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Beef Production Efficiency

The efficiency of beef production can be improved by applying knowledge of nutrition and breeding.

Allen Trenkle and R. L. Willham

Summary. In the production of high quality protein, feed grains will continue to be used to finish cattle for market as long as economics dictates. Production systems could be developed that would make ruminant animals less competitive with humans for feed grains, but the costs of instituting such programs would be prohibitive. Sufficient genetic variation exists either between or within breeds for the cattle population to be adapted to new management programs and for current methods of beef production to be significantly improved.

Today in the United States, questions are being asked about the role of animals in food production because they consume feed grains that could otherwise be used directly for human consumption. However, livestock, especially cattle, have been an integral part of grain production agriculture for thousands of years. They have served as power; refuse scavengers; a means of transportation of the grain after consumption; producers of fertilizer; a highly flexible food reserve; sources of fiber, leather, and biochemicals; harvesters of forage from adjacent nontillable land areas; as well as a source of high quality protein that nutritionally complements basic grain diets.

Because ruminants utilize many materials not digestible by simple-stomached animals, including man, they have attracted attention in several recent reviews (*1*). Ruminants are not as efficient as some other species in converting feed grains and oil seed meals to meat. Whether agriculture becomes limited to crop production in the future depends on the ability of the livestock industry, especially that part of the industry utilizing ruminants, to integrate efficient production systems into total agriculture output, and on the potential for improvement in animal production through the application of research. In this article we discuss research developments in nutrition and genetics which may improve the efficiency of meat production from beef cattle, currently the most conspicuous consumers of feed grains.

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Efficiency of Protein Production

Efficiency is the production of a desired effect with a minimum of input, or it can be considered as the ratio of output to input. There is no single expression that describes the overall efficiency of the beef industry, much less that of animal agriculture. The inputs and desired outputs for a breeding herd are quite different from those for animals used for slaughter. The desired output for breeding animals is reproduction, whereas that for market animals is production of high quality beef. Economically, inputs of labor, capital, land, and population size are most important. Around four animals exist in the breeding herd per market animal produced (*2*). To assess the outputs or inputs of animal agriculture in the same units is impossible. For feedlot cattle, the efficiency of protein production may be expressed as protein produced over protein consumed, but there is no efficiency ratio that can be used to include the value of insulin extracted from the pancreas. To simplify the discussion, biological efficiency will be considered as product nutrients per feed nutrient.

Changes in body composition can have a marked effect on efficiency. Fatty tissue contains more energy per gram than muscle tissue, so that a given quantity of feed will produce less fat than lean muscle. On a caloric basis the accumulation of fat is more efficient than protein gain because there is less heat loss from lipid synthesis. When protein utilization is the basis for comparison, young lean animals are more efficient in converting feed protein to product protein than animals which mature early and accumulate fat. Already in the United States there is a trend toward the consumption of greater proportions of lean beef. This trend alone will have a great influence on the efficiency of beef production in terms of converting feed supplies to lean meat, and will bring about changes in feeding and breeding systems used by the beef industry.

The singular advantage of the ruminant animal is its ability to use large quantities of low quality roughages and proteins in the production of a high quality protein. Cellulose, being a basic structural carbohydrate in all plants, is one of the most abundant organic compounds in the world. It makes up about 10 percent of the dry weight of leaves and about 50 percent of the structure of plants and is widely distributed in all parts of the world. Modern harvesting methods collect the grain and leave the fodders and straws in the field. Much of the land, because of topography, soil type, and climatic conditions, is not suited for extensive crop production and must be left in native vegetation or used to produce forage crops (for example, grass or legumes). Only about 10 percent of the earth's surface can be tilled for intensive crop production. Forage plants are often sparce and not easily harvested. Most roughages lack density and are not easily packaged for transport over long distances. Consequently, much of the roughage is not utilized in any food-producing system. It could be used effectively, however, by grazing animals or by harvesting it and feeding it to nearby cattle or sheep.

