corresponding changes in risks in these cows.

A simple model of the impact of dystocia with reasonable assumptions is shown in Table 1. Use of sexed semen for breeding nulliparous heifers reduces the dystocia rate by 3.7%. The value of that reduction is $5.38 per calving, and the savings per unit of semen is $2.15. For breedings of milking cows, the reduction in dystocia rate is only 1%, the savings per calving is $1.48 and the savings per unit of semen is $0.42. Assuming a reasonable distribution of parities in the herd (37% first lactation, 63% older cows), the overall impact of 100% sexed semen use versus 100% conventional semen use would be a 2% reduction in dystocias, a savings per calving of $2.93 and a savings per unit of sexed semen of $0.93.

It is unlikely that sexed semen will be used on every animal to be bred; therefore, the effects will be further reduced in a herd by its limited use. If reasonable estimates of sexed semen usage by parity in the herd are made (Table 1), the herd-level impact of sexed semen use on dystocia is quite small, a reduction of only 0.6% in dystocias and a savings per calving of only about one dollar. Therefore, while sexed semen use will have an impact on dystocia and associated consequences, it will not become a principal reason to use sexed semen in a dairy herd.

Genetic Selection for other than Production Traits

Because genetic advances in traditionally selected traits will be accelerated by use of sexed semen, there will be an opportunity to add other traits to the selection criteria for AI bulls. Efforts could be made to select for better performance in areas such as mastitis, stillbirths, feet and leg structure, udder conformation and reproduction. Broadening the number of traits being selected will reduce the rate of improvement for any particular trait, but the overall rate of genetic advancement will be accelerated.

Embryo Transfer

It seems very likely that once sexed semen is available at a price deemed "reasonable" by the market, the embryo transfer industry will shift entirely to sexed semen, presuming that the desired sires are available in sufficient quantity. In general, embryo transfer breedings have a clearly defined preferred gender outcome, and sexed semen will make a significant contribution to those breedings. Sexed semen may be used for in-vitro fertilization of ova harvested from ovaries retrieved at slaughter from top genetic merit cows.

Culling Growing Heifers

With sexed semen, dairies would be more likely to cull poor performing growing heifers, avoiding losses

Table 1. Impact of using sexed semen on dystocia and its costs.

Estimating the value of decreased dystocia with gender enhanced semen		
loss per case of dystocia (Demataweva *et al*, 1997)	**$147**	
number of calvings	100	
Gender distribution of calvings		
sexed semen breedings		
percent female births from semen	**85%**	
	parity 1	**parity ≥2**
single births	99%	94%
twins	1%	6%
single female births	84%	80%
single male births	15%	14%
conventional breedings		
percent female births from semen	**48%**	
	parity 1	**parity ≥2**
single births	99%	94%
twins	1%	6%
single female births	48%	45%
single male births	51%	49%
Dystocia rate by gender of calf and parity		
rates developed from Cady, 1977 and 1980	**parity 1**	**parity ≥2**
females	7.4%	2.4%
males	17.4%	5.3%
twins	17.5%	6.4%
Dystocias comparing 100% use of each breeding option with a given parity group		
parity 1	**sexed semen**	**conventional**
single females	6.2	3.5
males	2.6	9.0
twins	0.2	0.2
dystocias: parity 1	9.0	12.6
dystocia rate if all breedings used a particular type of semen	9.0%	12.6%
reduction in dystocia rate from using sexed semen: percent of births	3.7%	
parity 2 or greater		
single females	1.9	1.1
males	0.7	2.6
twins	0.4	0.4
dystocias: parity ≥2	3.0	4.1
dystocia rate if all breedings used a particular type of semen	3.0%	4.1%
reduction in dystocia rate from using sexed semen: percent of births	1.0%	
reduction in herd dystocia rate given the herd's mix of parities	**parity 1**	**parity ≥2**
proportion of calvings	37%	63%
	sexed semen	**conventional**
dystocias in first parity	3.3	4.7
dystocias: parity ≥2	1.9	2.6
total dystocias	5.2	7.2
total dystocia rate	5.2%	7.2%
total reduction in dystocia rate per birth with sexed semen	**2.0%**	
Impact of the use of sexed semen comparing 100% use of each breeding option and herd's parities		
	parity 1	**parity ≥2**
savings per calvings from reduced dystocia	$ 5.38	$ 1.48
savings per unit of semen	**$ 2.15**	**$ 0.42**
overall herd savings per calving from possible reduction in dystocias	$2.93	
overall added value per unit of sexed semen semen from reduction in dystocias	**$0.93**	
Impact of sexed semen a mix of sexed semen and conventional semen	**parity 1**	**parity ≥2**
percent of calvings bred with sexed semen	**36%**	**24%**
reduction in dystocia rate with actual breeding mix	1.3%	0.2%
savings per calving	$1.94	$ 0.36
savings per unit of semen	$ 0.78	$ 0.10
overall reduction in dystocia across all parities given the breeding mix	**0.6%**	
overall savings per calving in the herd	**$ 0.94**	
Semen use by parity group	**parity 1**	**parity ≥2**
units of semen per calving	2.5	3.5
average units of semen per calving in the herd given parity distribution	3.1	

associated with bringing them into the herd only to have them perform inadequately as milking cows. This might include heifers with chronic pneumonia, heifers slow to conceive, or heifers positive for specific diseases.

