chapter

Advances in Reproductive Biology and Their Effects on Animal Improvement

Chapter 9

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Advances in Reproductive Biology and Their Effects on Animal Improvement

Background

During the past 30 years, new technologies have led to a fundamental shift in the way the United States produces meat and livestock. One set of these technologies-the subject of this section-uses knowledge of the reproductive process in farm animals to increase production. ‘l-he impacts of existing breeding technologies have been great, and much progress **is still possible through their continued use.** The development of new technologies is inevitable as well.

in a market economy like that of the United States, the factor that most influences the adoption of technology is economics. New technologies in reproductive physiology will be used widely only if they increase the efficiency of breeding programs—i.e., only if they provide greater control over breeding than present methods do, and only if the economic advantages of the increased control can be recovered. *

But economic factors are not the only ones that influence technological change—e.g., poultry and livestock production have influenced and have been influenced by:

- Government regulation such as meat grading standarcls;
- increased awareness of health effects, such as from the use of antibiotics in livestock feed;
- environmental concerns, such as the problems of waste removal, especially near factory farms;
- the growth of knowledge, in-e. g., the reproductive processes of farm animals and the accuracy of evaluating the genetic merit of breeding animals; and
- complementary technologies such as re**frigerated storage and transportation.**

New technologies, from breeding to food delivery systems, have reshaped the traditional American farm into a modern production system that is increasingly specialized, capitalized, and integrated with off-farm services. Applied genetics in animal production has been one of the forces behind these changes. The technologies that have sprung from it include not only the new, esoteric techniques for cellular manipulation discussed in other parts of this report, but also more well-known technologies, like artificial insemination. *

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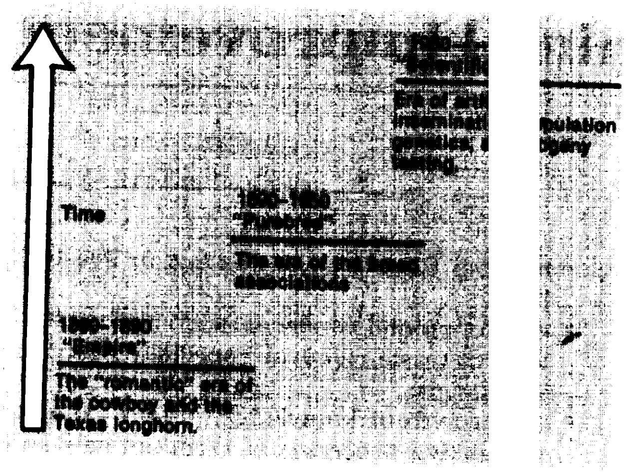
* [illegible] selected for discussion in **discussion in this part the report** manipulation of sex cell ion [illegible] speculative technol- [illegible]ipulations at the st ions [illegible] level are assessed [illegible] ii [illegible] was made to cover all te[illegible]nologies with potential **for improving the genetic qualities of** management **management techniques like** ion ar **detection and pregnancy diagnosis omitted, as** otne **various other methods for improving reproduction efficiency.**

The scientific era in livestock production

Producing purebred beef livestock has been **the dominant breeding objective throughout** most of the 20th century. The open range of the American West and Southwest—the “romantic” era in beef cattle production—lasted until about 1890. (See figure 30,) Then the range was fenced-in and the longhorn was replaced with new breeds by the turn of the century—the beginning of the “purebred” era.

Pedigree records and visual comparison of conformation to breed type were the basic tools

Figure 30.—Eras in U.S. Beef Production n



Genetic Activity in the try," journal paper No. J-7923 of the Iowa Agricultur nomics Experiment Station, Ames, Iowa, Project N also Yao-chi Lu and Leroy Quance, *Agriculture Prod ing the Limits*, USDA, ESCS, Agriculture Information

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of breeding programs. They were rein an institutional system of breed ass and yearly competitions at county stock shows, and by import regulation hibitions against artificial inseminatio restricted innovation. In rearing an sale to the slaughterhouse, early bre farmers more often than not were sati producing a calf or pig that survived early, and grew rapidly. Because of rate of newborn deaths, the producti "average" animal was a considerable ment in its own right; the intricacies of cated breeding methods were beyon pacity of small operations and were di carry out on large spreads. Producing winning purebred was left to the far the time, money, or luck to breed ani met the strict standards of the bree ations and the trained eyes of the judge shows.

During the first half of the 20th breeding objectives became more farmers and breeders began to look at other than mere external physical at Breeding for multiple-purposes led di the beginning of the "scientific" era in b

The increased use of AI for dairy

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which took place about 30 years ago- ning of the scientific era—was an start for applied genetics in anima While practitioners and purchasers quick to grasp its promise of imme fits, and while using AI was cheaper ing a bull, its expected genetic effect realized immediately. Dairymen ha that semen from bulls selected fro herds and chosen on the basis of an formance would result in rapid g provement. They were wrong; pro much less than projected. Because mi tion is a sex-limited trait, records relatives were needed for the eva sires. Unfortunately, the records o were usually limited to comparisons herd, were confounded by manage other environmental factors, and w ened by small sample sizes. The ma responsible for the difference betwee mediocre-performing herds turned management, not genetics; separatin fects of genetics from the effects of improved husbandry was extremely di

Controlled breeding

The objective of any breeding prog increase production. The scientific era vided the breeder with a variety of new ogies that help in manipulating and c the reproductive processes of the anim crease genetic gain. The breeder's bas selection, or deciding which animals t e.g., in beef cattle, a breeder can now s a wide variety of performance or e traits. (See table 30.) However, simply "I better beef cattle" is not a workable from a manager's point of view. Tend lean steaks and roasts, high fertility, c weight at weaning are all specific, me objectives of breeding.[1] [2] Other goals, those pertaining to temperament, resistance, food efficiency and

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[1] T. C. Cartwright, "Selection Criteria for Beef Cattle ture," *Journal of Animal Science* 30:706, 1970.

[2] Larry V. Cundiff and Keith E. Gregory, *Beef Catt* USDA, Agriculture Information Bulletin No. 286, vember 1977.

Table 30.—Heritability Estimates of Some Economically Important Traits

Trait	Heritability
Calving interval (fertility)	10%
Birth weight	40
Weaning weight	30
Cow maternal ability	40
Feedlot gain	45
Pasture gain	30
Efficiency of gain	40
Final feedlot weight	60
Conformation score:	
Weaning	25
Slaughter	40
Carcass traits:	
Carcass grade	40
Ribeye area	70
Tenderness	60
Fatthickness	45
Retail product (percent)	30
Retail product (pounds)	65
Susceptibitity to cancer eye	30

SOURCE: ff and K Cundiffand KeithE. Gregory, Beet y, USC Breeding, USDA, Agriculture Information Bulletin No.2B6, revised November1977, p.9.

may also have economic value,[3] but they are much harder to measure.

The extent to which important economic or performance traits are genetically determined and heritable varies from trait to trait and from animal to animal. (See table 30.) Heritability is defined as the percentage of the difference among animals in performance traits passed from parent to offspring*—e.g~ bulls and heifers with superior weight at weaning might average 5 pounds (lb) more than their herdmates. Because weaning weight has an average heritability estimate of 30 percent, the offspring of these top performing animals can be expected to average 1.5 1b heavieratweaningthan their contemporaries (0.30 X 5 = 1.5). This improvement can normally be expected to be permanent and cumulative as it is passed onto the next generation. The improvement accumulates like compound interest in a savings account; gains made in each generation are compounded on the gains of previous generations.

Like land, equipment, and cash, breeding stock represents capital available to the commercial farmer. Because all inputs must be used efficiently, modern herd or flock managers cannot afford to leave reproduction to chance mating in the pen or on the range. These pressures for efficient production have been described as follows:[4]

> **Where dairymen are judged by the number of cows milked in an hour, there is no place for the slow milking cow or the man who will patiently milk her out. There is no place for the time-consuming hurdle flock of sheep, for the small flock of chickens maintained under extensive conditions, or for the sow that must be watched while she farrows. By degrees all classes of stock are being subjected to selection which favors animals that need a minimum of individual attention.**

The scientific basis for modern breeding has developed slowly over the last century. Applied genetics—one part of today's programs-has helped modernize livestock and poultry breeding by elaborating on the variation of continuously distributed traits in a population; carrying over what was known about rapidly reproducing laboratory species, like fruit flies or mice, to the much slower reproduction of large farm animals; and developing the statistical techniques for predicting breeding values or merit and analyzing breeding programs.[5]

Two examples show the power of breeding tools and the increased efficiency and productivity of today's breeders' stocks.

- Over the past 30 years, the average milk yield of cows in the United States has more than doubled. At the same time, the number of dairy cows in the United States has been reduced by more than 50 percent. (See figure 31.) Of this increase in output and efficiency, more than one-fourth can be attributed to permanent genetic change for at least one breed (Holsteins) participating in the Dairy Herd Improvement Program. (See figure 32.)
- Poultry production in the United States has become the most intensive industry among

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* and genetic assc iation association are important in decisions dual matings. Mc mat reed ng programs a programs are concerned in it h spreading rapid gain rapidly throughout a population ; thustwo o thus two ment refinements for selection enter the pirt tion interval, and selectio and selection differential.