Cellulose is a polymer of glucose molecules joined by β-1,4 linkages. Many bacteria and fungi produce enzymes capable of hydrolyzing this bond, and the digestive tract of all herbivorous animals has developed to provide an environment in which microorganisms that digest cellulose can grow and multiply. The stomach of ruminants is divided into the rumen, reticulum, omasum, and abomasum. The ruminoreticulum provides the environment for the microbial fermentation of feeds before they are subjected to the gastric secretions and digestion in the abomasum. Ruminants are better adapted to use low quality roughages than other herbivores because the end products of the fermentation, as well as the microbes, are made available

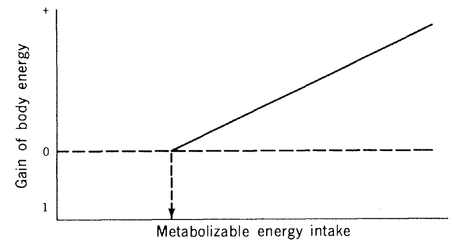

Fig. 1. The relation between intake of metabolizable energy and level of production. If animals are fed less than the level required for maintenance, there will be a loss of body weight. Metabolizable energy is gross energy of the feed corrected for losses of energy in feces, urine, and digestive gases.

to the host animal. In ruminants, the microorganisms utilize part of the food consumed by the host animal for their own growth and metabolism before any nutrients become available to the host. Cellulose and starch are broken down to glucose which then is rapidly fermented by anaerobic glycolysis to short-chain fatty acids of which acetate, propionate, and butyrate are the most abundant. These acids are absorbed from the rumen and serve as a source of energy for the host. Most proteins are also extensively degraded to amino acids which are deaminated and decarboxylated to produce fatty acids, carbon dioxide, and ammonia. The ammonia is utilized by the microbes to synthesize proteins or is absorbed from the rumen and converted to urea in the liver. Part of the lower efficiency of ruminants in comparison with other species is attributable to the energy and nitrogen losses from the fermentation.

Nutrient Metabolism and the Refinement of Feeding Standards

Historically, the greatest improvements in efficiency related to food production from animals have come from a better understanding of the metabolism of nutrients and of the nutrient requirements of the animals themselves. Animals will be most productive when all the nutrients required to satisfy their needs are supplied by the diet or, in the case of ruminants, by the diet and fermentation, no nutrient being given in excess of these requirements. The proper balance of nutrients will vary for animals from different genetic sources, for animals in different stages of their life cycle, and for animals with different levels of production. In addition to having knowledge of their nutrient requirements, we need to have knowledge of the biological availability and concentration of nutrients in feedstuffs. Data on the chemical composition of feeds has been accumulating over many years. Laboratory methods to measure the biological availability of nutrients in feeds are not available for every nutrient. Some techniques have been developed, and the refinement of these methods continues to attract the interest of scientists. When more data become available on the nutrient requirements of the animals, the nutrient composition of the feed resources, and the biological availability of the nutrients in feeds it will be possible to formulate diets which best supply the nutrient needs of the animals. In many modern cattle feed yards, computers are used to formulate these diets. In the developing areas of the world, however, increased supplies of feeds will have the greatest influence on improvements in animal production rather than the use of complex technology to refine the feeding standards.

Regulation of Feed Intake

In the life cycle of cattle production, most of the feed is needed for maintenance (vital body functions, movement, and body temperature). Basal metabolism is related to body surface and often is expressed as a function of body weight according to the equation: basal metabolism (kilocalories) = 70 $\times$ (body weight)$^{0.75}$. It is unlikely that significant improvements in the efficiency of animal production will be brought about by decreasing basal metabolism. Because larger animals require more feed for maintenance, they have to be more productive (more pounds of calf, meat, or milk) to be as efficient as the smaller animals. The relation of size of cattle to efficiency of production is being investigated (*2, 3*). The ideal size will probably vary with several factors such as intensity of production, level of feed supplies, and input of management. Improvements in efficiency will be realized with a better understanding of these interrelationships.

