Effect of Inbreeding on Lifetime Performance of Dairy Cows

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Take Home Message

- Inbreeding is expensive. For cows that survive to freshen the first time, each 1% increase in inbreeding reduces lifetime net income by $22 to $24.
- Inbreeding results from the mating of related individuals. Relationships between dairy animals are increasing over time because of selection toward similar breeding objectives.
- There is no magic level of inbreeding that is acceptable.
- Inbreeding should be managed in a herd breeding programs rather than avoided. Outstanding bulls should be used if the benefits of genetic improvement exceed losses from any possible inbreeding depression.
- Inbreeding in offspring differs for each sire-dam combination, making mate assignments important if inbreeding is to be managed properly. Blanket recommendations of a bull as an “outcross” to groups of cows may not be effective in reducing the impact of inbreeding.

Introduction

Selection for improved lifetime economic performance or any other aggregate genotype tends to increase relationships among individuals in a population as the most desirable genotypes are found in a few individuals. Intensive selection reduces the number of individuals chosen to have major impact on future generations in populations such as diary cattle where AI and embryo transfer techniques are applied. Dr. Hansen’s presentation at this conference has highlighted the current trends in the dairy industry. Globalization of semen marketing efforts has increased ties between previously unrelated dairy populations. Inbreeding has emerged as a factor to consider in assigning mates for production of replacement females.

Effects of inbreeding on performance of commercial dairy cattle are almost entirely negative. Inbreeding decreases cow survival, single lactation production, and reproductive performance. Inbreeding increases calf mortality, increases age at puberty through retarded growth, and increases rate of disposal or loss of replacement heifers prior to first calving. While inbreeding has played a role in development and improvement of specialized strains of livestock, costs clearly outweigh benefits in commercial applications.

Management of herd breeding programs to control the effects of inbreeding requires pedigree information. The development of large, specialized dairies in North America in recent years has been accompanied by decreased emphasis on individual animal identification. Many large herd managers have questioned the benefits of individual cow ID to their operation. Avoidance of inbreeding losses is one such benefit. Inbreeding will reduce performance of animals whether herd management recognizes those losses or not. One objective of this paper is to encourage complete identification of cows by sire and dam and maintenance of historical pedigree files for use in herd breeding programs.

Several years ago, we began a study at Virginia Tech to learn more about the effects of inbreeding on lifetime performance of the dairy cow. The work reported here is a result of the dedicated efforts of Ms. Lori Smith, now an employee of the Animal Improvement Programs Laboratory, USDA, Beltsville, MD. The study was based on lifetime performance of cows in herds classified for type by the Holstein Association (USA) between 1983 and 1993. Studies using classification data usually are dominated by registered cows, but 54.5% of all cows in the original data were grades. Cows scored under special programs to obtain early type proofs on progeny test bulls were included as were all cows in herds which classified, not just the cows observed by the classifier. A wide range of US dairy conditions was represented in the study, as over 2.6 million cows were included.

▪ Measuring Lifetime Performance

We used a measure of lifetime economic merit called Lifetime Relative Net Income. This function is calculated from production variables available on many thousands of cows involved in the DHI program. The function assigns value to each kg of milk, fat, or protein produced by a cow across her lifetime. We define "lifetime" as including all lactations initiated prior to 84 months of age. She is credited with an average value for each calf born which includes reproductive costs to produce that calf, and average death losses and sex ratios. Finally, she is credited with a net salvage value, which reflects the change in her worth from calfhood to culling as a mature animal. Relative net income is called "net income" because charges are made against the cow for her rearing (which vary depending on her age at first freshening), her maintenance costs while in the milking string, and maintenance while in the dry cow lot. Finally, feed costs of production are applied separately for each kg of milk, fat, and protein produced. Milk is cheaper to produce than fat. Protein is the most expensive milk component to produce.