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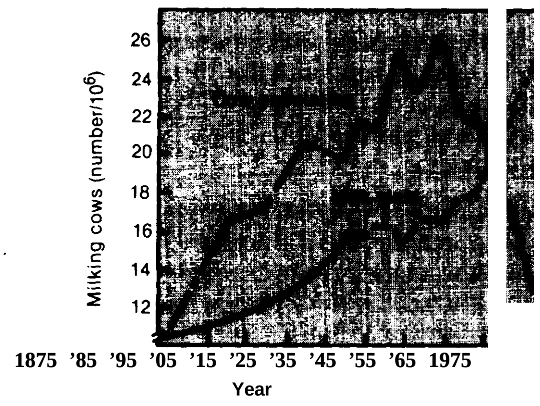
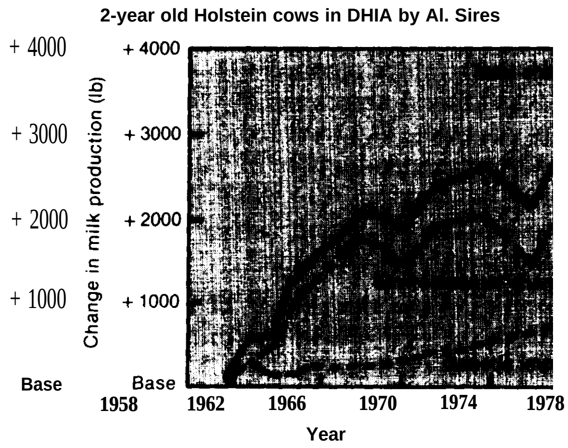
Figure 31 .—Milk Yield/Cow and Cow Population, United States, 1875-1975



SOURCE: J. Reid, “Progress in Dairy Cattle Production,” *Agricultural '' A Food Chemistry. 1 Cr Present, and Future,* R. *1 Future* (cd.) (Westport, Corm.: Avi Press, 1978).

Figure 32.—Milk Production per Cow (Holsteins) in 1958=78 (New York and New England)



SOURCE: R. H. Foote, Department of Animal Science, Cornell University, Ithaca, from unpublished data of R. W. Everett, W. E University.

those for farm species. For turkeys, the use of Al in breeding for breast meat has been so successful that commercial turkeys can no longer breed naturally. The big-breasted male, even when inclined to do so finds it physically impossible to mount the female. As a result, a full 100 percent of the commercial turkey flock in the United States is replaced each year using Al. In other species of poultry as well, production processes have become equally efficient. As A. W. Nordskog has noted:

> Compared with the breeding of other economically important animals, poultry breeding has been the first to leave the farm . . . to become part of a sophisticated breeding industry. On a commercial level, chickens have been the first to be commercially exploited by the application of inbreeding-hybridization techniques, as earlier used in corn, as well as by methods of selective improvement using the principles of quantitative genetics. Thus, the poultry industry, compared to other animal industries, seems to have been the quickest to apply modern methods of genetic improvement, including the employment of formally trained geneticists to handle breeding technology plus the use of computers and other modern business methods.[6]

Scientific production

Farm resources include land, labor, capital, and, increasingly, new knowledge. Today, those who innovate recapture the costs of innovating by maintaining output while lowering costs or by increasing output while holding costs down. Some results of the drive toward efficiency have included included increasing specializat ion, intensified use of capital and land relative to labor and integration of production phases.

Poultry and livestock operations have slowly become specialized over the past 50 years. The farmer who used to do his own breeding, raising, feeding and slaughtering is disappearing. Now, the beef cattle industry in the United States consists of: the purebred breeder who provides breeding stock, the commercial producer, the feeder, the packer, and the retailer. Similar specialization has occurred for most other species—e.g., less than 15 primary breeders maintain the breeding stock that produces the 3.7 billion chickens consumed each year in the United States. The emergence of other specialized services—such as AI providers, manage-

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‘A. W. [6]A. W “Success and Failure of Quantitative Genetic Theory in Poultry” in Poultry” in *of the International Conference on Quantitative Genetics,* Edward s. Edwar et al. (cd.) et al. (t Iowa: Iowa State University Press, 1977), pp. 47-51.

ment consultants, equipment manufacturers—has accelerated the trend toward specialization, and has given the commercial operator more time to concentrate on his specific contribution to the chain of production.

Intensification is the increasing use of some inputs to production in comparison to others. Increasing the use of land and capital relative to labor describes the development of U.S. agriculture, including livestock raising, in this century. The "factory" farm typifies this trend. Herds and flocks are bred, . born, and raised in enclosed areas, never seeing a barnyard or the open range. The best examples of land- and capital-intensive systems are those of poultry (layers, broilers, and **turkeys),** confined hog **pro**duction, drylot dairy farming, and some veal production.

The greater use of land has been encouraged by several factors, including improved corn production for confined hog feeding, programs of preventive medicine curtailing the spread of diseases in close spaces, and environmental control (light, temperature, water, humidity) to increase output under closely controlled conditions. However, extensive ranching for beef and sheep is still common in the United States; the difficulties associated with detecting estrus ("heat") in these species and their relatively slow rates of reproduction have made it uneconomical to invest in them the capital necessary for intensive farming. Furthermore, beef and sheep on extensive systems forage on marginal land that might otherwise have no use. Beeflot feeding, or the fattening of cattle before slaughter at a centralized location, is the only aspect of the beef industry that is land-intensive; in 1977, approximately one-fourth of U.S. beef cattle were fed."[7]

Linking phases of production to eliminate waste or inefficiencies in the system has progressed with great speed. For some species, such linkages now extend from breeding to the supermarket (and, in the case of fast food chains, to the dinner table). Integration includes the linking of supply industries (feeds, medicines, breeding stock) with production and then with marketing services (slaughtering, dressing, packaging). Entire industries and the Government in combination have produced a complex chain of operations that makes use of Government inspectors, the pharmaceutical industry, equipment manufacturers, the transportation industry, and the processed feed industry in addition to the traditional commercial farmer.

Because of this complex linkage, meat grades, cuts, and packaging have become fairly standard in the American supermarket. Shoppers have come to expect these standards; consumers wanting special services have learned to pay more for them. Thus, the American farm has changed radically over the past 30 years. This change has been described as follows:[8]

> **As farming enterprises grow larger, their management have to equip themselves with information and resort to technologists to help them reach decisions and plan for more distant goals. Industrial developments of this kind widen the range of farming activities, since the old style farmer, sensitive to local markets and operating on hunches, remains as a contrast to those for whom farming is rapidly becoming more of a programme than a way of life.**

Resistance to change

New **technologies in U.S. agriculture and new ways of producing food and fiber have been both a cause and an effect of the movement from farms to cities in the 20th century. Commercial farmers, operating on thin or nonexistent profits and under extreme competition, have had strong reason to innovate. They have been forced by the availability of new technologies either to do so or to watch their potential earnings go to the neighboring farmer. Various policies that have been adopted to soften the impacts of the "technological treadmill," have somewhat slowed the exodus from the farms. They** may have been adopted for social reasons, but they have also become increasingly costly to society. The taxpayer pays for them; **the con**sumer pays as well for every failure to innovate on the farms.

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[7] ertz, **P.** [illegible] **et al.,** ***Another Revolution in U.S. Farming?*** USDA, [illegible] Agricultural Economic Report No. 441, December 1979.

[8] [illegible] **et al., op. cit., p. 9.**

Besides a lack of capital or a lack of interest in innovating, some farmers have resisted applied genetics because efficiency is not their most important priority. This attitude has been described as follows:

> It is easy to see why breeders are unreceptive to the science of genetics. The business of breeding pedigree stock for sale is not just a matter of heredity, perhaps not even predominantly so. The devoted grooming, feeding and fitting, the propaganda about pedigrees and wins at fairs and shows, the dramatics of the auction ring, the trivialities of breed characters, and the good company of fellow breeders, constitute a vocation, not a genetic enterprise.

Farmers are traditionally an independent group. Many believe that they may not directly recapture the benefits of participating in a breeding program based on genetics; having no records on one's animals is often preferable to discovering proof that one's herd is performing poorly. On the other hand, one impact of AI has been to demonstrate to farmers the value of adopting new technologies. Furthermore, the economic reward of production records has increased, since AI organizations purchase only dairy sires with extensive records on relatives.

Some future trends

Applied genetics in poultry and livestock breeding comprise a group of powerful technologies that have already strongly influenced prices and profits. Nevertheless, the effect of genetics is only just beginning to be felt; much improvement remains to be made in all species. It has been observed that modern genetics:[10]

> . . . provides a verifiable starting point for the development of the complex breeding operation that many populations now require . . . (which) are as far removed from simple selection as the motor car is from the bicycle.

Of these technologies, some are already in regular use, some are in the process of being applied, and others must await further research and development before they become generally available.

Societal pressures are one of the many factors that influence the introduction of these technologies. Several developments around the world will have a clear impact on innovation in general and on genetics in particular:

- An expanding population, with its growing demand for food products of all kinds.
- The growth in income for parts of the population, which may increase the demand for sources of meat protein.
- Increasing competition for the consumer's dollar among various sources of protein, which could reduce demand for meat.
- Increasing competition for prime agricultural land among agricultural, urban, and industrial interests. Less-than-prime land may also be brought back into production as demand rises, and the same pressures may cause land prices to rise high enough to encourage greater, or intensified, use of land in livestock production.
- Increasing demand for U.S. food and fiber products 'from abroad, leading to opportunities for increased profits for successful producers.

Changes like these will strongly affect the way American farmers produce food and fiber products. The economics of efficiency and a growing world population will continue to place pressure on the agricultural sector to innovate. In animals and animal products, efficiencies will be found in all steps of production. Efforts will be made to increase the number of live births and to reduce neonatal calf fertility, presently one of the costliest steps—in terms of animals lost–throughout the world. Estimates of the potential monetary benefits of the application of knowledge obtained from prior research in reproductive physiology range as high as $1 billion per year. Another area for great economies in production is genetic gain. Much genetic progress remains to be made in all species.

Certain technologies promise to increase the ability of farmers to capitalize on the genetic improvement of economically important traits. Suppliers of genetic material (semen, embryos) will focus increased attention on the value of their products for sale both in the United States and abroad.

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p. 170.

P. Cunningham, Developments in the Improvement," in *15th International Conference on Animal Blood and Biochemistry,* 7:191, 1976.

The development and application of certain key technologies will affect related technologies—e.g., the availability of reliable estrus detection and estrus synchronization methods should increase the use of AI and embryo transfer in beef and dairy cattle, thereby spreading genetic advantage. Further progress in the freezing of embryos should facilitate the genetic evaluation of cows and heifers.