As illustrated in Fig. 1, for a given size of animal a greater proportion of the feed consumed is used for productive purposes as level of feed intake is increased. This is because the maintenance requirements are related to body weight and remain constant at a given weight. The physiological regulation of feed intake of ruminants is complex and not completely understood (*4*). It is thought that a full digestive tract physically limits the consumption of bulky feeds such as forages. The consumption of diets composed largely of grain are thought to be regulated by sensitivity to chemical factors which serve as signals in the regulation of caloric homeostasis. Several studies, which have not been published, have been conducted at various experiment stations to evaluate a feed intake stimulant given the common name Elfazepam. The use of this compound shows some evidence of increasing feed consumption, especially of diets composed of roughages.

Because the energy is more concentrated in grains than roughages, cattle can obtain more metabolizable energy from diets containing grain than from those containing roughage. Also, the starches of grain are fermented differently in the rumen so a greater proportion of the gross energy of the grain is available to the animal for productive purposes than that from roughages. These two factors make grain a more efficient feed than roughages for fattening cattle. Therefore, when there are surpluses of grain and prices are low, high concentrations of grain are used in cattle feeds. Only as grain prices increase relative to the cost of roughage, will roughages be substituted in large quantities for grain fed to cattle to be slaughtered. For maintenance, the useful energy available from roughages and grains is more nearly equal, so that the prices of grain usually favor the use of more roughages for maintaining breeding animals. As demand for grain in the world trade increases it will be necessary, in those parts of the world where large quantities of grain are fed to cattle, to feed less grain and more roughage. A large part of the increased amounts of roughages fed will probably come from the by-products of crops and crop residues.

Table 1. The influence of diethylstilbestrol on the utilization of dietary energy and protein for body weight gain of feedlot cattle. Data calculated from Fowler *et al.* (*28*).

Diethylstilbestrol (mg/day)	Animals (No.)	Empty body weight gain (kg)	Composition of gain (%)			EG/EC*	Efficiency of gain*	
			Moisture	Protein	Fat		PG/EC†	PG/PC‡
Cattle fed on corn grain								
0	9	158	24.7	9.5	63.4	33.5	3.2	11.3
20	9	181	30.9	11.7	54.4	29.6	4.2	15.0
Cattle fed on corn silage								
0	10	144	20.9	8.2	68.7	34.7	2.0	7.7
20	10	177	31.6	12.1	53.3	30.0	3.5	13.3

*Ratios of energy gained to energy consumed. †Ratios of protein gained to energy consumed. ‡Ratios of protein gained to protein consumed.

Increasing the Availability of Nutrients

Efficiency of beef cattle production could be increased if more of the nutrients in a given quantity of feed were available to the animal during digestion and absorption. Lignin, which is present in the woody parts of plants, occurs in close association with cellulose and prevents attack of the cellulose by microbial enzymes. Partial breakdown of the lignin by treatment of roughages with strong alkali increases the availability of the cellulose. The treatment of large quantities of roughage with alkali is cumbersome, however, and not widely practiced, but other methods may be more applicable. For example, the partial predigestion of roughages with enzymes or selected microorganisms may greatly improve the nutritional value of roughages. The processing of feeds by grinding, steaming, flaking, pelleting, and ensiling is being widely practiced in the cattle feeding industry (*5*).

The energy losses from the fermentation in the rumen are less if propionate is produced instead of acetate and butyrate. The production of propionate from glucose results in the utilization of hydrogen, whereas conversion of glucose to acetate or butyrate produces hydrogen and carbon dioxide, which results in the formation of methane. Methane is lost from the rumen as a gas and represents a significant loss of energy. Attempts are being made to reduce the generation of methane in the fermentation, but to date no method has been found that has practical applications. Changing the fermentation in favor of propionate has been used as the basis for the development of monensin, which is used as a feed additive for the improvement of feed utilization of feedlot cattle (*6*). The formation of greater quantities of propionate results in more metabolizable energy being available to the animal from a given quantity of feed. Cattle fed monensin require 10 percent less feed per pound of gain. This compound is effective in cattle fed grain or roughage. It has been cleared for use in feedlot cattle and in the near future may be available for use in grazing cattle.