The equation used to calculate Relative Net Income is as follows:

$$\begin{aligned}
\text{RNI} = & \sum_{i=1}^{n}\left[\sum_{j=1}^{3}\text{Component}_{ij}\left(\text{Value}_j - \text{Cost}_j\right)\right] \\
& + (\text{number of lactations})(\text{net value of a calf}) \\
& + \text{net salvage value} \\
& - (\text{total days in milk})(\text{daily expenses per day in milk}) \\
& - (\text{total days dry})(\text{daily expenses per day dry})
\end{aligned}$$

In this equation, the net value of milk produced is summed over lactations using actual production instead of ME values. The difference in the value of each component and the cost of feed to produce the component is the net value assigned to each unit of each component produced. The values associated with each unit of each component were based on one of two marketing systems: a market where milk is marketed for fluid purposes and a market where milk is used for cheese production. Per unit costs of production were highest for protein and lowest for milk (carrier). Other costs involved in keeping cows in dairy herds after they enter the milking string are included in the last two terms in the equation. Daily expenses are higher when the cows are in milk because of extra depreciation expense of facilities such as the milking parlor and to cover the costs of extra labor during lactation. Expenses per day during the dry periods are less.

One other important adjustment is made to RNI before it is used in research. The cow is charged “rent” for each day she spends in a stall in the herd. This charge is called “opportunity cost” and is used so that a cow isn’t credited with simply being allowed to survive in a herd. Keeping one cow eliminates the opportunity to keep another, potentially more profitable, cow in her place. We estimate opportunity cost separately for each herd and year of first freshening based on the average RNI of cows freshening for the first time in that herd and in a specific year. For most herds, opportunity costs go up over time because the average two year old first freshening in later years is genetically superior to cows freshening for the first time years earlier. When we are all done with the statistical manipulation, the average relative net income adjusted for opportunity cost (RNIOC) for all cows in a population will be close to zero. That doesn’t mean the farmers made no money. What it means is that farmers tend to cull cows at about the time when a replacement animal would be at least as valuable if given the same stall space.

There is a lot of variation from one cow to the next in RNIOC. The numbers are negative for cows culled in first or early second lactation when rearing cost has not been recovered. Cows with four or five lactations will have accumulated substantial income totals. By the way, total opportunity cost will be highest for the cow with the most days in the milking herd. She has to justify her stall space every day. Our purpose in developing RNIOC is not to make a precise estimate of just how valuable each cow is to her owner. We don't have the information on enough individual cows to do that and to make studies like the one covered in this paper. Our purpose is to make the best use we can of the DHI data that are available. RNIOC is a very reasonable approximation of economic utility of individual cows. It gets the right cows at the top and the right cows at the bottom of profit lists for individual herds.

Another lifetime performance variable appearing frequently in research studies is length of productive life. In the US, genetic evaluations are available for productive life measured as months in milk (maximum of 10 months/lactation) by 84 months of age. We used days in milk in this study. Lifetime totals of milk, fat, and protein produced are also useful measures of lifetime performance.

▪ Estimation of Inbreeding Coefficients

Effects of inbreeding on animal performance can only be estimated if inbreeding and performance are both measured. Producers in North America are used to recording production, type, somatic cell score, and other measures of performance. The other critical piece of data required to convert performance records into genetic evaluations for performance or into scientific results is pedigree data. Registered breeders make substantial investments in recording, maintaining, and checking accuracy of pedigree data. Producers with grades may or may not make much investment in the same process. The dedication of producers to animal identification and pedigree recording has a large impact on estimates of effects of inbreeding. *More importantly to the producer, pedigree data is critical to managing inbreeding through mate assignment*.

Genetic evaluations in the United States have required that performance records include a valid birth date, calving date, animal identity, and sire identity. Dam identification is not required for genetic evaluations. Dam ID is critical to estimate inbreeding. A study in Iceland found an average inbreeding coefficient of 1.82% when animals were required to have sire, dam, and at least one grandparent identified. When a minimum of four generations of complete pedigree data were required, the average inbreeding coefficient was 2.70%. Incomplete pedigree data will have an effect on estimation of inbreeding coefficients. Just how important that can be to estimation of the effects of inbreeding will be shown momentarily.

