Effect of Inbreeding On Cow Performance & Mate Selection in Dairy Cows

By Bennet G. Cassell
Extension Dairy Scientist, Genetics and Management
Department of Dairy Science
Virginia Polytechnic Institute and State University
Blacksburg, VA, 24061-0315
540-231-4762
fax 540-231-5014
bcassell@vt.edu

Western Dairy Management Conference

Effect of Inbreeding On Cow Performance & Mate Selection in Dairy Cows

As a group, dairy producers agree fairly well about what they want to change in dairy cows through genetic selection. There is disagreement about which bull is the 'best' bull, but general agreement about which bulls are in the top group. Consequently, cows and A.I. bulls have become more related over time because a few individual animals appear frequently in pedigrees. For instance, Pawnee Farm Arlinda Chief and Round Oak Rag Apple Elevation are each responsible for about 12% of the genes segregating in the U.S. Holstein population.

We need to recognize that this isn't a situation where mismanagement has set the woods on fire. Selection efforts to improve dairy cattle have been effective. Other dairy populations around the world have turned to U.S. genetics to improve their own cows. Globalization of semen marketing efforts has increased ties between previously unrelated dairy populations. Inbreeding has emerged as a factor in assigning mates to produce replacement females. Simply put, more of our cows are fairly closely related to the bulls that we want to use as service sires than was the case several years ago.

Where Does Inbreeding Come From?

Inbreeding results from the mating of related individuals. The closer the relationship between the parents of an individual, the greater is the inbreeding produced. Calculation of inbreeding is a tedious process if done accurately using realistic pedigrees. Even remote ancestors of both parents contribute some to inbreeding. If we ignore the remote relationships, we understate the problem caused by inbreeding. Consider a commercial herd that relied heavily on young sires. The sires of those young sires are very good bulls. Their daughters would be used as bull mothers in the next generation of young sires. Use of young sires for several years would result in matings of daughters of young bulls from previous years to current young bulls whose dams were half sibs to the sires of cows being mated. It took five minutes to figure out how to state that pedigree and most producers would ignore such a relationship. However, it produces over 3% inbreeding and probably would not be the only source of inbreeding in such a pedigree.

What Does Inbreeding Do?

Inbreeding makes pairs of genes alike or homozygous. It reduces the genetic diversity within an individual. Diverse genes make animals more adaptable to varied environmental conditions. Diverse genes reduce the likelihood of undesirable homozygous recessive characteristics like mule-foot, RVC, Weavers, and many other unnamed and usually unknown genetic defects. The opposite of inbreeding depression is hybrid vigor, which results from mating of unrelated or genetically diverse parents. Mules are the result of mating mares (usually from very large breeds of horses) to burro stallions. The parents are diverse and the offspring are tough. If you understand the causes of hybrid vigor, you also have a pretty good concept of the consequences of inbreeding.

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.

What Are The Economic Consequences?

Several years ago, we began a study at Virginia Tech to learn more about what inbreeding does to 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. The data were by no means restricted to registered cows as 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 U.S. dairy conditions was represented in the study, as over 2.6 million cows were included.

Measuring Lifetime Performance: Relative Net Income

We used a measure of lifetime economic merit called Lifetime Relative Net Income, which is calculated from production records on many thousands of cows in the DHI program. We assign a value to each kg of milk, fat, or protein produced by a cow across her lifetime. 'Lifetime' includes all lactations initiated prior to 84 months of age. The cow 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:

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

The net value of milk produced – component times the difference in value and cost of production – is summed over lactations using actual production instead of ME values. We used two sets of values for each component: one where milk is marketed for fluid purposes and one 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, just as they are on operating dairy farms.

We charge each cow '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 considered valuable simply because she was 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 any year is genetically better than cows born 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, though some of you recall times when that certainly seemed to be the case. 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. Our purpose is to make the best use we can of the DHI data that are available. RNIOC gets the right cows at the top and the right cows at the bottom of profit lists for individual herds.

We have genetic evaluations for productive life in the U.S. based on months in milk (maximum of 10 months/lactation) by 84 months of age. We used a similar trait in this study, but used days instead of months in milk. Lifetime totals of milk, fat, and protein produced are also useful measures of lifetime performance.