Because the loss of nutrients during the fermentation can be excessive with certain feeds, attention has been given to protecting nutrients as they pass through the rumen. The protection of proteins has been studied the most (*7*), the object being to protect those of high nutritional quality so that more of their amino acids are made available to the animal, and to allow the poorer quality proteins or urea to serve as a source of nitrogen for the microorganisms. Some protection has been achieved by careful heating of the proteins or by treating them with chemicals, such as formaldehyde, with which they form complexes. Much remains to be learned in this area but some recent studies at Iowa State University indicate that cattle require only one-third as much supplemental protein when soybean meal is treated with formaldehyde as they require when this protein source is fed unprotected. Protection of proteins will be more important when low-quality roughages are used as cattle feeds because they contain only small amounts of protein and therefore require more supplemental protein than other feeds. Protection of other nutrients may also be possible to improve efficiency of their utilization. Protection of lipids to increase the bypass of unsaturated fatty acids is being researched as a means to reduce the concentration of saturated fatty acids in meat and milk from cattle.

Improving Efficiency of Feed Utilization by the Animal

It has been known for many years that younger animals are most efficient in the conversion of feed to meat, and that bulls are more efficient than steers in this conversion (*8*). These differences are partly related to the composition of the gain, the gain of the young animal containing more lean and less fat, but other factors related to the endocrine system are also involved. It was discovered over 20 years ago that estrogens increase the growth of cattle and sheep (*9*), the increased weight being made up of more muscle and bone and less fat (Table 1). Estrogens increase the efficiency of utilization of dietary protein or energy for growth by more than 30 percent. Because diethylstilbestrol, the synthetic estrogen used extensively in beef cattle, is a carcinogen, its use may not be continued in the future. There are other products, however, which contain naturally occurring estrogenic compounds and bring about responses similar to diethylstilbestrol in cattle. Estrogens are thought to stimulate growth of cattle by increasing the secretion of growth hormones from the anterior pituitary gland (*10*).

It has recently been observed that the effects of monensin, which acts in the gastrointestinal tract, and the effects of hormones that change endogenous growth hormone levels are additive. The increase in gain brought about by combined monensin and hormone treatment has been over 20 percent and the improvement in conversion of feed to gain has been about 29 percent (Table 2). As our knowledge of the endocrine system involved in the regulation of growth of cattle increases, other methods for the administration of hormones may be developed that will produce even more dramatic improvements in the conversion of dietary nutrients to beef. It may also become possible to prolong the high conversion efficiency of the young calf up to the time of slaughter.

Table 2. Influence of hormone implants and monensin on weight gain and efficiency of feed utilization by feedlot cattle. Summary of eight experiments conducted in Indiana, Iowa, and Minnesota.

Treatment	Gain (kg/day)	Ratio of gain to feed (kg)
None	1.08	0.119
Implant	1.23	0.129
Monensin	1.13	0.136
Implant + monensin	1.30	0.153

Alternative Feed Supplies

If cattle were fed sources of nutrients which could be digested by ruminants but not utilized by humans, then beef production would become less competitive with human food supplies. The use of by-products and crop residues has already been referred to. With greater knowledge of the nutrition of cattle and increased availability of nutrients from roughages it will be possible to produce acceptable finished beef entirely with noncompetitive feeds, such as by-products and crop residues. A group of cattle fed a ration containing 77 percent noncompetitive feeds (60 percent corncobs, 15 percent cane molasses, 2 percent urea, 15 percent corn, 7 percent soybean meal, and 2 percent vitamins and minerals) in an experiment in progress at Iowa State University are gaining 1 kilogram per animal per day.

One nutrient source that has received much attention is urea, which can be used to replace a portion or all of the supplemental protein in cattle feeds (*11*). Nutritionists generally agree that protein is a major limiting nutrient for animal production, especially ruminants fed forages and roughages. The use of urea in the United States has increased from no use of practical significance in the early 1940's to 180 × 10^6 kg in 1976. The present annual usage is equivalent to the nitrogen in 1050 × 10^6 kg of soybean meal. The combined use of urea and protected proteins could result in beef production becoming even more efficient.

Animal and poultry wastes are also an alternative source of nutrients for animal production. These materials contain nitrogen, minerals, and energy which can be utilized by cattle. These wastes contain the end products of protein metabolism which can be degraded in the rumen and utilized in a way similar to the way urea is used by rumen microorganisms. Some of the undigested energy components of the feed are further modified by the microorganisms in the large intestine of ruminants and nonruminants, before excretion, and if the wastes are properly processed (ensiled, heated, dried, or chemically treated) they can be fed to cattle.