Extended Lactations

At least hypothetically, a dairy assured of enough pregnancies for replacements might delay re-breeding cows, thereby extending their lactation, increasing the proportion of adult life spent milking (not dry), or even reducing a cow's total number of lactations, thereby avoiding risks of the transition period. This is possible because, with sexed semen, fewer calvings per cow are needed annually to provide adequate replacements for the dairy. Given current lactation performance and the natural decline in production across the lactation, this seems unlikely to be a desirable strategy. If this were a profitable strategy for some cows, one would expect it to already be a practice across the industry to some degree, with the extra replacements purchased from other dairies. Because this is not currently a prevalent strategy on dairies suggests that the value of early lactation peak milk is simply too compelling, and timely re-breeding and returning to early lactation after another calving is too valuable.

Specialized Dairy Sectors

For some specialized dairy sectors, the value of replacement heifers may remain significantly above the cost of rearing, making sexed semen more valuable. Organic dairies, for example, may have continuing demand for replacement heifers that qualify as organic animals for sale to other dairies wishing to convert to or expand organic production. This type of situation may also apply to breeds with smaller base populations but growing popularity, e.g., some of the breeds being used in crossbreeding programs and grazing dairies. These opportunities are likely to remain as relatively small sectors of the total US dairy production market.

Table 2. Simplistic and flawed model of the economics of sexed semen.

Simplistic and flawed model of the value of sexed semen			
100	cows bred		
conventional semen		**sexed semen**	
60%	conception rate	45%	conception rate
167	units of semen used	222	units of semen used
$ 10.00	semen price	$ 40.00	semen price
$ 1,667	cost of semen	$ 8,889	cost of semen
44%	percent fertile heifers	84%	percent fertile heifers
44	number of heifers produced	84	number of heifers produced
56%	percent bulls and freemartins	16%	percent bulls and freemartins
56	number of bulls and freemartins	16	number of bulls and freemartins
$ 1,800	price of a springing heifer	$ 1,800	price of a springing heifer
$ 1,300	cost to rear a heifer	$ 1,300	cost to rear a heifer
$ 500	profit per heifer	$ 500	profit per heifer
$ 200	sale price of a bull calf or freemartin	$ 200	sale price of a bull calf or freemartin
$ 22,000	income from heifers	$ 42,000	income from heifers
$ 11,200	income from bulls and freemartins	$ 3,200	income from bulls and freemartins
$ 33,200	total income	$ 45,200	total income
$ 31,533	income minus semen costs	$ 36,311	income minus semen costs
$ 4,778	**advantage (disadvantage) of sexed semen**		
$ 22	**advantage per unit of sexed semen used**		

Economic Evaluations

Table 2 shows a model of the economics of using sexed semen: simple and wrong. This sort of evaluation is an appealingly simple approach to the question of how much sexed semen is worth. It assumes that all cows (or in this case heifers) bred will get pregnant and deliver a live calf, and that all calves are either sold at birth (bulls and freemartins) or grow to become replacements (heifer calves). This approach, particularly if applied to today's prices for replacement heifers, can show a respectable profit per unit of semen. In this case the profit is $22 per unit, given a price differential of $30 (conventional AI at $10 and sexed semen at $40). Unfortunately, the lack of many important inputs makes the model useless. The model is included in this discussion only to serve as a warning against such a simple evaluation.

Table 3 shows a slightly more complex model that begins to account for such things as pregnancy losses and death of calves. In essence, the model follows the population to be bred through its breeding cycles, allowing sexed semen to be used for a specified number of initial breedings, and then conventional semen for later breedings. Expenses include the cost of semen, a charge for extending the age at first calving for using sexed semen (some heifers will calve at a later age in the sexed semen-bred group), and adds the cost of culls of those few heifers that remain open at the end of the allowed breeding period. The model also more accurately accounts for the loss of heifer calves from birth to their first calving. For the possible pool that could be bred with sexed semen, animals could be bred at only their first insemination or for more inseminations (this model allows up to six cycles to be bred with sexed semen, breeding any remaining open animals with conventional semen). Conventional semen will result in more pregnancies than sexed semen if a limit is set for the length of time heifers are eligible to be bred (set in the model at eight cycles or a 168 day breeding window). This makes the differential in conception rates between the two types of semen a critical factor in determining their relative value. Some pregnancies are lost, some calves are stillborn and some living calves die or fail to get bred, all factors that reduce the number of productive heifers resulting from the breedings. Only these living, pregnant springing heifers bring significant value from

Table 3. Model of the value of sexed semen by following a breeding cohort: heifers.

Using sexed semen				100	cows to breed
Conventional semen					
estrus detection	**conception rate**				
50%	60%	1st breeding cycle			
50%	60%	even cycles			
50%	60%	later odd cycles			
45%	percent fertile females per pregnancy				
395	days old at breeding start	13.0	start age in months		
8	cycles until DNB	17.8	months maximum breeding age		
9%	abortions and stillbirths: heifer calves				
11%	abortions and stillbirths: bull calves				
4%	loss of heifer calves from birth to weaning				
2%	loss of heifers from weaning to first calving				
$ 1,571	conventional semen costs	157	units of conventional semen		
$ -	sexed semen costs	-	units of sexed semen		
$ 9,123	cost of average days to preg past breeding start			434	ave days
$ 2,882	cost of culled heifers in brd. pool	5.8	# culled	$ 19	**diff in age cost**
$ 13,576	total costs (meaningless; the difference between the programs is all that matters)				
$ 17,628	net income from heifer replaceme	36	# of heifer calves raised to calving		
$ 5,766	income from bull calves	46	# of bull calves sold		
$ 23,394	total income	82	total calves with value		
$ (3,500)	**advantage of breeding with sexed semen for the whole breeding program**				
$ (35)	**advantage (disadvantage) with sexed semen per heifer entering the breeding program**				
-35%	*percent return on additional expenses for sexed semen program*				
$ (20)	advantage (disadvantage) per unit of sexed semen used				