Other trends that may influence technological change include the shifting availability of research funds, changing consumer tastes, and growth of regulations (for instance, stricter controls on environmental quality or hormonal treatments). The expansion of an animal rights movement may influence the degree to which confinement housing, and therefore controlled breeding, is acceptable. And increased energy costs may either encourage development of the technologies (through efforts for greater efficiency) **or discourage them (through greater use of forage and extensive systems).**

Technologies

Sexual reproduction is a game of chance. Because sperm and ova each contain only a random half of the genes of each parent, the number of possible combinations that can result is nearly infinite. Some progeny are likely to survive and reproduce; **others die either before birth or without producing offspring.**

The great variation achieved through sexual reproduction produces certain animals that satisfy the needs and desires of the breeder far more than others. On the other hand, the offspring of these outstanding animals are usually less so than their parents, although they are generally still above average.

Animal breeders have invested great effort in improving succeeding generations of domestic animals, both by limiting the differences due to the chance associated with sexual reproduction and by taking advantage of the favorable combinations that occur. Examples of these efforts include keeping records, establishing progeny testing schemes, amplifying the reproduction of outstanding individuals by AI and embryo transfer, and establishing inbred lines to capitalize on their more reliable ability to transmit characteristics to their offspring.

Because of these efforts, and because dairy cattle breeders have adopted innovative technologies through the years, far more is known about reproduction in the cow than in other farm animals. The demand for milk and beef has provided an impetus for the speedy introduction of technologies that might prove economically advantageous.

Several observations can be made about the state of the art for **16 technologies that enhance the inherited traits of animals. (See also app. II-C.)**

The technologies are at different stages of research and development.

The practice of AI in dairy cattle has had the greatest practical impact of all the genetic technologies used in the breeding of mammals. In contrast, not a single farm animal has been successfully raised after a combination of in vitro fertilization and embryo transplant. The usefulness of several of the technologies for animal production, such as recombinant DNA (rDNA) and nuclear transplantation, is purely speculative at this writing.

The usefulness of the technologies differs from species to species.

These differences can often be explained by biological factors-e. g., sperm storage capabilities are currently limited for swine because freezing kills so many of the sperm. Management techniques are important as well; extensive beef-raising systems have in the past made estrus detection and synchronization impractical, thereby limiting the use of AL (Fewer than 5 percent of the U.S. beef herd are artificially inseminated, compared with 60 percent of the national dairy herd.) And economics can also play **a** role; in general, the lower **an** animal's value, the less practical the investment in the technologies, some of which are relatively expensive.

Several technologies are critical to the introduction of others.

A **methodology that could reliably induce estrus synchronization increases the economic feasibility of AI and embryo transfer. Likewise, the refinement of embryo storage and other freezing techniques would advance the development of those technologies still being developed, like sex selection and embryo transfer.** Advances in in vitro fertilization will be especially useful to a better understanding of basic reproductive processes and therefore to the development and application of the more speculative technologies.

The technologies interrelate.

All the technologies combined make possible almost total control of the reproductive process of the farm animal: a cow embryo donor may be superovulated and artificially inseminated with stored, frozen sperm; the embryos may be recovered, then stored frozen or transferred directly to several recipient cows whose estrous cycles **have** been synchronized with that of the donor to insure continued embryonic development. Before the transfer, a few cells may be taken for identification of male or female chromosomes as a basis for sex selection. Finally, two embryos may be transferred to each recipient in an effort to obtain twins. (See **figure 33.)**

Techniques not yet commercially applicable all require embryo transfer in order to be useful. They include in vitro fertilization, parthenogenesis, production of identical twins, cloning, cell fusion, chimeras, and rDNA technology.

The technologies described in this section are designed to increase the reproductive efficiency of farm animals, to improve their genetic merit, and to enhance general knowledge of the reproductive process for a variety of reasons, including concern with specific human medical problems, such as fertility regulation and better treatments for infertility.

Technologies that are presently useful

SPERM STORAGE

The sperm of most cattle can be frozen to – 196° C, stored for an indefinite period, and then used in in vivo fertilization. Although many of the sperm are killed during freezing, success rates [or successful conceptions (table 31)] combined with other advantages of the technologies are enough to ensure widespread use of the technology. Short-term sperm storage (for one day or so) is also well-developed and widely used.

The major advantages of storing sperm **are** the increased use of desirable sires in breeding (see figure 34), the ease of transport and spread of desirable germplasm throughout the country and the world, and the savings from slaughtering the bull after enough sperm has been collected. The sperm can also be tested for venereal and other diseases before it is used. Therefore, the use of sperm banks is expected to increase. Little change is anticipated in semen processing, other than the continued refinement of freezing protocols, which differ for each species.

ARTIFICIAL INSEMINATION

The manual placement of sperm into the uterus has played a central role in the dissemination of valuable valuable g throughout the world's herds and flocks. Virtually all farm species can be artificially inseminated, although use of the technology varies widely for different 33.) spe 100 percent of the Nation's domestic turkeys are produced via AI compared with less than 5 percent of beef cattle. Even honey-

Table 31.—Results of Superovulation in Farm Animals

	Average number ovulations normally expected	Number of ovulations with superovulation
COW		*6-8*
Sheep	1.5	9-11
Goat	1.5	
Pig	13	30
Horse	1	1

SOURCE: George [illegible] Animal Reproduction Laboratory, Colorado State University, Fort Collins, [illegible]

Figure 33.—The Way the Reproductive Technologies Interrelate

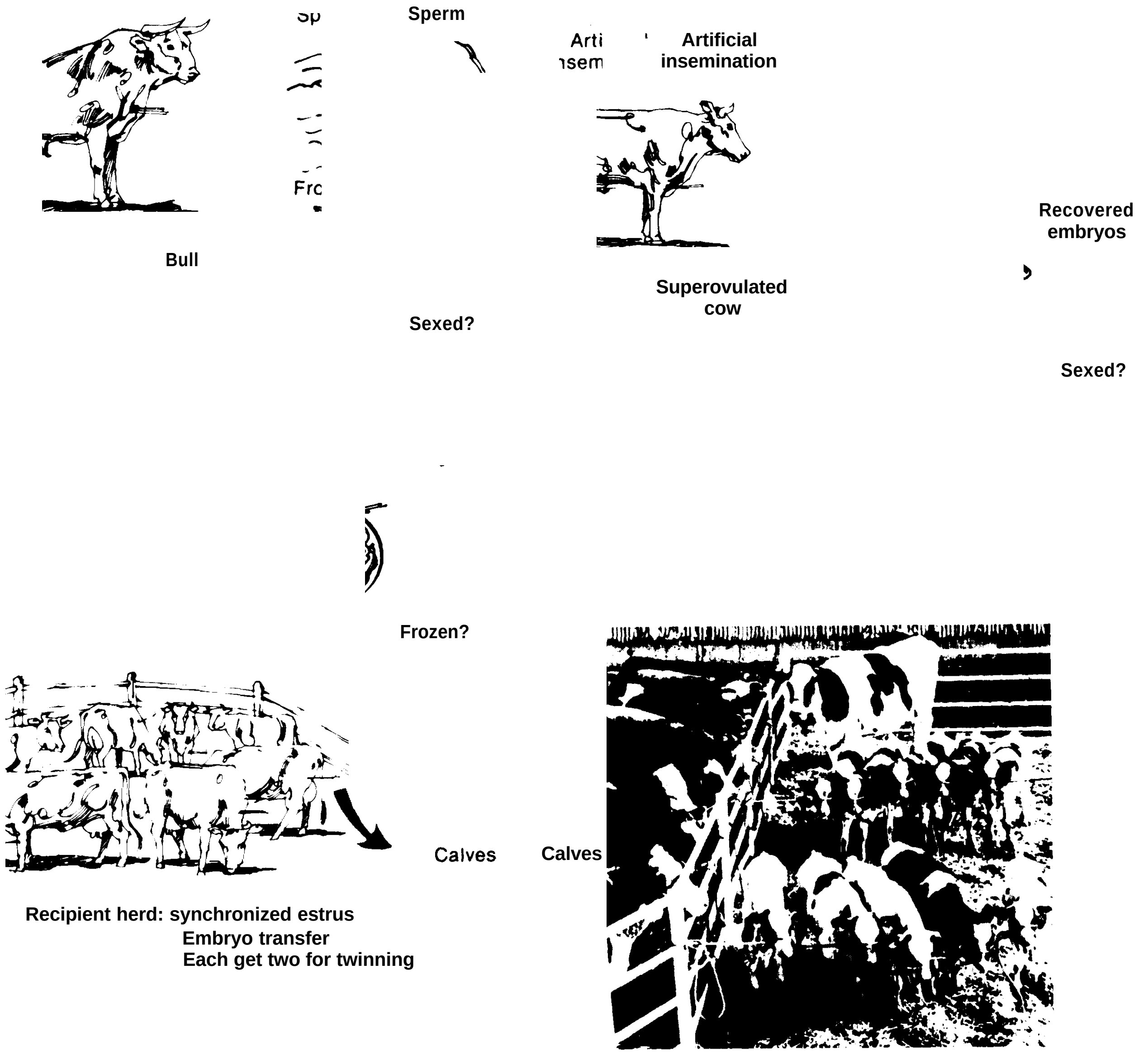
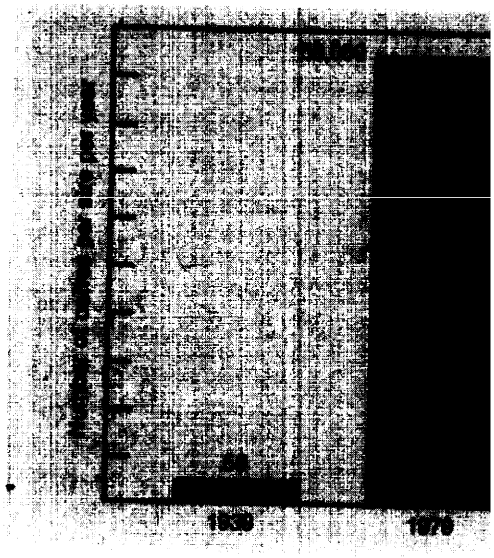


Photo Credit: Science

These 10 calves from Colorado State University were the result of superovulation, in vitro culture, and transfer to the surrogate mother cows on the left. The genetic mother of *all* 10 calves is at upper right

SOURCE: Office of Technology Assessment

Figure 34.—Change in the Potential Number of Progeny per Sire per Year From 1939 to 1979



SOURCE: R. H. Foote, Department of Animal Science, Cornell University, Ithaca, N. Y., unpublished data.

bees and fish can now be artificially inseminated.