Breeding

The efficiency of beef production could be increased by genetic manipulation of the cattle population. Such increases would be brought about primarily through the impact of size, rate of maturity, and milk differences on economics rather than by biological efficiency. Exploitation of existing genetic differences and the creation of capital improvement through selection are both viable means to achieve increased efficiency. For a historic account of the development of existing genetic differences in cattle, see (*12*).

Before the Charolais breed of cattle gained importance in the early 1960's, only the three British beef breeds (Hereford, Angus, and Shorthorn) were available to beef producers in the United States. In 1967 the Canadian government provided the means to import frozen semen into the United States from numerous continental European breeds. These imports included semen and then breeding stock from a variety of types from dairy, dual-purpose, to beef breeds. This introduction of new germ plasm, although sought by the scientific community (*13*), was accomplished by the beef industry. Only recently (*14*) has there been a large-scale comparative evaluation of these introductions. These diverse genetic groups or breeds are important to the beef industry because breed formation is a slow process with the low reproduction rate of cattle (0.86 calf per cow per year on the average).

Commercial producers of beef now have a choice among at least 30 breeds and their cross combinations. After this initial selection of breeds or breed crosses, the producer has a choice among the breeding herds and the animals within these herds of the chosen breeds or he can use frozen semen. This is the current population structure or hierarchy existing in the breeding herd that supplies the germ plasm to the roughly 97 percent of the beef industry engaged in market production. Beef breeding is still done primarily by small breeders rather than by large breeding companies.

The design of sound breeding programs by breeders and producers requires a knowledge of the kind and amount of genetic variation available to make genetic change (*15*). For breeders and producers to use new and relatively sophisticated technology in the conduct of their breeding programs requires economic incentive and creative extension programs. Table 3 shows a synthesis of beef breeding research that has been accomplished to describe the kind and amount of genetic variation available in the beef population. The synthesis is derived from many research papers on beef breeding that have appeared primarily in the *Journal of Animal Science*, from reviews on beef breeding (*16, 17*), and from knowledge of the genetic characteristics of the species studied. The table has been used extensively to disseminate breeding technology (*18–20*). Coupled with the genetic values are relative economic values that are just now receiving attention from economists and geneticists.

To simplify the table, the numerous traits measured in beef research are placed in three classes: reproduction, production, and product. In broad biological terms, the classes can be defined as reproductive, physiological, and morphological. The reproductive traits, such as calf crop percentage weaned, are complex traits dealing with the interaction of the sire, dam, and the resulting calf. The production traits in the breeding herd, such as cow weights and weaning weights of the calves, deal with mature size and milk production differences. These traits influence the costs of calf production. The production traits in market animals, such as rate and efficiency of gain in the feedlot, deal with growth and maturity rate differences. The product traits, such as yield of edible product and meat quality grade, deal with lean-to-bone ratio and fat deposition rate differences in the product, beef.

The headings under genetic values in Table 3 refer to differences, expressed as a percentage of the mean performance for the particular class of traits, among broad types such as dairy, dual-purpose, or beef breeds; to the amount of heterosis, expressed as a percentage of the mean performance for the particular class of traits, expected from crossing breeds either between or within the types; and to the fraction or percentage of the differences among individuals of the same breed that are treated alike, which is genetic or is available for selection. All the figures under genetic values are an expression of genetic differences that are given either as percentages of the mean or as percentages of the variation found for the traits in a particular class. These figures give a general description of the kind and amount of genetic variation available in the beef cattle population.

Table 3. Current beef industry values: a synthesis of research information on genetic values and some relative economic values. The reproduction class of traits includes calf crop percentage, calving interval, calving ease, and survival percentage, for example. The production class of traits includes mature size and milk production in the breeding herd and rate of gain and efficiency in the feedlot for market animals. The product traits include measures of the amount of product and its eating quality.