		$ 30.00	**semen price differential**				
Sexed Semen		15%	**conception rate differential**				
estrus detection	**conception rate**						
50%	45%	1st cycle		$ 10.00	conventional semen price		
50%	45%	even cycles		$ 40.00	sexed semen price		
50%	45%	later odd cycles		$ 2.50	cost of an extended day to calving		
85%	percent fertile females per pregnancy			$ 1,800	value of a springing heifer		
395	age at breeding start			$ 1,300	cost to rear a heifer to calving		
8	cycles until DNB	17.8	maxbred age	$ 125	value of a live newborn bull calf		
9%	abortions and stillbirths: heifer calves			$ 500	cost of a culled, open heifer		
11%	abortions and stillbirths: bull calves			$ 800	money spent: culled heifer		
6	# of cycles using sexed semen			$ 300	value of culled heifer		
				$ 100	cost of lost heifer calf	difference	**NPV**
$ 184	conventional semen costs	18	units of conventional semen			$ (1,386)	$ (1,386)
$ 6,963	sexed semen costs	174	units of sexed semen			$ 6,963	$ 6,963
$ 11,060	cost of average days to preg past breeding start			444	ave days	$ 1,937	$ 1,794
$ 5,309	cost of culled heifers in brd. pool	10.6	# culled			$ 2,426	$ 2,246
$ 23,515	total costs (meaningless; the difference between the programs is all that matters)					$ 9,940	$ 9,616
$ 9,940	**additional costs of sexed semen breeding program**						
						difference	
$ 29,745	net income from heifer replacements	61	# of heifer calves raised to calving			$ 12,117	$ 9,619
$ 1,983	income from bull calves	16	# of bull calves sold			$ (3,783)	$ (3,502)
$ 31,728	total income	77	total calves with value			$ 8,334	$ 6,116
$ 8,334	**additional income from sexed semen breeding program**			**NPV ot total advantage (disadvantage)**			$ (3,500)
$ 56	extra semen cost per heifer in the sexed semen program						

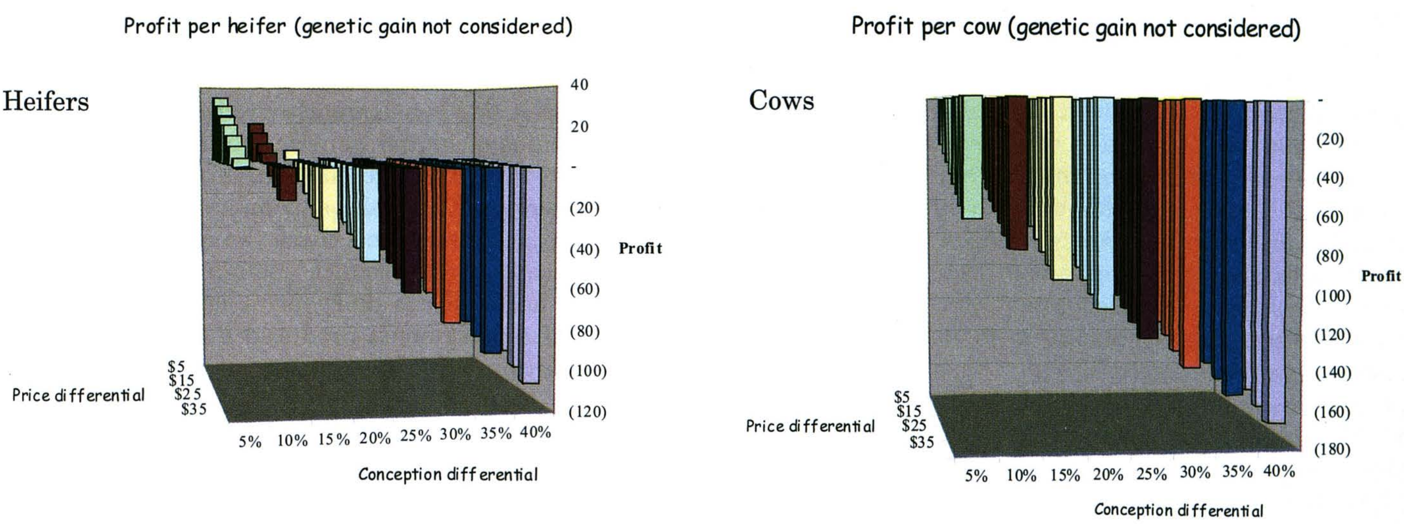


Figure 1. Model of the value of sexed semen by following a breeding cohort showing the impact of differential in conception rates and price differentials.

the female embryos resulting from a conception. On the other side of the gender divide, bull conceptions suffer similar losses until a living bull calf is born and can be sold.

Springing heifers and bull calves sold constitute the principal revenues in the model. The expense side of the evaluation includes the cost of the semen (the differential cost is a key factor) and the cost of raising those females that live to become springers.