Estimation of Inbreeding Coefficients

Producers in the U.S. 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 require that performance records include a valid birth date, calving date, animal identity, and sire identity. Dam identification is not considered essential, but it 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. We learned just how much difference a complete pedigree made in estimates of inbreeding depression in this study.

Estimates of inbreeding for cows included in genetic evaluations are calculated by USDA. When gaps are found in pedigree information, inbreeding is based on 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 of the Animal Improvement Programs Laboratory, USDA, Beltsville, MD, worked out those assumptions to use on the large amount of incomplete pedigree data USDA has on grade animals. He assumed 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. In other words, the best we can do under such circumstances is to make an organized guess.

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, actual relationships could very well be a lot greater than a guess based on averages. Inbreeding, by definition, is half of the relationship between the parents. If we guess at the relationships between parents, we will never overestimate by very much, but we 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. A.I. 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

Our estimates of inbreeding depression come from entirely registered and entirely grade herds.

Our purpose was to see how different the results were. Both answers will be presented, but please be advised to concentrate on results from registered herds. We were frankly surprised at the large differences in our estimates. 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.

Inbreeding Depression For Lifetime Economic Merit

We estimate that each 1% increase in inbreeding costs the producer $24 if milk is sold to fluid markets and very nearly as much, $22, if milk is sold for cheese production. The 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.

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.

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

	(Inbreeding depression per 1% increase in inbreeding)	
trait	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

We did not see any 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 vs. 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 had very few grade cows that we knew were highly inbred. That doesn't mean that the cows were outcrosses. It does mean that we didn't know which ones were inbred. The responses in Table 1 depend on what we know. I have 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.

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 A.I. bulls, but what I have done so far suggests that lots decisions will be made between matings that produce 2% to 4% inbreeding. A mating program that avoided some maximum inbreeding would ignore lots of those 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 A.I. 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 using results from registered cows in Table 1.

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. The losses in Table 2 are based on 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.

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

trait	total losses from two kinds of matings: 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

Table 2 shows 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. Such an effort is more than many producers now make, but it won't prevent inbreeding that results from more remote relationships. 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.

How Might Farmers Manage Inbreeding In Sire Selection and Mate Assignment?

If inbreeding is not a concern in a mating, the sire chosen will be the bull with the highest combination of PTA's for traits in a selection index. The highest TPI bull would be a potential mate for cows in a herd where the owner wanted to improve TPI. Of course, semen price and availability, risk of proof changes, and a common sense approach to using more than one bull in a breeding program mean that the choice seldom comes down to using the bull with the absolute highest index among available A.I. sires. If inbreeding might affect the outcome of a mating, choice of mate for a specific cow means that each prospective sire's PTAs need to be adjusted (specifically, reduced) for the amount of inbreeding that one mating would produce. This means that each bull has a different effective proof in each mating that produces any inbreeding. Only when he is mated to unrelated cows can his published PTA or index be used to

Table 3. Pedigree information for four Holstein cows in the Virginia Tech dairy herd in Fall 1998 and four A.I. bulls used as service sires during the same period.

animal	sire	maternal grandsire
Cow 2962	Leadman	Likabul
Cow 2860	Blackstar	Cleitus
Cow 3280	Elton	Jetstar
Cow 3420	Bert	Elton
7H4638 Terry	Tesk	Blackstar
7H4637 Winchester	Aerostar	Cleitus
7H4937 Bubba	Oscar	Blackstar
1H3390 Eddie	Benchmark	Blackstar

see where he ranked against other bulls.

Table 3 shows four cows from the Virginia Tech dairy herd and four A.I. Holstein bulls used in our breeding program in the fall of 1998. What follows is a step by step procedure to identify the best mate for these four bulls to improve milk production. In practice, a selection index like TPI or Net Merit should be used instead of a single trait. The process is tedious if done by hand, but the principal is simple. A cow should be mated to a bull whose selection index adjusted for inbreeding is the highest available. Sometimes the work affected service sire choice and sometimes the inbreeding caused by any of the possible service sires was low enough that the process just wasn't worth the trouble.

The pedigree information in Table 3 shows that cow 2860 is an aunt to three of the four bulls as her half sisters by Blackstar were dams of Terry, Bubba, and Eddie. Table 4 shows the percent inbreeding produced by each of the sixteen matings. Some of the relationships producing the indicated inbreeding are not apparent in Table 3.