Class of traits	Genetic values			Economic values (relation)	
	Breed types differences* (%)	Heterosis† (percentage increase)	Heritability‡ (percentage of variation)	Breeding herds§	Market feedlots‖
Reproduction	20	10	10	5	0
Production	50	5	40	1	2
Product	10	0	50	0	1

*These are average differences among breed types when given comparable treatment expressed as a percentage of the mean performance. The relative values are the issue rather than the absolutes. Large differences among breed types exist for production traits while relatively small differences in product traits exist when types are taken to a similar composition. †Heterosis is defined as the difference between the cross and the average of the parental breeds. This difference is expressed as a percentage of the mean performance. ‡Heritability is defined as the fraction of the variation, among individuals of the same breed that are treated alike, that is genetic. Selection advance is predictable by the product of heritability and the superiority of the selected parents. §The relative economic value of the trait class in the breeding herd under commercial production. ‖The relative economic value of the trait class in the market animals under commercial production.

Large differences exist among types and even among breeds within types, especially for the production class of traits, because of differences in growth rate and milk production among the breeds. Heterosis can be obtained from crossing breeds, especially for the reproductive complex. The heterosis potential is large enough to be commercially important. The amount of genetic variation available for selection within breeds is high enough for the production and product traits to suggest commercial improvement. Note that the amount of heterosis to expect and the amount of genetic variation within breeds is negatively correlated. This relationship is true for most species and does create problems in breeding program design.

The columns under economic values refer to the commercial herds that produce the market calves and to the market product, calves which are not expected to reproduce. This division, which emphasizes the segmentation of the beef industry into calf producers and feeders, clouds the economic incentives for the breeders producing germ plasm for the beef industry. Reproduction, or the creation of new wealth, is at least five times as important in commercial operations as growth and milk production, as indicated by calf weaning weight. Production traits, such as gain in the feedlot, are about twice as important as the quantity or quality of the product currently, but this relation could change quickly depending on market demands.

Table 3 summarizes the genetic potential for change and the relative importance of such change and clearly suggests some opportunities for improving the efficiency of beef production. The importance of reproduction to commercial producers coupled with the heterosis potential for improving the reproductive complex indicates that crossbreeding could effectively increase overall efficiency of beef production. The large differences among breed types, especially for the production traits, suggests that complementarity or the selection of breeds to use in a program that complement each other could affect big changes in the industry. The column labeled heritability indicates that the breeders producing germ plasm for the commercial industry can improve the production and product traits by selection and pass this increase directly to the producer through the use of superior stock. No one breed or type appears to be best for all classes of traits or economic situations, so crossbreeding for both heterosis and complementarity, together with selective improvement of the breeds, appears to offer opportunities for improving efficiency by optimizing growth rate, mature size, milk production, and rate of maturity (important because of the age at which rapid fat deposition occurs) and to a limited extent by improving biological efficiency.

The basic problem encountered in applying the genetic potentials commercially is the extremely low reproductive rate of cattle. Heterosis has been exploited in species such as corn, poultry, and swine, which all have a much higher reproductive rate than cattle. That is, the extent to which an optimum breeding structure can be attained rests on whether it can be practiced economically, given the reproductive potential. When this is coupled with small herd size (less than 50 head on the average), a secondary enterprise except for ranches, and the increasing value of grazing land, the probability of research information being fully utilized is remote. However, the beef industry completely replaced the Longhorn and other cattle with British beef breeds and has introduced new germ plasm since 1967 which has definitely expanded the genetic potentials of the beef population. The key is to have the research information available when the economic incentives arise.

Improving the reproductive potential of cattle can reduce the cost of production (by spreading breeding-herd expenses over more animal units), increase the potential that can be realized from crossbreeding, and increase the response to selection (by having larger numbers from which to choose). Improving calf crop 1 percent from 86 percent with 30 million cows gives 200 thousand more calves or 340 thousand fewer cows for the same number of calves. Artificial insemination provided the means for introducing new germ plasm and now is recognized as a tool for breed improvement when used in conjunction with sire evaluation. The dairy industry has obtained a greater than 1 percent improvement in milk production per year by using superior sires evaluated through their early progeny test for milk (*21*). The use of artificial insemination to spread the daughters of a sire over many herds, and the Dairy Herd Improvement Association's record program coupled with the sire summaries published by the U.S. Department of Agriculture, has made such improvement possible. The general use of artificial insemination in the beef industry could produce similar results in seed-stock production and enhance the use of systematic crossbreeding programs. Breakthroughs that would make artificial insemination as easy as using a bull in commercial production are being researched.