Given this model and conditions that apply to breeding nulliparous heifers (60% conception with conventional semen; 45% with sexed semen) and a $30 price differential, use of sexed semen loses $35 per heifer that enters the breeding pool, even with an assigned price of $1,800 for a springing heifer (Table 3). Figure 1 shows the two scenarios across a variety of price and conception rate differentials. As the graphs show, if heifers sell for $1,800, using sexed semen in this simple model is only profitable at fairly low differentials in price (probably less than $15 added cost for sexed semen) and at low differentials in conception rate (less than 10% difference). This model assumes that heifers would be bred with sexed semen during as many as the first six cycles after the start of breeding. This was set based on sensitivity analyses that showed this to be the best level of potential utilization given the other input constraints, and when the potential for genetic gain is included (described later in the paper). When using this model that depends primarily on returns for extra heifers (as shown in Table 3), the optimal use of sexed semen would be only on the first breedable cycle. In that case, the loss per heifer in the breeding pool is only $9, not $35.

This second model serves to frame the outside limits of the possible value of sexed semen, but there remain important aspects not considered. Results displayed in Table 3 are based on a value of $1,800 for a springing heifer which mimics conditions as they now exist where there is a strong demand for replacements. Even under these positive market conditions, sexed semen can only be profitable if there are very small differentials in the price of sexed semen and small negative impacts on conception (Figure 1). If there was an adequate supply of heifers and the value of a springing heifer dropped to $1,400, the value of sexed semen would drop further, with a loss of $114 per unit of semen given the modeled assumption. At this likely steady state situation, the use of sexed semen never achieves profitability based solely on the value of the extra heifers produced.

To this point, the analysis has been based on breeding nulliparous heifers that have relatively high conception rates. This tends to minimize the negative impact of reduced conception rates inherent with sexed semen. If the same models are run but the conception rates in adult cows are used, e.g. 35% with conventional semen and 25% with sexed semen, and with some other input adjustments to reflect conditions for cows, the economics of sexed semen become even more difficult. The loss per cow bred based only on the value of extra replacements is now $88. If replacements are only worth $1,400, the loss per cow increases to $141. If sexed semen is only used for the first breeding of cows, these numbers can be reduced to losses of $21 and $33, respectively.

The deterministic outcomes of these models that seek to justify the value of sexed semen on the basis of increased female offspring are obviously dependent on the input assumptions shown in Tables 2 and 3. Assumptions can be contrived that generate a profit from sexed semen based primarily on the value of the extra heifer calves born, but to do so one has to select an array of fairly unlikely input conditions, given current dairy management and sexed semen technology. None of these models include the value of sexed semen to a dairy in terms of biosecurity.

Incorporating Genetic Gain

If sexed semen seems difficult to justify based on extra heifer calves it produces or by reducing dystocia, are there other values that justify its use on dairies? The answer is yes, although the arithmetic becomes more complex and will require more sophisticated management than a simple rule like "breed virgin heifers on their first service with sexed semen". The key to value of sexed semen lies not in the opportunity to simply have more heifers, but in the opportunity to produce better heifers.

If a dairy uses sexed semen to breed cows without attention to genetic merit (as assumed in the models considered above), then there is no genetic gain from the "cow side" of the breeding, only from the "bull side", i.e. the relative genetic merit of the bull used compared to the average cow in the breeding pool. If, however, the dairy could source more of its heifer replacements from the better cows in the herd by using sexed semen to breed those cows, then the dairy would gain genetic merit from those female offspring from both sides of the breeding.

Since the genetic merit of cows on a dairy is normally distributed, one can calculate the average genetic merit of any subpopulation of cows; Figure 2 illustrates such a distribution. A population of cows to be bred can be segmented into three parts. The "top end" of the distribution of dams could be targeted for breeding using sexed semen and consequently produce more replacement females of higher genetic merit. In the middle genetic portion of the population, dams could be bred with conventional (and less expensive) conventional semen. If properly managed, these two upper populations of better cows could produce enough replacements to meet the needs of the dairy, or at least to match the number of replacements produced if the entire breeding population were bred using conventional semen.

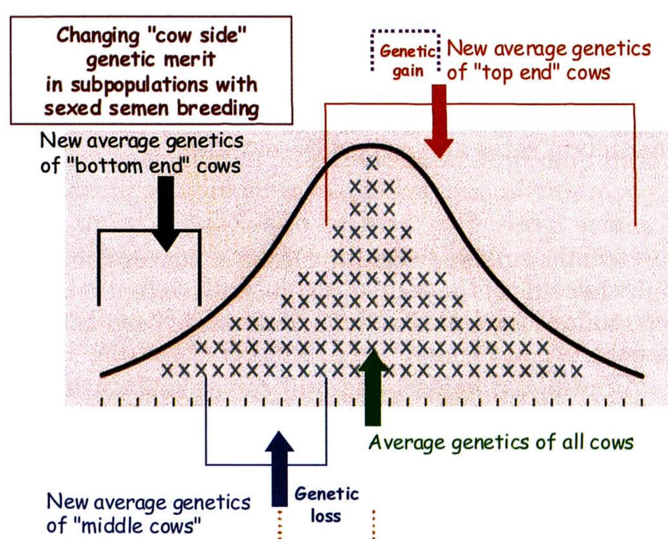


Figure 2. Segmentation of the breeding pool with sexed semen breeding programs.

Given that the need for replacements has been matched, the remaining "bottom end" of dams could be bred in a variety of ways. If also bred with conventional semen, any resulting female offspring could be sold as calves or raised and sold as marketable replacements, depending on market and farm conditions.