It permits the widespread use of germplasm from genetically superior sires. It saves the farmer the cost of maintaining his own sires and is valuable in disease control, especially when germplasm, rather than animals, is imported or exported. An important barrier to the **wider use of** Al, **especially in producing beef cattle, is the need for application of reliable estrus detection and estrus synchronization technologies.**

An expanded role for Al in the future will depend on the availability of accurate information about the genetic value of sperm available for insemination. A nationwide information system for evaluating germplasm presently exists for only one species, dairy cattle.

ESTRUS SYNCHRONIZATION

Estrus, or "heat," is the period during which the female will allow the male to mate with her. The synchronization of estrus in a herd, using various drug treatments, greatly enhances Al and other reproduction programs.

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SUPEROVULATION

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In the future, future creased unde **physiological mechanisms will facilitate forts to** forts to **technology. has additional commercial potential sheep and cattle** asm husbar **much current is directed** the towards de **and testing a commercial procedure.**

EMBRYO RECOVERY

The ability collect fertilized ova the oviducts uterus is necessary step transfer or storage and many experiments in reproductive biology. The technology is is **important for research into producing identical twins, performing** forming **biopsies** ior **sex** for sex deter **and other projects.** for **superovulation, art i insemination, and** and embryo **it** takes it **collect embryos a** from **heifer reaching puberty. When some disorder has damaged the oviducts or uterus,** uterus **recovery from** valuabl **makes procreation possible.**

Both surgical nonsurgical methods are ing in use. Surgical recovery is necessary for sheep, goats, and pigs; such operations are limited by the development of scar tissue.

surgical embryo recovery is preferred for the cow and the single ovulation of the horse. The approach is especially important in dairy cattle, since it can be performed on the farm without interrupting milk production.

No significant advances can be predicted for the immediate future.

EMBRYO TRANSFER

Embryos can be removed from one animal and implanted into the oviduct or uterus of another. Both surgical and nonsurgical methods are currently in use, though success rates of the latter are much lower.

The technology can obtain offspring from females unable to support a pregnancy, increasing the number of offspring from valuable females and introducing new genes into pathogen-free herds. Because more offspring can be obtained from the donor, undesirable recessive traits can be rapidly detected. The technology is also used, along with short- or long-term storage of the embryos, as a means of transporting germplasm rather than the whole animal. Current barriers to its further use are the costs in personnel and equipment, especially for surgical procedures, and the provision of suitable recipients for a successful transfer.

The use of embryo transfer should increase in the future, especially with animals of high value. Nonsurgical methods will increasingly replace surgical ones, especially for cows and horses. A role for embryo transfer can also be predicted in progeny testing of females, obtaining twins in beef cows, obtaining progeny from prepubertal females, and in combination with in vitro fertilization and a variety of manipulative treatments (production of identical twins, selfing or combining ova from the same animal, genetic engineering).

EMBRYO STORAGE

The ability to store embryos increases the advantages of embryo transfer procedures, lowers the cost of transporting animal germplasm, and reduces the need to synchronize estrus in recipients. It will also be important in the study and control of genetic drift in animals.

Adequate culture systems hort. orn **short-term storage of embryos.** e bee develope | id-error and are r **and are not optimally for farm species at present.** ess. cow **embryos** stor **been** 3 day in le tie **in the tied oviduct of**

t storage. **storage, or freezing** ne enlbr.yes, **exists, but** need to o im **to** or As **As many** ne **two-thirds** no **the stored embryos die with present methods. However, for some uses embryo freezing is already profitable.**

in **the future, the** ent of precise or **precise** ure t **culture** v would he n the **help the opment of all technologies** the pro- **the prolonged manipulation** le **gametes and embryos outside the** ive tract. Ev **tract. Event as freezing technology** nearly a **nearly all embryos taken from cattle in North America will be stored, rather than transferred** ely.
It appears that embryos successfully stored survive for several centuries and possibly for

SEX SELECTION

The ability to determine the sex . the born, or of sperm at in will have nu- **numerous practical and experimental applications. The most** method **method is** ng, by **means of which nearly** : of embry **of embryos can be sexed. Another method, which tries to** ex-speci **sex-specific products** or **certain genes, is under development. A reliable method for separating** ucing sperm fr **sperm from producing sperm has not been achieved, though several patents are held on** sts of tl **tests of this type.**

Before any method has cal **practical effect on the production of farm animals it must become simple, fast, inexpensive,** nd harn **and harmless to the embryo. The present state of the art is largely a consequence of research in male fertility and in sperm survival after frozen storage.**

TWINNING

Twins can be artificially induced using either embryo transfer or hormonal treatments. The first approach is more effective. Selection among female sheep for natural twin tion has been very rewarding, while selection for twinning in other species has not received much attention.

Twinning in nonlitter-bearing species would greatly improve the feed conversion ratio of producing an extra offspring. The most important barriers, besides the high cost of embryo transfer techniques, include extra attention needed for the dam during gestation, parturition, and lactation.

More speculative technologies

IN VITRO FERTILIZATION

The manual joining of egg and sperm outside the reproductive tract has, for some species, been followed by successful development of the embryo through gestation to birth. The species include, at this writing, the rabbit, mouse, rat, and human. Consistent and repeatable success with in vitro fertilization in farm species has not yet been accomplished. The cases of reported success of in vitro fertilization, embryo reimplantation, and normal development in man are beginning to be documented in the scientific literature.

The in vitro work to date has attempted to develop a research tool so that the physiological and biochemical events of fertilization could be better understood. Despite the wide public attention it has received in the recent past, the technology is not perfected and will have little practical, commercial effect in producing individuals of any species in the near future.

Practical applications would include: a means of assessing the fertility of ovum and sperm; a means of overcoming female infertility by embryo transfer into a recipient animal; and, when coupled with storage and transfer, a means of facilitating the union of specific ova and sperm for production of individual animals with predicted characteristics.

Many of the practical applications should become available within the next 10 to 20 years. Further development, along with the storage of gametes, should allow fertilization of desired crosses. This technology may be combined with genetic engineering and sperm sexing in the more distant future.

PARTHENOGENESIS

Parthenogenesis, or "virgin birth, " is the initiation of development in the absence of sperm. It has not been demonstrated or described for mammalian species, and the best available information indicates that the maintenance of parthenogenetic development to produce normal offspring in mammals is presently impossible.

CLONING

The possibility of producing genetically identical individuals has fascinated both scientists and the general public. As far as livestock are concerned, there are several ways to obtain genetically identical animals. The natural way is through identical twins, although these are rare in species other than cattle, sheep, and primates. For practical purposes, highly inbred lines of some mammals are already considered genetically identical; first generation crosses of these lines are also considered genetically identical and do not suffer from the depressive effect of inbreeding.

Laboratory methods for producing clones include dividing early embryos. The results of recent experiments in the production of identical offspring using these techniques are shown in table 32.

Another methodology involves the insertion of the nucleus of one cell into another, either before or after the original genetic complement of the "receiver" cell is destroyed. Researchers have found in certain amphibia that nuclear transplantation from a body cell of an embryo into a zygote can lead to the development of a sexually mature frog.

Table 32.—Experimental Production of Identical Offspring

Methodology	Result
Dividing 2-cell embryo in half	1 pair identical mouse twins
Dividing morulae[a] in half	8 pairs of identical mouse twins
Dividing 2-cell embryos in half	5 pairs of identical sheep twins
Dividing 4-cell embryos in four parts	1 set identical sheep quadruplets

[a] An embryo with 16 to [illegible] cells; resembles a mulberry.

SOURCE: Benjamin G. [illegible] School of Veterinary Medicine, University of Pennsylvania, [illegible] Square, Pa.

The ideal technique for making genetic copies of any given adult mammal involves inserting the nucleus from a body cell (not a sex cell) from an adult individual into an ovum. Achieving this will probably take years, if indeed it is possible at all, since there is some evidence that most adult body cells are irreversibly differentiated. *

Serious technical barriers must be overcome before advantages in animal production can be foreseen.

CELL FUSION

This technology fuses two mature ova or fertilizes one ovum with another. Combining ova from the same animal is called "selfing." The combination of ova has resulted in very early development of the transferred embryo, but no further development has been reported.

Cell fusion technology may someday prove useful for transferring genetic material from a somatic cell into a fertilized single-cell embryo for the purpose of cloning. Selfing would rapidly result in pure genetic (inbred) lines for use as breeding stocks. The technique could also lead to the rapid identification of undesirable recessive traits that could be eliminated from [illegible] species.

CHIMERAS

The production of chimeras requires the fusion of two or more early embryos or the addition of extra cells to blastocysts. These genetic components may be from closely related but different species.

Live chimeras between two species of mouse have been produced. However, practical applications of chimera technology to livestock are not obvious at this stage of development. The main objective of this research is to provide a genetic tool for a better understanding of development and maternal-fetal interactions.

RECOMBINANT DNA AND GENE TRANSFER

The mechanics of directly manipulating the DNA molecules of farm animals have not yet been worked out. However, cells from mice have been mixed with pieces of chromosomal DNA, which became stably associated with the cells' own DNA. In addition, on September 3, 1980, the successful introduction of foreign DNA into mouse embryos was announced. The embryos were implanted into surrogate mothers who gave birth to mice containing altered DNA. whether or not the DNA was active is unknown at this writing.