Research in the field of reproductive physiology includes work on twinning. Investigators are using hormone manipulation in attempts to exploit this in herd situations where twinning would be desirable. Breeding by artificial insemination at ovulation is nearly ready for application in the field. With newly introduced breeds, ''super-ovulation'' of purebred females and techniques for ova transfer to donor cows are being used to produce several offspring per valuable cow per year. It is more difficult to evaluate cows accurately than it is to evaluate bulls that can have large numbers of progeny in many herds in a short time. General increases in calf crop percentages hold a high potential for increasing efficiency.

Directional genetic change in the cattle population can benefit the beef industry. The exploitation of heterosis and complementarity by selection of breeds and breed crosses in a systematic crossbreeding program can improve efficiency as well as the selection of superior individuals within the breeds. Current research is directed primarily toward the evaluation of the germ plasm introduced into the United States (*17*). Matching genetic potential to available management resources (such as feed available) has presented new problems of evaluation (*20, 22*). Just how best to exploit this new resource of breed differences is also receiving attention (*23*). Systematic rotational crossbreeding (with sires from two or more breeds being used in rotation); specific three-breed crosses (that can better utilize the complementarity of a small, crossbred cow for maternal heterosis and a large sire breed for growth and carcass merit); and synthetics (which are cross-combinations of several breeds used to circumvent the difficulty of systematic crossbreeding in small herds) are all options to be researched (*24*). Improvement in biological efficiency through the use of breed differences is not the primary issue, because Smith *et al.* (*25*) showed that there are small differences among breeds when all are slaughtered at a constant carcass composition.

Large improvements in the efficiency of beef production can be obtained by reducing the costs of the breeding herds, reducing the costs of time and in feed for maintenance by increasing growth rate, and reducing the amount of fat produced in the carcass from the optimum utilization of breed differences. Utilization of crossbreeding in the breeding herd alone can improve output from 20 to 50 percent. By simply taking feedlot cattle of a given breed combination to their optimum slaughter weight can improve the efficiency of production. As research information makes it possible to evaluate and define the potentials for the newly introduced germ plasm, the industry will better utilize the potentials that are available to improve efficiency.

Genetic improvements within breeds are being made. Most beef research in this area has been to describe the amount of genetic variation available and the genetic correlations among the traits within breeds, but a few long-term selection studies are under way (*26*). Eleven breeds have established sire evaluation programs on a national scale. Through these programs, the genetic structure of the breeds (which are subdivided into small partially isolated genetic groups, herds within breeds) can be clarified such that sires can be accurately evaluated and the superior one used extensively through artificial insemination for breed improvement. This opportunity came through the Beef Improvement Federation which is a federation of all performance organizations in the industry. The federation has codified the record systems and through participation of beef researchers has acted as the innovator for genetic technology use in the industry (*12*). Genetic improvement by selection within a herd is slow. For a single trait with 40 percent of the observable differences heritable, around a 1 percent improvement in the mean per year is expected. Current changes in the performance of particular breeds have come about by exploitation of existing herd differences through the widespread use of the germ plasm from these herds over the breed. Breed changes in skeletal size, and the resulting changes in rates of maturity and growth, can be made because of the high heritability of general size. The big problem, as always, is in the choice of goal or direction of selection by the many individual breeders producing the germ plasm for the industry.

Improvements in the efficiency of beef production within the immediate future are most likely to come from the matching of breed and breed-cross potentials with management systems. Such matching and use of crossbreeding could improve beef efficiency by 15 to 20 percent on a national basis where the improvements within the breeds might result in a 1 percent advantage per year at best, but they would be capital gains.

Systems

The beef industry is highly segmented, as is the research work of the various disciplines of animal science that contribute information to the efficiency of beef production. Efforts are under way to integrate the disciplines of genetics, nutrition, and physiology with economics to define production functions and develop optimum beef production systems. Such analyses are useful to point out areas where basic knowledge is imperative but lacking, to examine possible interactions among discipline inputs, and to formulate sound, demonstrable recommendations for extension. Examples of systems research in beef production have been discussed (*2, 27*). Systems research is a new area of opportunity in the beef industry.