Inbreeding will affect the offspring of cow 2860 more than it will affect the offspring of cow 3280. If we had an entire herd of cows like 2860, we might want to choose some different bulls without any Blackstar blood so close up in their pedigrees. On the other hand, if all the potential relationships between cows and service sires were like those in Table 4 for cow 3280, I wouldn't be enjoying these days in Los Vegas giving this talk.

What do we do with the information in Table 4? We use it to adjust each sire's PTA for milk for the effects of inbreeding. For example, Bubba has a PTA of 2939 lbs. milk from the November 1998 USDA proofs. When mated to cow 2860, he produces 6.25% inbreeding. Table 1 shows that each 1% of inbreeding reduces milk production by 37 kg or 82 lbs. Inbreeding in this mating will reduce Bubba's effective PTA from 2939 lbs. by 513 lbs. (6.25 X 82 lbs.) to 2426 lbs. When we choose a mate for cow 2860, an unrelated bull with a PTA milk of 2426 would be just as good a choice as Bubba with his unadjusted proof of 2939. Table 5 summarizes 16 other calculations just like this example.

How does inbreeding affect our selection of mates for these cows? First of all, Eddie is not in the same category as the other bulls for improvement of milk. We used him for different reasons. Winchester and Bubba had the highest milk proofs and were close enough to be considered equal. As mates for cow 2860, Winchester becomes the better bull because he produces less inbreeding. Bubba gets the nod for cow 2962 and 3420, however. Also notice the change between Terry and Winchester as mates for cow 3420. Terry will improve milk production more than Winchester in this mating, though he would not do so on average cows in the population.

In the years to come, farmers will have access to mating programs that accomplish this process for all cows and heifers to be bred in a herd. Prospective service sires will include a much larger group than the four used in this example. The approach will not be necessary for all matings, but it will certainly improve results of some matings in most herds. For some herds, the procedure will not work because pedigree data will be missing on the cows to be bred. We had complete pedigrees on our registered Holstein cows.

It may well be that the real value of registered

Table 4. Inbreeding produced by matings between four A.I. Holstein bulls and four cows in the Virginia Tech herd in the fall of 1998.

	(cow number)			
bull	2860	2962	3280	3420
Terry	6.25	1.56	0.73	0.68
Winchester	4.00	2.20	0.29	3.61
Bubba	6.25	0.88	0.88	0.59
Eddie	6.25	1.81	0.51	1.08

Table 5. Effective PTAs for milk from four A.I. Holstein bulls when mated to four cows from the Virginia Tech herd.

		(proof adjusted for inbreeding with cow)			
bull	Nov '98 proof	2860	2962	3280	3420
Terry	2722	2241	2644	2712	2716
Winchester	2944	2616	2764	2920	2648
Bubba	2939	2426	2867	2867	2891
Eddie	2118	1606	1970	2076	2029

(or identity enrolled cows) in the coming years will be that data base of pedigree information stored in the computers at Brattleboro, VT. Mating programs that adjust for effects of inbreeding can turn those records into increased income from many cows on dairy farms.

Conclusions

Our goal should be to recognize the losses associated with inbreeding, but not to try 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 should be used 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.

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 A.I. 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 A.I. need to continue to be used in herd breeding pro-

References:

1. *Cassell, B.G. 1999. Inbreeding. Va. Cooperative Extension Publ. 404-080. Revised January 1999.*
2. *Short, T.H., and T.J. Lawlor. 1992. Inbreeding in the U.S. Holsteins and its effect on yield and type traits. J. Dairy Sci. 75(Suppl.1):154. (Abstr.)*
3. *Sigurdsson, A., and J.V. Jonmundsson. 1994. Inbreeding accumulation and pedigree completeness in the Icelandic dairy cattle population. Proc. 5th World Congr. Genet. Appl. Livest. Prod., Guelph, ON, Canada XVII:140-143.*
4. *Smith, L.A., B.G. Cassell, and R.E. Pearson. 1998. The effects of inbreeding on the lifetime performance of dairy cattle. J.Dairy Sci. 81:2729-2737.*
5. *Wiggans, G.R., P.M. VanRaden, and J. Zuurbier. 1995. Calculation and use of inbreeding coefficients for genetic evaluation of United States dairy cattle. J. Dairy Sci. 78:1584-1590.*