Knowledge of the genetics of farm animals must improve before rDNA or other gene transfer methods will be of practical benefit in producing meat and livestock products. Before genes can be altered they must be identified, and gene loci on chromosomes must be mapped. Work toward this goal has begun only recently and rapid progress cannot be anticipated. Multivariate genetic determinants of characteristics are anticipated to be the rule.

Genetics and animal breeding

Two characteristics distinguish the reproduction of farm animals from that of single-cell organisms: animal reproduction is sexual–male and female germ cells must be brought together to initiate pregnancy and produce offspring; and animal reproduction is slower (the generation interval is longer), thus the economic benefits of specific gene lines may take years to be captured. These two characteristics limit the speed and extent to which genetic improvements can be made. Reliable information about the genetic value of particular individuals is the key to overcoming limitations, for it can simplify specific breeding decisions and spread desirable genes throughout the Nations's herds and flocks.

The use of applied genetics for farm species is indirect. Breeders do not work with individual genes; rather, they must accept a genetic pack-

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• 8 . it was 1981, it was reported that body cells from a very coul embryo could [illegible] as donors of nuclei for cloned mice.

that are tha **both beneficial** and **harmful** tr its.[11] The breeder's most **capital is in the** ed in th **with** nals w **he** which 'J-o Tt **this** trade this capital to **the genetic his** ue of his **stock, the breeder must** have reliable infor **the genetic value the** of the g ers **is considering introducing.** Since an individu farme **does** lly **the** have the co **collect** to e **process data** on performance of i **outside his own herds, must turn to outside sources of** ource **when deciding which** ne which new g **to reduce.**

requirements ir **such** te **information system** tem are at **the** e Int **States today, such system exists.** In e **National** Na operat e D ry Herd Imp **Program is** I HDI is a model pro **could be** a ap ted **species where the benefits** from advanced technolo **be enhanced** by ava lability of populaation

The ***The*** *Cooperative Dairy Herd Improvement Program*

Over the past 50 years, the U.S. dairy industry has used test records of individual animals to help in breeding decisions. lecisions is a nationwide program for collecting, analyzing, and disseminating information on the performance of dairy of dair It is the result of a memorandum of understanding among Federal and State agencies, local dairymen, and industry groups across the United States.

In In NCD **Dairy Herd Improvement Association** sociati **officials go to the dairies to collect the performance data on individual animals. These data then become part of the** art o ***Dairy*** *al Dairy Recc* ***Plans.*** The data are standard for da participating herds across the United States. They are sent to the Animal Improvement Programs Laboratory orator at USDA in USDA in Md., which analyzes them and incorporates them into the into the "U **Sire Summary** List, " **published biannually.** These summaries are public information.

In addition to the official plan, NCDHIP also includes several unofficial plans, which have less stringent regulations for data collection but which offer each dairyman a comparison of his herds with other herds across the Nation. The results of unofficial plans are not intended to be used as guidelines for selecting germplasm from outside one's herd.

The following characteristics contribute to NCDHIP's success:

- ***It is a cooperative program;*** **no** group or individual is forced to participate. Nevertheless, it has successfully brought together individuals, State and Federal agencies, breed associations, and professional and scientific societies for the pursuit of a com**mon goal.** It is **almost totally financed by the dairymen themselves.** In the national coordinating group, all those with an interest in the industry have a voice in formulating policy for the program.
- It ***is flexible;*** **a dairyman can use the performance records from the unofficial plans to evaluate the animals within his herd or he can turn to the official sire summaries to make comparisons with participating herds throughout the Nation. These data are useful both for comparing the performance of one's herd and breed with others and for selecting new germplasm for introduction into the herd.**
- ***Its data are regarded as impartial;*** disinterest **on the part o-f the local DHIA official who collects the data and the high security surrounding the processed information are central to the program's success. AIPL's analyses and sire summaries are respected both nationally and internationally, in no small part because of freedom from commercial pressures.**

Approximately 36,000 herds with almost 2.8 million cows were enrolled in the official plans of NCDHIP in 1979. In each of 18 years recorded between 1961 and 1978, cows enrolled in the Official Dairy Recordkeeping Plans in NCDHIP have outproduced cows not enrolled by over

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[12] For a complete history of performance **dairy** tine in the Unite(State J. ee: G ***The*** I King ***Cooperative*** *Dairy Herd* ***Program,*** ent P **Herd Improvement** ...... ter 9 No 4 July /\ **KS.**

4,000 lb of milk per lactation. In the testing year (1977-78), the superiority surpassed 5,000 lb per cow. This 5,()()()-lb superiority represents 52 percent more milk **per lactation. The increases in production per cow result from improvement in both management techniques and genetic producing ability.**

Several factors influence the rates of participation in the NCDHIP from State to State, from region to region, and from breed to breed. In some States, expansion of NCDHIP membership is not a high priority of the State Cooperative Extension Service. In some areas, the relative importance of dairying as an enterprise is low; therefore, a strong local DHIA organization does not exist. Likewise, in areas where dairying is a part-time operation, dairymen have less time and initiative for participating in the program (although many participate in NCDHIP's unofficial plans). Where dairymen rely on their own bulls and use little AI in breeding, progeny testing is extremely limited. No single factor causes dairymen in some States to take greater advantage of the superior germplasm available to them. The importance of strong national leadership cannot be overemphasized in explaining the great differences among breeds in participation rates. (See table 33.) Farsighted leadership played a large role in developing the genetic gain of Holsteins, which represent 90 percent of the U.S. dairy herd today.

The genetic gains resulting from NCDHIP are impressive, suggesting a model for spreading genetic superiority throughout the Nation's other herds. NCDHIP also shows the importance of combining reliable evaluation of germplasm with the use of reproductive technologies. These technologies are of only academic interest when they are used alone; it is when superior germplasm can be spread throughout the Nation that the American consumer benefits.

Table 33.-National Cow-Year and Averages for All Official Herd Records, by Breed May 1, 1978-Apr. 30,1979

	Cow-years (#)	Milk (lb)	Fat [illegible]	Fat (lb)
[illegible]	17,135	11,839	[illegible]	469
[illegible]	57,577	10,858	4.64	504
[illegible]	2,297,684	15,014	3.64	547
ersey	89,449	10,231	4.90	501
rown swiss	24,247	12,368	4.04	500
[illegible] shorthorn	2,130	10,451	3.65	381
[illegible] and others	83,139	13,077	3.80	497

[illegible] U.S. Department of Agriculture, Science and Education Administration, *Dairy* [illegible] *55, #2,* December 1979, pp. 5-6.

Other species

Progeny testing schemes for other species are not as developed as they are for dairy cattle. There are several reasons for this lack of testing:

- ***Difficulty in establishing a selection objective around which to design a testing program.*** **Milk yield and fat content were obvious traits for selection in dairy cattle. other species have no such simple traits for selection. It has been observed that, "The lack of definition of economic selection objectives in a precise, soundly based manner is one of the serious weaknesses of much animal breeding of the past. "[13]**
- ***Differences in management systems.*** **Artificial insemination is essential to the introduction of superior germplasm; where it is difficult to practice AI, elaborate testing schemes are not useful—e.g., in the Nation's beef herds, progeny testing will have to await more widespread use of AI. Though swine are increasingly raised in confined housing systems, poor fertility of boar sperm after freezing and thawing and heat detection difficulties have limited the use of AI.**
- ***Conflicting commercial interests.*** **Beef bulls, for example, continue to be sold to some extent on the basis of fancy pedigrees and lines, with relatively little objective information on their genetic merit. Although some genetic improvement programs now exist, the beef breed associations may not support interbreed comparisons because some breeds would show up poorly.**
- ***Conflicts between short- and long-term gains.*** **Cross-breeding for the benefits of hybrid-**

‘31.. A. [illegible] of Livestock [illegible]," *Out-* [illegible] ,“ [illegible] 108, 1970 *1970.*

ization is particularly attractive to owners of commercial herds and flocks who constantly replace their stocks. This genetic improvement is noncumulative—the improvement does not continue from generation to generation. At present, no strong interest exists for improving the Nation's beef herd as a whole, and the individual breeder cannot effectively evaluate the germplasm available to him.

Swine.—There is no Nationwide testing program for hogs in the United States. * However, a study of needed research prepared by the USDA in 1976 noted that the production rate of approximately 13 pigs marketed per sow per year in the United States could be significantly improved. The biological potential is at least 20 to 25 pigs per year. Similarly, a successful breeding program, along with other managerial changes, could reduce the fat and increase the lean content of pork by as much as 10 to 15 lb per carcass.

The ARS study noted that ". . . an area that warrants particular attention is the development of a comprehensive national swine testing program leading to the identification, selection, and use of genetically superior boars, together with guidelines for the development and use of sow productivity and pig performance indexes. "[14] In the case of swine, the increased use of intensive housing, which allows reproductive control, should increase the impetus for progeny testing. Likewise, pinpointing areas where considerable improvement remains to be made should lead to the identification of selection objectives.

Beef.—After World War II, a few breeders became increasingly interested in problems of inbreeding and the economic costs of dwarfism. By that time, some had been trained in genetics and some breed associations and State agencies initiated localized testing programs for these traits. In 1967, a "Beef Improvement Federation" of local and breed groups was formed to try to consolidate the different systems of the State improvement programs. The Federation is now involved in: [15]

- establishing uniform, accurate records,
- assisting member organizations in developing performance programs,
- Encouraging cooperation among all segments of the industry in using records,
- Encouraging education by emphasizing the use of records,
- developing confidence in performance testing throughout the industry.

Despite these efforts, only about 3 percent of beef cattle nationally are recorded. This relatively low participation rate, when compared with NCDHIP, has both a technological and an institutional explanation. Under the largely extensive beef raising system in the United States, AI is difficult as long as estrus detection technologies are unavailable. Natural stud service is usually more economical. Institutional barriers also prevent the development of a strong genetic evaluation program–e.g., the breed associations are not all eager to have their breeds consistently compared with others. Likewise, some owners of bulls for stud service would lose business in a strict testing scheme.