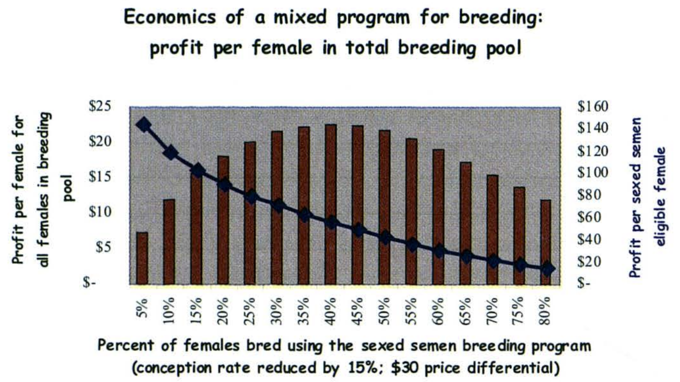
This next level adds considerable complexity to the issue. It is no longer an issue of "use sexed semen" versus "use conventional semen" on the breeding pool. First, the dairy must be able to reliably rank its breeding pool based on genetic merit. Many dairies cannot do this or can do so only with a large degree of error. For those who can rank genetic merit with some degree of reliability, the question now becomes one of degree. For most dairies, it would be profitable to use sexed semen for the first insemination on the best dam in the breeding pool. It would not make sense to use sexed semen for the eighth breeding of the worst female in the population. The important question is: where is the cutoff between these two extremes? The answer is not simple, and as always in matters of economics, it depends on a host of factors that impact on the decision.

Table 4 shows part of a complex deterministic economic model that considers this question. It builds off the model shown in Table 3, but includes the economic impact of accounting for the value of genetic gain in replacements sourced by the partial use of sexed semen, compared against the baseline of all conventional semen use. In the example shown, the top 30% of virgin heifers are bred using sexed semen (in this case for up to as many as six cycles), and the bottom 70% are bred with conventional semen. That top 30% suffers the loss of $35 per animal in the sexed semen breeding pool discussed above, resulting in a net loss of $11 (0.30 x $35) per animal in the total pool. As a result of the improved genetics of the selected population producing replacements, however, there is also a gain of $32 per heifer in the total pool. The net gain per heifer in the pool is $22 ($32 - 11) profit per heifer (the numbers suffer from the appearance of error due to rounding in display). Thus, under these conditions, including a heifer price of $1,800, it would be profitable to use sexed semen on the top 30% of the virgin heifers in the breeding pool. But is this the optimal proportion to breed with sexed semen?

Figure 3 attempts to answer this question. The bars in the top chart show the average profit per heifer in the breeding pool; this is highest if the top 40% of the pool were bred with sexed semen. At that level, the average profit per heifer in the breeding pool is $23. The line in Figure 3 shows the profit per heifer actually bred with sexed semen. Note that the profit can be quite substantial for the very best heifers. Breeding the top

Table 4. Model including the value of genetic gain for heifers.

Sexed semen economics, including for the value of genetic gain		nulliparous heifers
$ 10.00	milk price minus marginal feed cost	
$ 30	semen cost differential: if not the same bull, enter the sexed semen bulls PTA Milk differential below	
15%	percent reduction in the absolute value of the conception rate (not proportion of conceptions)	
1,800	value of a springing heifer	
8%	discount rate	- sexed semen bull PTA Milk differential compared to conventional AI bull used
30%	**percent of the sexed semen breeding pool at least initially bred with sexed semen: top end heifers**	
61%	% of female **replacements** per animal exposed to the sexed semen program	
36%	% of female **replacements** per animal exposed to conventional semen program	2.7 number of lactations
	69% percent additional replacements from pool of animal bred with sexed semen compared to conventional AI	
21%	% of all replacements that are extra sexed semen program heifers from the "top end" animals	
51%	% of all replacements that are from the sexed semen program	
79%	percent of the total population needed to produce replacements (including conventional semen if used)	
665	standard deviation of PTA Milk of maternal (breeding pool) population (ME Milk)	
771	average PTA Milk of the sexed semen heifers from the "top end" breedings (cow-side gain)	
239	average PTA Milk of the rest of the population produced with bottom tail discarded (cow-side gain)	
349	**average gain in PTA Milk of all the replacements, derived from both sexed semen and conventional breedings**	
	$ 195 NPV gain at time of breeding for the sexed semen program-derived heifers: milk and offspring	
$ 88	**average value of genetic gain discounted to the time of breeding for all replacements: milk and offspring**	
36%	proportion of the breeding pool that produces a replacement female	
$ 32	**genetic gain per animal entering the sexed semen program breeding pool**	
$ (11)	weighted gain or (loss) per animal entering the sexed semen program breeding pool: extra females, extended days to calving, etc.	
$ 22	**total gain (loss) per animal entering the sexed semen program breeding pool**	
$ 72	profit per heifer that is bred using sexed semen	
$ 56	extra semen cost per heifer that enters the sexed semen program	
129%	return on the investment in sexed semen program semen costs	



Heifers at $1,400

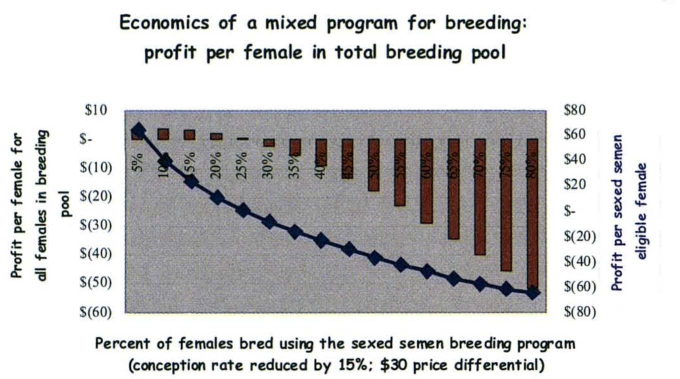


Figure 3. Impact of the proportion of the population bred with sexed semen on profit of the average animal in the breeding pool, and those bred using sexed semen heifers. Heifers valued at $1,800.