Conclusion

The primary justification for animal production today is society's desire and need for high quality protein. In the production of such protein, domestic animals are consumers of, as well as producers of, protein and energy. Beef production in the United States will continue on a large scale, especially in operations in which the cow-calf pair is used as a harvester of low quality roughage. Feed grains will continue to be used to finish cattle for market as long as economics dictates because of the maintenance savings and the more palatable product that can be obtained from cattle at a younger age. The challenge is to develop production systems that will make ruminant animals less competitive with humans for grains and high quality protein feeds. Current knowledge of ruminant nutrition would be adequate to accomplish much of this, but the costs are prohibitive. Sufficient genetic variation exists either between or within breeds for the cattle population to be adapted to new management systems and for current methods of beef production to be significantly improved.

In European nations, beef production will continue to be a by-product of the dairy industries. For the developing nations with the potential to produce cattle, the development of a beef industry will depend on the economic climate and world trade. History is replete with cattle populations with no markets.

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NEWS AND COMMENT

Chemical Plants Leave Unexpected Legacy for Two Virginia Rivers

The tourist passing through Virginia enjoys what for the most part is still a fine scene—the soft outlines of distant mountains, the sweep of lush valleys, and splendid pastoral vistas and riverscapes are all there to please the eye. Indeed, the official slogan "Virginia is for lovers" is credible enough, for, besides the state's natural blessings, relatively little of it has been touched by the kind of industrial development that grossly pollutes or defaces. This being so, it is surprising and disconcerting to learn that three Virginia rivers are now so badly contaminated by toxic substances that well over 300 stream miles have been closed to fishing, or at least to the taking of fish for eating.

One of these rivers is of course the James, on which most commercial fishing is now prohibited from Richmond to the Chesapeake Bay because of contamination by Kepone. But equally remarkable, though little attention has been given to it outside Virginia, is the contamination of much of the Shenandoah River and the North Fork of the Holston River by mercury.

In fact, this latter problem seems of special significance, both with respect to its persistence—which is extraordinary—and to the questions of regulatory philosophy and practice to which it gives rise.

Not all of the Shenandoah River is contaminated, only the South Fork, which many regard as the best of it. Indeed, if it had been the conscious intent of some malevolent force to do mischief to an exceptional natural treasure, the South Fork of the Shenandoah could have served well as the object of such perverse designs.

Flowing over a bed of limestone and frequent ledges, the South Fork runs northward in a series of great loops between the Blue Ridge Mountains on the east and the Massanutten Mountain on the west. For the canoeist or the float fisherman (the South Fork is famed for its smallmouth bass fishing), the scene is ever-changing but is always good and sometimes spectacular, especially when the winding river turns toward the steeply rising slopes of the Massanutten. Along with the rest of the Shenandoah, the South Fork has long been a prime candidate for consideration as part of the national system of wild and scenic rivers, and was so listed in President Carter's environmental message of last May.

Although the Shenandoah was known to have some water quality problems, especially overfertilization from the runoff from farmland and other sources, it was not until this spring that state officials got word that part of the river might be heavily polluted with mercury. On 14 April a delegation from E. I. duPont de Nemours and Company, which has been manufacturing synthetic fibers at Waynesboro, Virginia, since 1929, called on Governor Mills Godwin and Virginia health and pollution control officials and brought the bad news.

Visible if minute globules of mercury had been discovered the previous September in the course of repairing a leaking water pipe beneath the Waynesboro facility's "old chemical building," where mercuric sulfate was used as a catalyst in the manufacture of acetate fiber between 1929 and 1950. Subsequently, analysis of sediment samples taken downstream from the plant in the South River showed that the sediment was heavily contaminated with mercury.

The readings for several samples exceeded 240 parts per million (ppm), compared to readings of less than 1 ppm for sediments tested upstream from the plant. Worse still, the one fish that DuPont had had analyzed for mercury contained 0.86 ppm, or substantially above