Goats.—Though little genetic work has been done on goats in the past, the dairy goat industry has become more visible in the past few years. The desire of goat breeders to participate in NCDHIP led to the formation of a Coordinating Sub-Group for Dairy Goats. A review of the research performed indicated a great need for research in almost every area of production. As a result, AIPL developed a plan for a genetic improvement program. The leadership in the dairy goat industry was convinced that it could attain genetic improvement faster and at a lower cost via NCDHIP than it could for any other type of research.

In 1979, AIPL received a $15,000 grant from the Small Farms Research Funding to supper the development of genetic evaluation proce

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*There are several State programs—in Indiana, North Carolina, and Tennessee. Some of these programs may test only growth and not litter size.

[14] U.S. Department of Agriculture, Research [illegible] ire, [illegible] Program, [illegible] Production, [illegible] No. [illegible] 1976.

[15] [illegible] in [illegible] S. Beef [illegible] Paper No. [illegible] Home [illegible] Station, [illegible] No. 2?,000, [illegible]

dures for goats. Genetic evaluations for yield of dairy goat bucks will be available before the end of fiscal year 1980. Because limited genetic improvement for yield has occurred in dairy goats in the past, these evaluations will probably have a significant impact on the industry. AIPL can virtually guarantee beneficial results because of the data available from NCDHIP, its own expertise in genetics, statistics, and computer technology, and the decades of highly effective research on genetic improvement of dairy cattle that can be adapted for the dairy goat industry. However, funding for the goat testing program remains on a year-to-year basis.

CONCLUSION

NCDHIP has shown how important genetic information is to the production of meat and dairy products. The obstacles to such a program are also formidable, but every failure to capitalize on genetic potential is paid for by American consumers. It **has also shown that where selection objectives can be identified and agreed on, and where conflicting interests can be brought together to develop a program serving all interests, genetic improvement can become a central objective in breeding programs across the country. Without reliable, evaluative data on breeding stock, the Nation's breeders will have little interest in adopting new breeding technologies as they become available.**

Impacts on breeding

An improvement in germplasm, like an increase in the nutritional content of fertilizer or new and improved herbicides and pesticides, increases the quality of the physical capital used on the farm. It is likely that much improvement can still be made in the germplasm of all major farm animal species using existing technology.

Selecting for desired characteristics causes a specific qualitative change; it enhances the efficiency of the information contained within each cell. The genetic information in each cell of a farm animal is either more or less desirable or efficient than information in the cells of another animal, depending on how it performs on important traits. Superior germplasm can be used in breeding decisions to upgrade a farmer's breeding or producing stock. (DHIA programs are the best example of how information might be distributed.)

Resources invested in genetics and in technologies related to genetics will have high payoffs—e.g.) in a classic **study**[16] of the payoff to research in hybrid corn and in subsequent studies of other types of genetic improvement, a high cost/benefit ratio for such research was found. The original study also showed that the absolute market value of a particular product is an important factor influencing the rate of return on a given research expenditure. In general, the greater the aggregate value of the product, the greater the rate of return on a research expenditure.[17] Thus, the large expenditures for meat and animal products in the United States suggest a great payoff in applied genetic research. Beef purchases alone account for between 2 and 5 percent of the American consumer dollar, and the total market value for beef is more than twice that for corn in the United States.

DAIRY CATTLE

Total milk production has been stable for many years. While milk production per cow has gone steadily upward, the number of cows during the past 35 years has decreased proportionately. (See figure 29.) Milk production per cow should continue to increase, assuming that no radical changes in present management systerns occur. The increase in production per cow could continue even if no bulls superior to those already available are found, simply as a result of more farms switching to existing technology and existing bulls. Moreover, bulls produced from this system are increasing in superiority.

The number of dairy cows calved as of January 1, 1980, was 10,810)000. It has remained relatively stable for the past year, but may de-

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"Research Cos **"Research** al Returns Hybr **Returns: and Related Innovations,** *"Journal of* nv 66:4 *Economy* **66:419,** also **1958. See** son, **R.** E. Waggone **P.** in **Waggoner,** \'. **W. tan, "Economic Benefit From Research:** on **Example From** 05:1 **"** *Science* **205: 1101, 1979.**

und umno Ha **and** "Technical Ch **"Technical Change in Agricul-** pers : **" Staff Papers series No.** rtment o Agriculture **of and Applied** iversity of [innesot **v** of Paul, Minr **St. Paul, Minn., 1973.**

crease to around 10 million in the next decade if milk production continues to increase.

Artifical Insemination.—An example of the interaction between technologies and genetic improvement is shown in table 34. The "predicted difference" (PD) in milk production represents the ability of individual bulls to genetically transmit yield—the amount of milk above or below the genetic base that the daughters of a bull will produce on average due to the genes they receive. As indicated in table ***34,*** the predicted difference for milk yield transferred via the bull shows an improvement from **122 to 908** lb for active AI bulls in the United States over the past 13 years.

This impressive improvement still lags behind what is theoretically possible. A hypothetical breeding program could result in an expected yearly gain of ***220*** lb of milk per cow, using AI; and the biological limits to this rate of gain are not known. In practice, the observed genetic trend in the U.S. national dairy herd is about 100 **lb—70 lb from** the PDs of bulls plus 30 lb or so from the female, most of which is actually carryover effect from the previous use of superior bulls.

AI organizations, many of which are cooperatively owned by dairymen, have not rigorously applied the principles of AI. Their efforts have been limited by reluctance to break with traditional selection practices, financial constraints for proper testing of young bulls to produce sires of cows, and too much emphasis on nonproductive traits of questionable economic value. The progress that has been made has resulted from the increased use of AI, the availability of data through NCDHIP, and the actual use of reliable genetic evaluations. If any of these three factors had been missing, far less improvement would have occurred,

Table 34.–Predicted Difference (PD) of Milk Yield of Active Al Bulls

Year	PD milk (lb)
1967	122
1968	198
1969	205
1970	276
1971	301
1972	346
1973	348
1974	338
1975	425
1976	501
1977	558
1978	748
1979	908

SOURCE: Animal Improvement Programs Laboratory, Animal Science Institute, Beltsville Agricultural Research Center, USDA.

Semen Storage.–It is doubtful that major technological changes in processing semen will occur, However, since the rate of conception is as important as the genetic merit of a sire to the economy of a dairy enterprise, more attention will be given to selecting sires of high fertility. Progress should be made in banking semen by AI studs as a hedge against costs of inflation. In the future, some of the increased costs of housing and feeding bulls will probably be offset by semen banking and earlier elimination of many bulls.

Sexed Semen.—Sexing of semen to produce heifer calves (for dairymen) or bull calves (for AI organizations) has been attempted without success for many years.

Perfect determination of the sex of progeny could practically double selection intensity in two ways—with dams to produce bulls for testing in AI and dams to produce replacements. If sexed semen is used with an AI plan, the theoretical improvement in milk yield would be 33 lb per year, with 23 lb due to selection of dams for replacements.

The value of this additional amount per year may not seem great for any individual cow, but when it is multiplied by a national herd of 7 million cows using AI and is accumulated for 10 years, the economic value, at $0.10/lb, is about $1.1 billion—an average of$110 million per year and **$231** million during the l0th year. The cost of sexing semen is not known, since no one has successfully done it. If a way is found, the cost would have to be under $10 per breeding unit for the procedure to be economical.

Embryo Transfer.—The transfer of fertilized eggs from a cow to obtain progeny has been accomplished with great success, Most transfers have involved popular or exotic breed-

ing animals with little regard for genetic potential.

Embryo transfer may never pay for itself in terms of milk production of the animals produced except indirectly through bulls. Rather, it is used mostly to produce outstanding cows for sale. Other commercial applications for cattle include obtaining progeny from otherwise infertile cows, exporting embryos instead of animals, and testing for recessive genetic traits,

Embryo transfer progeny must be worth $2,500 each to justify the costs and risks. About $1,500 of this represents costs **due to embryo transfer and** $1,000 **the costs of producing calves normally. If genetic gain from embryo transfer comes only from dam paths, the expected gain over** AI alone is 76 lb / yr. Extra gain at $0.05 / lb above feed cost would have to accumulate for 79 years before added gain would equal even a $300 embryo transfer cost per pregnancy. If less **semen is needed (allowing more intensive bull selection), the expected gain of** 129 lb / yr must accumulate for 46 years to balance an embryo transfer cost of $300 per pregnancy.

Embryo transfer and perfect sexing of semen would combine to improve genetic gain (in milk production) slightly. The use of less semen might be possible through application of in vitro fertilization. However, feasibility based on genetic gain would still require holding all costs down to around $50 to $90 per conception. The general conclusion is that costs of embryo transfer must be greatly reduced to be economically feasible if only genetic gain is considered.

Estrus Synchronization.—The availability of an effective estrus synchronization method would provide strong impetus for increased use of AI and embryo transfer in dairy cattle. The detection of estrus is an expensive operation; effective control of estrus cycling also requires intensive management, adequate handling facilities, and close cooperation between the producer, veterinarian, and AI technician.

Summary.—

Proper application of progeny testing with selection and AI can increase the genetic gain for milk yield more than two times faster than is occurring today. Improved evaluation of cows, proper economic emphasis on other traits, and strict adherence to selection standards are the keys. Biological limitations to this rate of genetic improvement cannot be anticipated in the foreseeable future.

AI of dairy cattle, with the present intensity of sire selection, should increase the net worth or profit of animals (increased value minus extra costs of the **AI program) about $10.00/head** per year. By 1990, ***8*** million dairy cows in AI programs would be worth about $800 million (8 X 10^6X 10 X 10 years) more at current market prices as a result of continued use of AI.

Sexing of semen when used with AI may pay for itself if the cost per breeding unit can be kept between $10 and $20.