5% results in a profit of $145 per heifer thus bred. These numbers are based on a replacement heifer value of $1,800. If the value drops to $1,400, the situation is quite different. The second chart in Figure 3 shows this scenario. The best average profit is at only 10% utilization of sexed semen, and is only $4. Breeding the top 5% of heifers now results in only $65 profit per heifer bred. Thus, there are still some "top end" heifers that are worth breeding with sexed semen, but not nearly as many as when heifers are valued at $1,800.

The most profitable use of sexed semen depends on how many "top end" heifers are bred, and on other factors as well. Figure 4 illustrates the impact of the proportion bred with sexed semen and the absolute value of reduction in conception rate from sexed semen. As the figure shows, if the impact on conception is small (5%), substantially more heifers should be bred with sexed semen than at higher reductions in conception. If conception rates were reduced by an absolute value of 25% (from 60% to 35%), essentially no scenario of sexed semen use is profitable.

As noted earlier, sexed semen does not need to be used for every breeding of a heifer. It could be used in the first breedable cycle, the first and second, and so forth. Figure 5 illustrates this relationship, again with heifers valued at $1,800. In this scenario, it pays to breed an eligible heifer more than just on her first cycle (actually five to six cycles) with sexed semen. If the same evaluation is done with heifers at $1,400, the most profitable use is only during the first breeding. This latter finding tends to be the same for cows: multiple breedings with sexed semen tend to be less profitable than using it only once and then switching to conven-

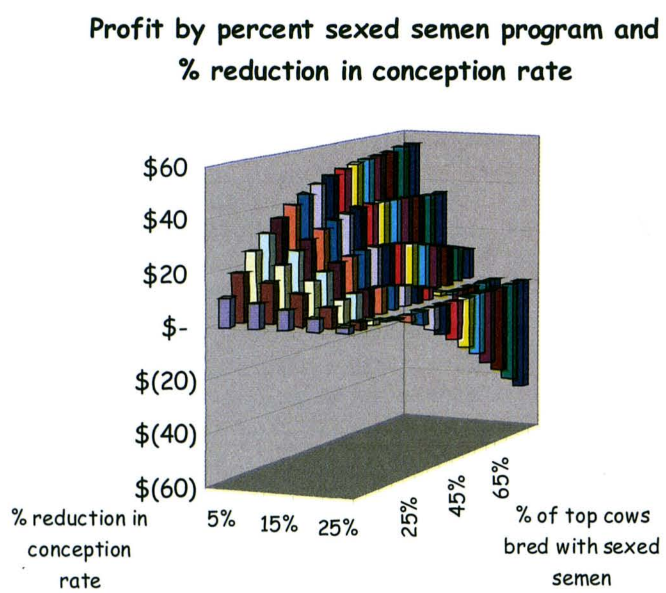


Figure 4. Impact of the level of use of sexed semen and the impact of conception on the profit per female in the breeding pool. Heifers valued at $1,800.

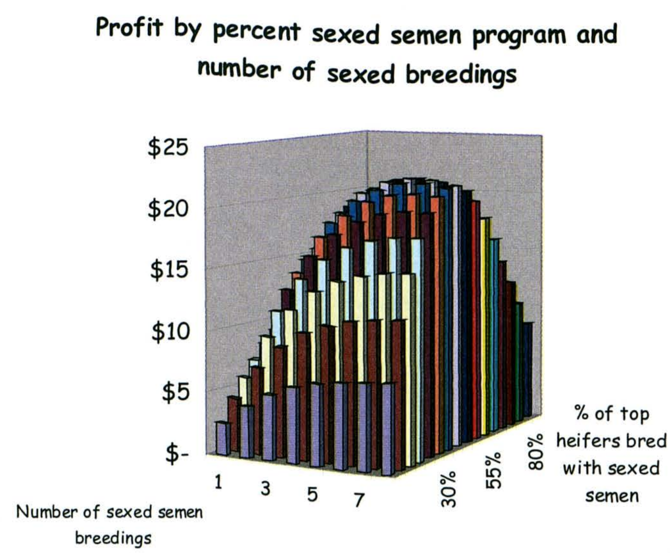


Figure 5. Impact of number of breedings using sexed semen by level of use: heifers.

tional semen. All of this is highly dependent on the genetic merit of the cow and the actual impact of sexed semen on conception. Better conception tends to support more sexed semen breedings.

Broadly speaking, in heifers there are two opposing economic forces at play, genetic gain (by breeding top merit animals for replacements) versus the extra costs (delayed calvings, extra heifers culled as open and the cost of sexed semen itself). These costs can be mitigated if extra heifers are worth substantially more than the cost of raising them. Knowing that these are the major influencing factors, one can predict the general direction of the economic outcome, even if one cannot calculate the actual numbers on the back of an envelope. There is a place for using sexed semen in virgin heifers, but that place will depend on farm and market conditions, semen price, conception rate difference and ability of the dairy to accurately rank its heifers by genetic merit.