Estimates of inbreeding for cows included in genetic evaluations in the United States are routinely available. Where pedigree information is incomplete, inbreeding is estimated on the basis of assumptions about average relationships. For instance, if a production record on a cow includes her ID and birth date, her sire ID, but no identification on her dam, assumptions are made about the relationship between sire and unknown dam. Dr. George Wiggans worked out those assumptions to apply to the large amount of incomplete pedigree data available on grade animals. He assumes that the relationship between known and unknown parents or between two unknown parents would be the same as between average known animals born the same year as the most recent parent. If dam ID is missing, the dam was assumed to have been born 3 years before the birth date of her daughter. The dam would usually be the youngest animal, especially if her daughter was sired by a proven bull, but that isn't always the case. Dr. Wiggans uses his procedure on USDA files for genetic evaluations of dairy cows. This means the cows all have sire ID, as records with missing sire ID are screened from the original files.

Think about the process of guessing about relationships between a bull and a cow when identification is missing. Average relationships between known animals are fairly small compared to actual relationships that can exist between cousins, aunts and nephews, half and full sibs. Estimated relationships would not exceed actual relationships by very much, even if animals were really unrelated. We might guess at a 2 or 4% relationship when the actual relationship is 0, for instance. On the other hand, average relationships could very well be a lot less than actual relationships that exist between an unidentified cow and an AI bull. Inbreeding, by definition, is half of the relationship between the parents. If you have to estimate the relationships between parents, you will never overestimate by very much, but you could underestimate by a lot.

Computer programs that will be developed to estimate inbreeding from each of several possible service sires to each cow will face the same problem when pedigree data are incomplete. This means that the value of complete pedigree data will go up for those breeders who choose to really deal with the inbreeding issue in their herd breeding programs. Registered animals once held a distinct lead over grade animals in genetic merit. AI closed the genetic gap between registered and grade cows, but there is an additional value of registered animals as producers of milk from the completeness and accuracy of the pedigree data available on them. That is a greater advantage than many people yet realize.

▪ Effects of Inbreeding

We examined the effects of inbreeding depression in entirely registered and entirely grade herds. Our purpose was to see how much difference quality of pedigree information might have on results. Both answers will be presented, but readers are advised to place greater reliance on results from registered herds. Those of us involved in this project were frankly surprised at the differences. Results from grade cows obscure what is really happening in our dairy cow populations. Remember that inbreeding depression that you don't know about (because of missing pedigree data) costs you just as much money as the inbreeding depression you could calculate.

Table 1. Comparison of inbreeding depression on production and lifetime performance traits for 257,449 registered and 449,343 grade Holstein cows.

Trait	Inbreeding depression per 1% increase in inbreeding	
	Registered cows	Grade cows
RNIOC, fluid market ($)	-24	-9
RNIOC, cheese market ($)	-22	-9
Age at first calving (days)	0.4	-0.2
Days of productive life	-13	-5
Total days in milk	-10	-4
First lactation ME milk (kg)	-37	-16
First lactation ME fat (kg)	-1	-1
First lactation ME protein (kg)	-1	-1
First lactation SCS	-0.004	-0.001
First calving interval (days)	0.26	0.21
Total milk (kg)	-358	-141
Total fat (kg)	-13	-5
Total protein (kg)	-11	-5

Inbreeding Depression for Lifetime Economic Merit

We estimate that each 1% increase in inbreeding costs producers $24 if they sell milk to fluid markets and very nearly as much, $22, if their milk is sold for cheese production. These losses appear to be linear, meaning that a mating which produces a calf with 2% inbreeding produces $22 to $24 less net income than a mating which produces a calf with 1% inbreeding. Comparison of animals at 12 and 13% inbreeding shows about the same difference. As we learn more about the effects of inbreeding in years to come, this observation may not continue to be valid, but, for now, it appears to be true.

Inbreeding Depression in Other Traits

Inbreeding produced undesirable effects on all the traits in Table 1 based on results from registered cows. First lactation milk production was reduced by 37 kg for each 1% increase in inbreeding. For many years, the expected loss in first lactation from 1% inbreeding was about 22 kg. We should expect greater losses with today's animals, as our cows are capable of higher production than cows of years ago. First calving interval is extended slightly (0.26 days) by inbreeding, suggesting that inbreeding has a negative impact on reproductive performance. Age at first calving was increased by inbreeding, which may be due to poorer reproductive performance or delayed puberty due to depressed growth of inbred calves.