Embryo transfer is unlikely to pay for itself genetically unless the cost is reduced to between $50 and $90 per conception. However, despite its high costs, it is used to produce animals of exceptionally high value. (See app. II-C for an explanation of reasons other than genetics why embryo transfer is used.)

Estrus synchronization is now available for use with heifers, and should increase the use of AI and consequently the genetic improvement of dairy cattle.

A secondary benefit of all technologies is the increased number of skilled persons who can provide technical skills as well as educate dairymen in all areas. Also, a unique pool of reproductive and genetic data has been accumulated.

BEEF CATTLE

There is no single trait of overriding ire-’ portance (like milk production in dairy cows) to emphasize in the genetic improvement of beef cattle, the rate of growth is a possibility. * It is also difficult to select for several traits at once,

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● Beef and dairy cattle are usually different breeds in the States. In the literature and in research they are often referred to as ies. In ot **species.** In other **countries, notably in Western Europe** so- **in Japan, so-called “dual purpose” cattle are used to produce both beef and milk. In the** old da **States, old dairy cows usually become hamburger.**

especially when some are incompatible—e.g., it is desirable to produce large animals to sell, but undesirable to have to feed large mothers to produce them. There are also other complications. Growth rate has two genetic components, for which one can select—the maternal contribution (primarily milk production) and the calf's own growth potential. Other traits of interest are efficiency of growth, carcass quality traits (such as tenderness), **calving ease, and** reproductive traits, such as conception rate to first service with AI,

Genetic improvement programs **for beef have two major advantages over those for dairy cattle traits such as growth rate and carcass quality can be measured in both sexes (whereas one cannot** measure the milk **production of bulls); and the traits are more heritable than milk production.**

Artificial insemination.—Between 3 and 5 percent of **the U.S. beef herd is artificially inseminated each year. This low rate is due to several factors, including management techniques (range v. confined** housing), availability of related technologies (especially, until recently, estrus synchronization), and the conflicting objectives of the individual breeders, ranchers, and breed associations.

Because little is known about the effectiveness of Al in spreading specific genes throughout the Nation's beef herds, analysts have concentrated on their reproductive performance. Calf losses are heavy throughout the Nation. The calf crop-the number of calves alive at weaning as a fraction of total number of females exposed to breeding each year—is estimated to be between 65 and 81 percent. To put these data in perspective, **USDA[18] has estimated that a 5-percent increase in the national calf crop** would yield a savings of $558 million per year in the supply of U.S.-grown beef. Techniques now available can produce such an increase when they are integrated into an adequate management program.

The standardized measure of weaning weight in beef cattle is the weight at 205 days, adjusted for sex of calf and age of dam. In a recent study in West Virginia—the Allegheny Highlands Project—calf weights have averaged an increase of 10 lb per year of participation in the project, via AI and crossbreeding. Estimates of increased value of calves statewide, should the same tests and AI program be expanded, add up to $3.6 million per year when calf prices average $50 per hundredweight.[19] Rapid adoption of AI could bring about this kind of increase in as little as 40 to 48 months.

The costs and returns of AI vary from farm to farm and with the number of cattle in estrus. In general, it becomes more valuable with smaller herds, more cows in estrus, higher conception rates, and better bulls. For purebred herds, even larger benefits have been estimated—e.g., in a 1969 study, the estimated increase in value per calf when AI was used was $30.02 on purebred ranches compared to $3.31 on commercial ranches in Wyoming.[20]

A major secondary, or indirect, benefit of the use of **AI** is feed saved for other uses. It has greatly reduced the number of sires necessary for stud service and, through radically improved milk production, the number of females as well. These reduced requirements together are equivalent to more than 1 billion bu of corn and other concentrates. This situation will be further enhanced as beef cattle AI expands.

synchronization of Estrus.—Differences in the rates of application of AI between beef and dairy herds can be explained partly by the differing management systems for the two types of classes of cattle. Dairy herds are kept close to the barn for milking and are accustomed to being approached by humans. In contrast, beef herds may number a few thousand head on 100,000 acres of arid pasture land. The detection of estrus under these conditions is difficult.

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[18] U.S. Department of Agriculture Research [illegible] "Beet Production," Production," Research [illegible] Repel't [illegible] (\ 20360 Washington, D.C.: USDA, [illegible]

[19] B. R. Baker, P. L. Lewis, and [illegible] evis, and [illegible] s, "Pro[illegible] 011 the Allegheny Highlands Project" [illegible] town, W. West W. Va.: West Virginia [illegible] January-December [illegible]

[20] I and "T. [illegible] evens "Artificial Insemination of [illegible] Cattle in Wyoming: An Analysis," Wyoming Agricultural Experiment Bulletin No. 496, 1969.

It has been predicted that the availability of prostaglindin agents for regulating estrus could increase the number of beef calves born from superior bulls by 10 times, and that perhaps 20 percent of the U.S. beef cow herd could receive at least one insemination artificially by 1990.[21] If this lead to a 50-lb increase in weight for 10 percent of the calves born, it should be worth $114 million to $122 million each year, assuming 80 or 85 percent net calf crop and $60 per hundredweight.

The implementation of recently developed estrus synchronization technology might increase the number of beef cows bred artificially by 4,000,000 in the United States. Such a program should be successful in advancing the calving date by one week (by decreasing the calving interval), and in increasing the quality of the calves produced. These new calves could be worth about $100 million annually, less about $50 million due to extra costs associated with the synchronization program.

Sex Control.—Sex control would have a dramatic effect on the beef industry. In 1971, it was projected that by 1980 sex control could have an annual potential benefit of $200 million based on 10 million female calves being replaced by male calves produced through the sexing of semen.[22] At the time of the prediction, the market value for steers was about $20 more than for heifers. (Steers wean heavier and gain more efficiently.) Now the margin is much greater–approximately $50. This potential method of biological control is more attractive than the use of additives like steroids or implants because of the possible hazards associated with them that preclude their use.

Embryo Transfer.—The possibilities for genetic improvement in beef cattle using embryo transfer have been analyzed. It appears that embryo transfer programs can be developed to increase the rate of genetic progress for growth rate; but the programs are much too expensive to be used over the entire population. One problem is that the economic value of the product of a beef cow is around 25 percent (or even less) of that of a dairy cow. Nevertheless, in populations in which AI is used, embryo transfer was found to be useful for obtaining more bulls from top cows. The females produced by embryo transfer would be worth marginally more than females produced conventionally, but the costs and influence of males could spread over the population through the use of AI. The extent of this use of embryo transfer would be very small; only a few hundred bulls would be produced per year for very large populations, and over 99 percent of the population would reproduce conventionally. However, such programs could have considerable economic benefit. Care must be taken to minimize increased inbreeding of the population with such a breeding scheme.

Summary.—

- AI could substantially improve economically important traits in beef herds. However, because of the diversity of traits considered important by different breed groups and the lack of a national beef testing and recording system comparable to NCDHIP, economic estimates of its value have not been developed.
- A sexing technology to produce mostly males (they grow faster than heifers) could be of enormous potential benefit to the beef industry. However, no successful technique yet exists.
- Estrus cycle regulation could lead to a substantial increase in the number of beef cattle in AI programs. The net benefit of this technology, coupled with AI, may be as high as $50 million per year. Similarly, the availability of reliable progeny records would add to the beneficial impact of AI in beef and would probably contribute significantly to its use in beef cattle.

OTHER SPECIES

Swine.—Much progress has been made in improving the overall biological efficiency of pork production in the United States. Improved

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[21] [illegible] Impact [illegible] prospects [illegible] Cattle," [illegible] *Symposium,* J. [illegible] J. H. [illegible]) (Kalamazoo, [illegible] pp. [illegible]

[22] [illegible] P. [illegible] Might Sex Ratio [illegible] in [illegible] Animal [illegible] *Am. Soc.* [illegible] *Science,* 1971, pp. 1-1o.

growth rates, feed efficiencies, carcass merit, and litter sizes have helped keep pork prices down and improve its quality in the Nation's markets. Pork today is leaner and contains more high-quality protein calories than it was just a few decades ago.

AI in swine production could expand, although it will be limited by the relatively poor ability of swine sperm to withstand freezing and by the problem of detecting estrus. It will be encouraged by the strong trend toward confinement housing and integration of all phases of hog production. The industry—especially the individual, family-farm type units—would benefit by the establishment of a progeny testing scheme to identify superior boars. Publicly available information on genetic merit would decrease dependence on a few corporate breeding organizations.

Embryo transfer in swine will be strictly limited by difficulties in developing nonsurgical methods of recovery and transfer, and by the low economic value per animal in comparison to cattle and horses. However, embryo transfer is useful in introducing new genetic material into breeding herds of specific pathogen-free swine and in transporting genetic material to various regions of the world.

Sheep.—The processes of selection and of crossing specific strains, which have been so effective in poultry and hogs, have been virtually ignored in sheep. Selection of replacement ewes from the fastest growing ewe lambs born as twins and the use of flushing to increase ovulation rates have led to annual increases of 1.8 percent in lambing; in one test the market weight of lambs ws increased by one lb per year of cooperation.[23]

Synchronization of estrus in ewes can be achieved with prostaglandin and many different progestogens. The technique is used extensively in many countries, but no products for this purpose are currently marketed in the United States.

AI rates abroad sometimes approach 100 percent. However, AI will not be used widely on sheep in the United States until systems for performance and progeny testing are implemented that will track the number of lambs born and their growth rate, and until routine freezing of raw semen is achieved.[24]

Goats.—The research performed on goats is largely designed for application to other animals. However, interest in goats in the United States and the demand for their products through the world is increasing.

NCDHIP has just started providing sire evaluations to goat breeders. These data, along with artifical insemination, should increase milk production. The genetic data might be of particular usefulness in the less developed countries where most goat raising occurs. Greater use of all reproductive technologies on valuable Angora goats might be expected.

