Improving Animals Each Generation by Selecting from the Best Gene Sources

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Animals, plants, and people can cooperate to make life better for each. People care for and improve their domesticated animals and plants, and in return those improved varieties of life improve human lives and feed billions of people. Modern methods of selection and reproduction increase genetic progress and result in domestic populations that are healthier and more productive than their wild relatives. With each generation, breeds possess more of the traits that breeders desire.

Natural and artificial selection both change populations. Natural selection uses well-known tools such as starvation, thirst, freezing, environmental stress, disease, infection, injury, and predators to genetically change populations. Males often must fight one another for mates. Natural mutations usually are harmful and cause many spontaneous abortions or deaths at early ages. Natural selection can take thousands or millions of years for improvement to occur.

Artificial selection produces specialized breeds by keeping varieties separated by fences, barns, or houses and by housing males and females separately. Genetic material can be quickly imported or exported, and global business networks distribute improved varieties efficiently using modern reproductive tools, primarily artificial insemination and embryo transfer. About 80% of dairy cows are inseminated artificially, and an additional 25,000 calves result each year from transferring embryos from elite females into other females. Thousands of males are progeny tested each year, but the next generation is sired mostly by the selected few males with the most desirable progeny. As an example of reproductive potential, one Holstein bull named Elevation born in 1965 had over 80,000 daughters, 2.3 million granddaughters, and 6.5 million great-granddaughters.

Inbreeding and possible concentration of harmful mutations are concerns in any breeding program. Breeders manage inbreeding by selecting males less related to the current female population, by crossbreeding, by adjusting genetic evaluations for inbreeding depression, and by using pedigrees and computer programs to choose mates that are less related to each other. Genetic tests reveal which animals have inherited harmful mutations, and animals free of known defects are then mated. Marker-assisted selection can trace the inheritance of a few individual genes, and in the near future genomic selection could help to trace the inheritance of all genes.

Breeders have developed highly specialized lines in some species. For example, in chickens, layers are selected for many traits but not meat yield, and broilers are selected for many traits but not egg yield or quality. Similarly, beef cattle are selected for many traits but not milk yield, and dairy cattle are selected for many traits but not growth rate or meat quality. Dairy cattle selection programs are featured in this paper because they are well documented, but similar strategies are used to improve other species.

Accurate data and pedigree files make rapid improvement of desired traits possible by allowing breeders to trace the inheritance of those traits. The Animal Improvement Programs Laboratory of USDA has collected dairy cattle records and pedigrees since 1895 and uses electronic records since 1960 to calculate genetic rankings of the top bulls and cows 3 times per year. Up-to-date information for all related animals allows breeders to maximize return on investment for selection programs both within breeds as well as across breeds. Genomic data, which will soon become available, will allow even better breeding decisions earlier in an animal's life.

Dairy breeders now select for many more traits than in past generations. Bull rankings for milk yield of daughters have been computed routinely by USDA since 1935. In 1977, dairy breeders began to select for protein yield instead of milk yield. Recent selection focuses as much on improving health and reducing costs as on improving income. Traits evaluated now include calving ease, conformation, longevity, mastitis resistance, fertility, and stillbirth rate. Table 1 shows the current percentage of emphasis placed on each trait in national genetic-economic selection indexes and the year that a genetic ranking for the trait was introduced.

National rankings from up to 27 countries for each of those traits are then combined by the International Bull Evaluation Service in Sweden into lists of the best bulls in the world. The best bull as of August 2007 is named O-Bee Manfred Justice. Table 2 compares traits of his daughters with those of average Holstein cows. Over the lifetime of an average daughter of Justice, economic advantage for those traits is $778. Already farmers are milking 10,401 of his daughters in the United States as well as 590 in France, 570 in Italy, 400 in Denmark, 267 in the Netherlands, etc., for a total of 12,670 daughters in 9 countries. Select Sires, Inc., the owner of Justice, last year sold 198,000 units of his semen at a list price of $40/unit, and the bull's total income is about $30 million to date. In 2006, the United States exported over 10 million units of bull semen worth over $60 million.

Cows produce much more milk today than in previous decades. In 1957, cows produced an average of 2.4 gallons of milk per day and by 2007, cows averaged 7.5 gallons of milk per day (Figure 1). Udders now carry three times more milk between milkings, but have not become too deep (close to the ground) or less healthy because breeders have selected for udder support and mastitis resistance. Fertility declined for several generations with selection for high milk yield, but more recently fertility has held steady or begun to improve. As a result of selection and improved management, animal protein is now very affordable. Adults need 50 grams of protein per day on average according to current USDA nutrition recommendations. Protein from animal sources generally costs less and requires fewer servings than protein from vegetable sources as shown in Table 3.

Consumers of milk, eggs, and meat create jobs for billions of animals that otherwise would not exist. Because of genetic selection and improved management, animals provide much of our food more efficiently than in past generations. Animals convert low quality plant materials such as cellulose into high quality human food, but are still not as efficient as many plants. If farmland is used to produce crops directly consumed by humans instead of for animal production, more citizens can be fed. The number of citizens currently fed per acre of farmland differs greatly across continents as shown in Table 4. Many people, especially in Asia and Africa, cannot yet afford the high quality protein and essential amino acids from animal sources that they would prefer. Perhaps in the future, people will cooperate even more to improve life for their plants, their animals, and their fellow citizens of Earth.

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Table 1. Year that genetic rankings began and current emphasis placed on dairy traits in national genetic-economic selection indexes.

Trait	Year begun	Emphasis (%)
Milk, butterfat	1935	23
Protein	1977	23
Calving ease	1978	2
Udder support	1983	6
Feet and legs	1983	3
Size	1983	–4
Longevity	1994	17
Mastitis resistance	1994	9
Fertility	2003	9
Stillbirth	2006	4

Table 2. Comparison of Justice daughters versus average cows in the same herds.

Trait	Justice daughter	Average Holstein
Milk production (gallons/day)	10.5	10.1
Protein production (pounds/day)	2.82	2.62
Somatic cell count in milk (1000/ml)	231	288
Productive life (months)	34.0	27.7
Pregnancy rate (%)	23.9	21.0
Calving difficulty (%)	3%	8%
Stillbirth rate (%)	6%	8%

Table 3. Cost per 50 grams of protein from animal and vegetable food sources.

Animal	Servings	Cost ($)	Vegetable	Servings	Cost ($)
Eggs	6	1.00	Lentils	5	0.30
Milk	6	1.40	Rice	17	1.00
Hot dogs	10	1.90	Bread	17	1.60
Hamburger	3	2.00	Bananas	38	2.75
Steak	1	2.40	Mixed nuts	5	4.00
Chicken	3	2.40	Tomatoes	31	27.00
Bologna	17	3.10	Apples	100	75.00

Prices from Weis grocery store, Odenton, MD, September 10, 2007

Table 4. Number of citizens fed per acre by continent.

Continent	Citizens (millions)	Farmland (millions of acres)	Citizens per Acre
Asia	3,634	1,150	3.2
Africa	767	435	1.8
Europe	729	666	1.1
North America	495	593	0.8
South America	322	243	1.3
Oceania	30	127	0.2

Data from year 2000

Figure 1. Increase in milk produced per cow per day across time.