Notice that the impact of inbreeding on total lifetime milk production, -358 kg, is nearly 10 times as great as the effect of inbreeding on first lactation yield. The cumulative effect of inbreeding across a cow's productive life is considerably larger than its effect on a single lactation. Inbreeding not only reduces how much milk a cow gives per day, it reduces the number of days the average cow remains in the herd to produce. Table 1 shows an inbreeding depression of 13 days of productive life and 10 days in milk for each 1% increase in inbreeding. Those days are lost at the end of life, when the cow is milking at mature levels compared to her first lactation performance. Looking at the various parts of a cow's total lifetime performance should reinforce the impact of the $22 to $24 loss in lifetime net income discussed earlier.

We did not see any meaningful effect of inbreeding on somatic cell score. The changes shown in Table 1 would be so small that they really play no role in mating decisions. At this point, we don't know much about what inbreeding does to body functions like immune response, disease resistance, and so forth. This is another part of the inbreeding story that is unfolding, but these results say that inbreeding has little effect on somatic cell scores.

Registered Versus Grade Cows for Inbreeding Studies

All the results in Table 1 showed more extreme effects of inbreeding in registered than in grade cows. The average inbreeding coefficient on the 257,449 registered animals was 1.67% with a standard deviation of 2.24%. For the 449,343 grade cows the average coefficient of inbreeding was only 0.57% with a standard deviation of 1.60%. We just didn't have many grade cows with any real measurable amount of inbreeding. That doesn't mean that they weren't inbred, but it does mean that we didn't know which ones were inbred. The responses in Table 1 depend on what we know. Those of us involved in this study had difficulty believing that grade producers actually were more effective in avoiding inbreeding that the registered herd owners. Certainly, a few registered breeders were willing to make some inbred matings. We strongly suspect that about the same inbreeding was occurring in both groups. However, we were only able to measure it in the registered cows with complete pedigree data available.

The most dramatic differences in registered and grade estimates of inbreeding depression were in the lifetime performance traits like RNIOC and lifetime total milk. We saw less than half as much depression of lifetime net income in grade as in registered cows. Lifetime total milk losses in grades were also less than half of what they were in registered cows. Our interpretation is that the results from grade cows dramatically understate what is going on. If we look at a mixed population of grade and registered animals, we would also underestimate the true effects of inbreeding. Conclusions should be based on the registered cows.

Effects of Inbreeding on Type Traits

We looked at the effects of inbreeding on type traits, but don't show them here because they were very small. We weren't the first researchers to see this result as Drs. Tom Short and Tom Lawlor found the same thing several years ago. We did see some small changes in udder traits that appeared to be the result of lower milk yield in the more inbred animals. Body traits were depressed by inbreeding. That effect appears to be real and does verify results of growth/inbreeding studies back in the 1950's that showed that inbreeding produced slower growing animals that never reached the mature size of outbreds. Overall, however, impact on type traits is NOT a reason to be concerned about inbreeding in dairy cattle.

Major Impact of Results on Producers

You will find mating programs around that manage inbreeding by avoiding certain close matings. This approach is better than ignoring inbreeding altogether, but it is not the best approach because it implies that inbreeding only matters if it exceeds a fixed amount like 6.25%. Our results show that inbreeding below that level is just as expensive per 1% increase in inbreeding as is inbreeding above that value. We have a lot left to learn about how much inbreeding would be produced by "typical" matings to popular AI bulls, but what I have done so far suggests that many decisions will involve matings that produce 2% to 4% inbreeding. A mating program that avoided some maximum inbreeding would ignore these decisions and cost you money in the process. What to do? Each possible mating in a herd should be evaluated to see how much inbreeding it produces. The mating sire's proof for an index of traits you are selecting to change in your breeding program should be reduced by the amount of inbreeding depression produced. The best service sire for each cow is the bull whose index, adjusted for inbreeding depression, is the highest. This approach requires a good computer and excellent pedigree data, but it is the best way to mate cows and make maximum genetic progress. I know of only one program that uses this approach today, but more will follow if that one program gains an edge.