Other technologies

The use of any reliable twinning or sex selection technologies will be limited until such procedures can be made simple, fast, inexpensive, and innocuous. No widespread use of these technologies should be expected within the next decade.

The more esoteric techniques for manipulating sex cells or the germplasm itself will have no impact on the production of animals or animal products within the next 20 years. In vitro manipulations, including cloning, cell fusion, the production of chimeras, and the use of rDNA techniques, will continue to be of intense interest. However, it is unlikely that they will have practical effects on farm production in the United States in this century. Each technique will require more research and refinement. Until specific genes can be identified and located, no direct gene manipulation will be practicable. A polygenic basis for most traits of importance can be expected to be the rule rather than the exception.

Should such techniques become available, limited use for producing breeding stock can be expected. Experience with early users of AI and

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[23] [illegible]

embryo transfer is strong evidence for the predicted use of the technologies, no matter what their economic justification. (See app. II-C.)

A major, secondary effect of animal research in reproductive biology is increased understanding leading to the possible solution of human problems—e.g., the concept, efficacy, and safety of the original contraceptive pill was developed and established in animals. It involves the same principle as estrous cycle regulation discussed above.

AQUACULTURE

Aquiculture is the cultivation of freshwater and marine species (the latter is often referred to as mariculture). While fish culture is about 6,000 years old, scientific understanding of its basic principles is far behind that of agriculture. Aquiculture is slowly being transformed into a modern multidisciplinary technology, especially in the industrialized countries. Increasing awareness of human nutritional needs, overfishing of natural commercial fisheries, and rising worldwide demand for fish and fish products are trends that indicate a growth in interest in aquiculture as a means to meet the food needs of the world's population.

As part of the trend toward the high technology and dense culturing of intensive aquaculture systems in the industrialized countries, problems of reproductive control, hatchery technology, feeds technology, disease control, and systems engineering are all being investigated. Reproductive control and genetic selection are important because most commercial aquiculture operations must now depend on wild seedstocks. Very little information on the animals in culture is available.

With all three of the aquiculture genera (fish, mollusks, and crustaceans), selective breeding programs have long been established, healthy gene pools are available, and advantageous hybridizations have been developed. In fish raising, culture systems often demand sterile hybrids, especially of carp and tilapia, Selective breeding of salmon has been limited by political pressures. Very little work has been conducted with catfish, the largest aquiculture industry in the United States. The use of frozen sperm, which has been successful, should increase because of the savings in transport costs. Although culture systems for mollusks are fairly well-defined, little applied genetics work has been done with these popular marine species. Some success has been reported in selection for growth rate and disease resistance of the American oyster, and selection for growth rate of the slow-growing abalone is underway. The crustaceans, of which the Louisiana crayfish is the largest and most viable industry, are the least understood. Successful hybrids of lobsters have been developed.

Aquaculture suffers from an insufficient research base on the species of interest. However, growing appreciation of and demand for marine species should result in increased support for basic and developmental work on all aspects of control, including basic reproductive biology.

POULTRY BREEDING

The quantitative breeding practices of commercial breeders have changed very little over the last 30 years. Highly heritable traits, such as growth rate, body conformation, and egg weight, are perpetuated by mass selection because little advantage is gained from hybrid vigor. Low heritable traits (egg production, fertility, and disease resistance) are perpetuated by crossbreeding and identified through progeny and family testing.

The goals of the industry are to increase egg production of the layers–both in quality and quantity–and, with broilers and turkeys, to improve growth rate, feed efficiency, and yield, as well as to reduce body fat and the incidence of defects.

The technologies of AI and semen preservation have accelerated the advances made through quantitative breeding technology. AI is widely used in commercial turkey breeding because of the inability of modern strains to mate. It makes breeding tests more efficient, steps up selection pressure on the male line, reduces the number of necessary breeder males, and increases the number of females that may be mated to one male. Semen diluents were introduced to the turkey industry about 10 years ago to lower the cost of AI. Currently, a little over half of the turkeys are inseminated with diluted semen.

Preservation of poultry semen by freezing is now practiced by several primary breeders. Although freezing chicken semen causes it to lose some potency, the practice allows increased genetic advancement and the distribution of genetic material worldwide.

The amount of genetic variation available for breeding stock is not expected to diminish in the near future. Ceilings for certain traits will eventually be reached, but certainly not in the 1980's. Advances in breeding laying chickens will be less dramatic than in the past, but efforts will continue to develop new genetic lines and to improve reserve lines and crosses to meet future needs.

The growth rate of broilers will continue t. increase at 4 percent a year, which suggests that birds will be reaching 4.4 lb in 5 weeks by the 1990's. Breeding for stress resistance will be increasingly important, not only because of the increased use of intensive production systems, but also to meet the physiological stresses resulting from faster growth and greater weight.

AI will assume increasing importance. Recent advances in procedures for long-term freezing of chicken semen will allow breeders to extend the use of outstanding sires. The sale of frozen seman may eventually substitute, in part, for the sale of breeder males.

Dwarf broiler breeders will also assume increasing importance over the new few years. The dwarf breeder female is approximately 25-percent smaller than the standard female, and even though the dwarf's egg is smaller and the progeny's growth rate slightly less than that of the standard broiler, the lower cost of producing broiler chicks from the dwarf breeder more than offsets the slight loss in their growth rate. Dwarf layers and the dwarf breeder hens could reduce production costs by 20 percent and 2 percent, respectively.

There is some interest among poultry breeders in cloning, gene transfer, and sex control but progress toward successful technologies is slow.

Issue and Options for Agriculture—Animals

ISSUE: Should the United States increase support for programs in applied genetics for animals and animal products?

Advocates of a strong governmental role in support of agricultural research and development (R&D) have traditionally referred to the small size of the production unit: U.S. farms are too small to support R&D activities. Throughout this century a complicated and extensive network of Federal, State, and local agricultural support agencies has been developed to assist the farmer in applying the new knowledge produced by research institutions. This private/public sector cooperative network has produced an abundant supply of food and fiber, sometimes in excess of domestic demand. Socially oriented policies have been adopted to soften the impacts of new technology and to rescue the marginally efficient farmer from bankruptcy.

Current projections of U.S. and world population growth show increasing demand for all food products. Other predictable trends with implications for agricultural R&D, include:

- growth in income for some populations, which will probably increase the demand for sources of meat protein;
- increasing competition among various sources of protein for the consumer's dollar;
- increasing awareness of nutrition issues among U.S. consumers;
- increasing competition for prime agricultural land among agricultural, urban, and industrial interests;
- increasing demand for U.S. food and fiber

products from abroad, leading to opportunities for increased profits for successful producers; and

- **increasing demands on** agricultural products for production of energy.

OPTIONS:

A. Governmental participation in, and funding of, programs like the National Cooperative Dairy Herd Improvement Program (NCDHIP) could be increased. The efforts of the Beef Cattle Improvement Federation to standardize procedures could be actively supported, and a similar information system for swine could be established.

The fastest, least expensive way to upgrade breeding stock in the United States is through effective use of information. Computer technology, along with a network of local representatives for data collecting, can provide the individual farmer or breeder with accurate information on the germplasm available, so that he can then make his own breeding decisions. In this way, the Nation can take advantage of population genetics and information handling capabilities to upgrade one of its most important forms of capital: poultry and livestock. Breed associations and large ranchers who sell the semen from their prize bulls based on pedigrees rather than on genetic merit may act as barriers to the effectiveness of such an objective information system.

The benefits of such programs would accrue both to U.S. consumers, in reduced real prices of meat and animal products, and to producers who participate in the programs, in increased efficiency of production. Consumers spend such a large part of their incomes on red meat that every increase in efficiency represents millions of dollars saved. Beef producers too, should welcome any assistance in upgrading their stocks. The price of semen has remained relatively stable, and semen from bulls rated highly on certain economic traits costs only a few dollars more than that from average bulls.

However, efficiency of production is not the only value to be upheld in U.S. agriculture—e.g., in milk production complex policies have been designed to maintain constant milk supplies without large fluctuations in price.

The NCDHIP model program for dairy cattle has shown that an effective national program requires the participation by the varied interests in program policymaking in an extension network, for local collection and validation of data and for education and of expertise in data handling and analysis. Also important is a strong leadership role in establishing the program. This option implies that the Federal Government would play such a role in new programs and expand its role in existing ones.

B. Federal funding** of **basic research in total animal improvement could be increased.

The option, in contrast with option A, assumes that it is necessary to maintain or expand basic R&D to generate new knowledge that can be applied to the production of improved animals and animal products.

Information presented in this report supports the conclusion that long-term basic research on the physiological and biochemical events in animal development results in increasing the efficiency of animal production, both in total animal numbers and in quality of product. Increased understanding of the interrelationships among various systems—including reproduction, nutrition, and genetics—gradually leads to the development of superior animals that efficiently consume food not palatable to humans and are resistant to disease.

Earlier studies also support the importance of basic research–e.g., the National Research Council found in 1977 that”. , . not as much fundamental research on animal problems has been conducted in recent years . . . it should receive increased funding. ”[25] USDA also found, in a review of various conference proceedings, congressional hearings, special studies, and other published materials on agricultural R&D priorities, strong support for more research on the basic processes that contribute to reproduction and performance traits in farm animals:

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search Council, *World Food and Nutrition St* ***Nutrition*** *Contributions of Research* Washington, D.C. author).
p.

Specific livestock research areas identified as having significant potential for increased production both **in the United States and developing countries include: 1) control of reproductive and respiratory diseases, 2) developing genetically superior animals, 3) improving nutrition efficiency, and 4) increasing the reproductive performance of all farm animal species.**[26]

Regardless of the effectiveness of present population control programs or of current trends in individual decisions about family size, the output of the Nation's agricultural activities must increase over the next decades if sufficient food is to be available for the world's population. Basic research is the source from which new applications to increase productivity arise.

S. U. S. Department of **Science** ure **Education Administration,** ministration *and Food Research Issues* earc *Priorities* (Washington, D. C.: author, 1978), xiii.