Moving from virgin heifers to milking cows makes using sexed semen more problematic economically. In cows, the impact of reduced conception is much larger. The conception rate in cows is lower, and any further reduction increases average days open in cows bred with sexed semen and increases the risk that a cow may not get pregnant and be culled. Table 5 shows a scenario with replacement heifers at $1,800, the top 30% of cows eligible to be bred with sexed semen, a 10% reduction in conception rate (35% versus 25%) and sexed semen used only on the first breeding cycle. Profits are much thinner than with heifers, only $1 per cow in the breeding pool and $3 per animal bred with sexed semen.

Figure 6 shows the graph for profit by percent of animals eligible for breeding with sexed semen. The "optimal" level is to use sexed semen in the top 20% of cows, but the profits, when there are profits, all hover around $1 per cow. The dairy can find better places to invest its money and energy. Even breeding the top 5% of cows with sexed semen only produces a profit of $19 per cow on an investment of $16 per cow bred with sexed semen. Clearly, the impact of reduced conception in cows is very hard to overcome. In fact, if the impact is larger than a 5% reduction in the absolute conception rate, it is hard to create a scenario that justifies use of sexed semen on any but the very best cows (Figure 7).

Values for the use of sexed semen have all depended on the bull being the same for both options, sexed semen or conventional. If the genetic merit of the bull used for sexed semen is less than the genetic merit of the bull used for conventional breedings, any genetic gain on the cow side is quickly lost. In the scenario shown in Table 4, if the bull used for sexed semen were

Table 5. Model including the value of genetic gain: cows.

Sexed semen economics, including for the value of genetic gain			milking cows
$ 10.00	mik price minus marginal feed cost		
$ 30	semen cost differential: if not the same bull, enter the sexed semen bulls PTA Mik differential below		
10%	percent reduction in the absolute value of the conception rate (not proportion of conceptions)		
1,800	value of a springing heifer		
8%	discount rate	-	sexed semen bull PTA Mik differential compared to conventional AI bull used
30%	**percent of the sexed semen breeding pool at least initially bred with sexed semen: "top end" heifers**		
39%	% of female **replacements** per animal exposed to the sexed semen program		
35%	% of female **replacements** per animal exposed to conventional semen program	2.7	number of lactations
	12%	percent additional replacements from pool of animal bred with sexed semen compared to conventional AI	
4%	% of all replacements that are extra sexed semen program heifers from the "top end" animals		
34%	% of all replacements that are from the sexed semen program		
96%	percent of the total population needed to produce replacements (including conventional semen if used)		
665	standard deviation of PTA Mik of maternal (breeding pool) population (ME Milk)		
771	average PTA Milk of the sexed semen heifers from the "top end" breedings (cow side gain)		
54	average PTA Milk of the rest of the population produced with bottom tail discarded (cow side gain)		
80	**average gain in PTA Milk of all the replacements, derived from both sexed semen and conventional breedings**		
	$ 193	NPV gain at time of breeding for the sexed semen program-derived heifers: milk and offspring	
$ 20	**average value of genetic gain discounted to the time of breeding for all replacements: milk and offspring**		
35%	proportion of the breeding pool that produces a replacement female		
$ 7	**genetic gain per animal entering the sexed semen program breeding pool**		
$ (6)	weighted gain or (loss) per animal entering the sexed semen program breeding pool: extra females, extended days to calving, etc.		
$ 1	**total gain (loss) per animal entering the sexed semen program breeding pool**		
$ 3	profit per cow that is bred using sexed semen		
$ 16	extra semen cost per heifer that enters the sexed semen program		
20%	return on the investment in sexed semen program semen costs		

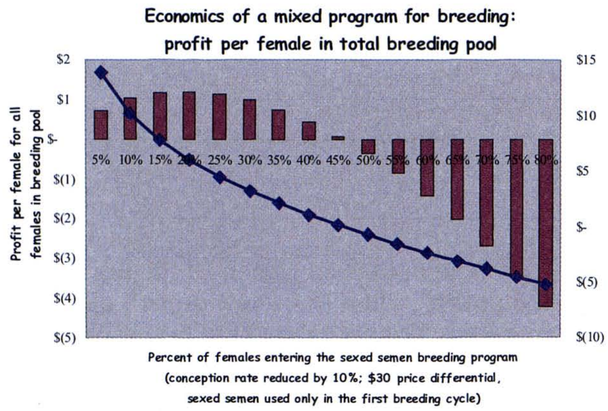


Figure 6. Impact of proportion of cows bred with sexed semen on profit.

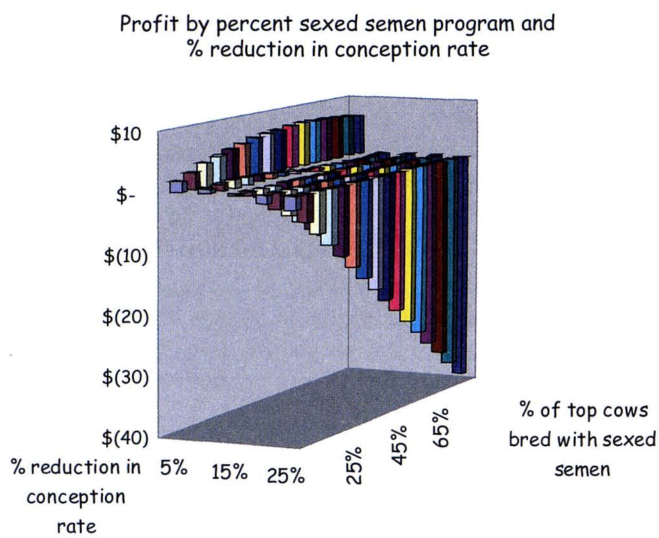


Figure 7. Impact of the level of use of sexed semen and the impact of conception on the profit per female in the breeding pool: cows.