▪ Impact of Inbreeding in Specific Matings

If a cow for which sire identification is missing just happens to be bred to a bull that is a son of her sire, a half sib mating results. Such a mating produces 12.5% inbreeding or more if other relationships also exist. Suppose a herd manager keeps good records and avoids those half sib matings, but forgets to look at the maternal grandsire of the service sire. A mating of a cow to the son of her half sister is an aunt-nephew mating. It produces 6.25% inbreeding. In the Virginia Tech herd, we have several older daughters of the Holstein bull, Blackstar. The active AI bull list includes many proven bulls whose sire is Blackstar, and more yet that are sons of Blackstar daughters. Carelessness on our part in breeding those Blackstar daughters could easily produce either kind of mating described above. Table 2 shows the effect of such matings. We used the inbreeding depression estimates from registered cows for these results.

The bottom line from Table 2 is that a mistake in mate assignment can be expensive. A loss of $150 of NET income from an aunt-nephew mating can pretty well wipe out any gain from genetic selection. It's also a loss that cannot really be recovered by management skill. It is also important to remember that the losses in Table 2 are from cows that survived to calve a first time. Additional losses due to embryonic mortality, calfhood diseases, reduced growth rates, and possible infertility of inbred calves should be expected.

My purpose in showing Table 2 is to demonstrate what can happen from a mistake. However, the more common losses in herd breeding programs will result from much more subtle mistakes. If a producer simply checks the sires and maternal grandsires of the bulls he is using against the sire of the cow being bred, avoiding any duplication, he will avoid both types of matings in Table 2. That effort is more than many producers now make, but it won't prevent inbreeding that results from more remote relationships. Those relationships are the ones, which have begun to build up, as Dr. Hansen's paper in these proceedings shows. What herd mating programs really need to control are the matings that produce 3, 4 or 5% inbreeding when an alternate mating to high ranking, but less related bulls are available.

Table 2. Inbreeding depression for half sib (12.5% inbreeding) and aunt-nephew (6.25% inbreeding) matings in Holstein cows.

	Total losses from two kinds of matings	
Trait	**Half sib matings (12.5% inbreeding)**	**Aunt-nephew matings (6.25% inbreeding)**
RNIOC, fluid market ($)	-305	-153
RNIOC, cheese market ($)	-272	-136
Age at first calving (days)	5	3
Days of productive life	-163	-82
Total days in milk	-129	-65
First lactation ME milk (kg)	-464	-232
First lactation ME fat (kg)	-15	-8
First lactation ME protein (kg)	-15	-8
First lactation SCS	-0.05	-0.03
First calving interval (days)	3.3	1.7
Total milk (kg)	-4480	-2240
Total fat (kg)	-165	-83
Total protein (kg)	-143	-72

It bears repeating at this point that our purpose should be to recognize the losses associated with inbreeding, but not to respond by trying to eliminate inbreeding altogether. Some buildup of inbreeding is a natural consequence of using heavily as parents those relatively few individuals that have the best genes for the assortment of traits we wish to change through selection. Those top sires need to be used as mates in herd breeding programs, but used in ways where the merit of the sire chosen as a mate is optimum AFTER the effects of inbreeding have been considered. This certainly is more work, requires more data, and demands that computers be used in planning a herd breeding program. But it is the best way to deal with inbreeding and inbreeding will be a bigger problem in the years to come than it is today.

Conclusions

The effect of inbreeding depression on lifetime performance of dairy cattle is several multiples of its impact on an individual lactation. We estimated losses of $22 to $24 in lifetime net income for each 1% of inbreeding in a mating. Complete pedigree information is essential to observe the true impact of inbreeding. Mating programs to avoid inbreeding entirely or even to reduce it to 2 or 3% are not likely to be economically justifiable if they ignore the merit of bulls chosen as mates in the process. The optimum mate for any cow is that bull whose genetic merit for the collection of traits under selection is highest after adjusting for effects of inbreeding in the given mating. This approach to sire selection means that each AI bull has a different effective proof for every cow. It is a process that requires computers and access to pedigree data bases. However, mate assignments that ignore the genetic merit of the bulls chosen and focus entirely on inbreeding make the cure worse than the ailment. The highest ranking bulls available in AI need to continue to be used in herd breeding programs.

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