400 lb (182 kg) of PTA Milk poorer than the bull used for conventional AI, the profit from use of sexed semen would drop from $22 per heifer in the breeding pool to only $3.

Conclusions

Sexed semen is a new and potentially important technology in dairy reproduction. It offers the promise of a more abundant supply of better replacement heifers, particularly if the technology can be made more widely available and if reductions in conception rates can be minimized.

Herds with better genetic information about their breeding populations have an opportunity to capture more value from sexed semen. They will use sexed semen to breed their better dams and make more rapid genetic progress than before. Herds that want to assure a more reliable and better quality of internally grown heifers will use sexed semen to source more replacements and improve biosecurity. Genetic selection can potentially place some emphasis on characteristics not routinely selected for today.

Because of its impact on conception, sexed semen is currently more applicable in virgin heifers than in cows. Its use without consideration of genetic merit is not likely to be cost effective; the gain in value for more heifers does not offset the various costs involved. Significant biosecurity concerns (not considered in any of the models presented in this paper) might tip the balance in favor of more use of sexed semen to produce replacements internally.

The optimal use of sexed semen depends on many economic and biological factors. There is no reliable "rule of thumb" that can dictate proper use across the variety of herds and economic scenarios possible. Proper use of sexed semen will require good genetic information on females in the breeding pool, and thoughtful calculation of the best targeted use in top genetic-merit candidates.

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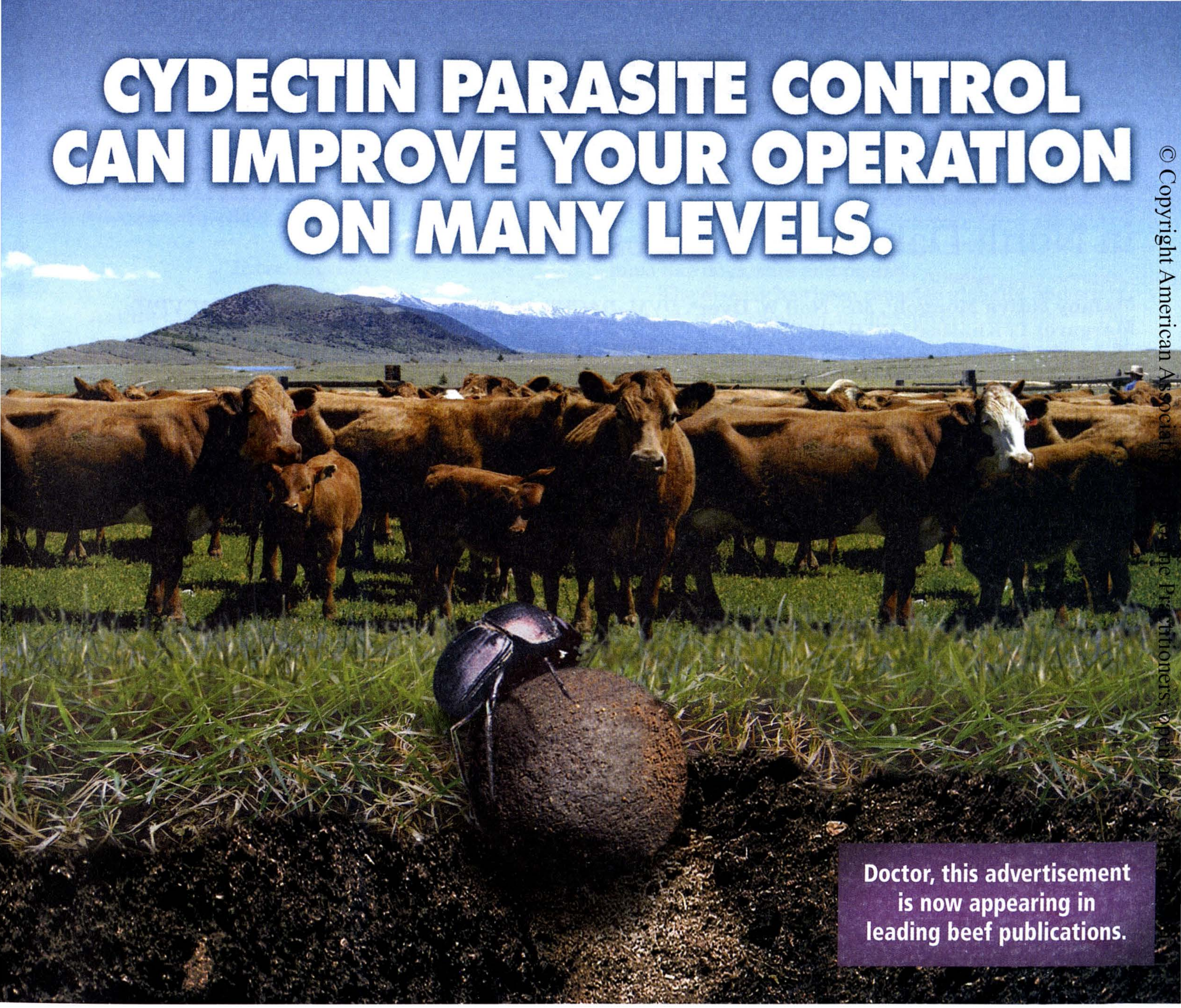

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