# Genetic Improvement of Beef Cattle Adaptation in America

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## Introduction

Management systems and environments differ widely for beef cattle populations across America. A typical animal may occupy several environments during its lifetime, each presenting a unique set of challenges. No animal or breed is maximally efficient in all environments, nor is any animal or breed maximally adapted to all of the challenges encountered in any one environment. To a certain degree, therefore, all beef cattle in America are less than optimally adapted. Profitability and maintenance of the integrity of production environments can be improved through programs to balance genetic potential for production, product quality and environmental adaptation.

With financial support from the USDA Agricultural Research Service and BIF and under the auspices of the National Beef Cattle Evaluation Consortium, concerned geneticists and cattle producers met in March, 2004[f] to define adaptation in beef cattle, characterize important stressors in major production environments and identify opportunities to improve adaptation through genetic means. Results were presented in a symposium in October, 2004. This document will describe those conclusions and identify strategies for improvement.

## Why are American beef cattle less than optimally adapted?

Response mechanisms to environmental challenges have been evolving in cattle populations for millions of years. Adaptation has been successful, and populations capable of sustained production now exist throughout most inhabited regions of the world. Why, then, are American beef cattle less than optimally adapted? There are several reasons.

Prior to domestication, cattle had a demanding but uncomplicated job description; they had first to survive and then to reproduce. To facilitate accomplishment of these goals, anatomical, physiological, immunological and behavioral mechanisms evolved that were appropriate to conditions in Eurasia, their center of origin. Thousands of bovine generations hence, their domestic descendents in contemporary America face vastly different parasites, diseases, stresses and nutritional challenges. It is not surprising that **a gene pool conferring adaptation to past and distant environments confers less than optimum adaptation to current, and indeed, to future conditions.**

Cattle were domesticated in western Asia some 10,000 years ago. Cattle and cattle production technologies subsequently migrated outward from centers of domestication, eventually to colonize much of Europe, Africa and Asia. With an estimated initial migration rate of six miles per decade[g1], natural selection could easily accommodate adaptation to newly encountered environments. During recent times, however, the speed of migration has accelerated (air freight can transport animals, gametes and embryos throughout the world in a matter of hours). Management systems are changing more rapidly as well, typically in the direction of greater intensification. Compared to only a few decades ago, for example, cows now produce their first calf at two rather than three years of age, animals are maintained at higher density per unit of land area

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and cattle are fed to market on higher energy diets. In many instances, **management systems and environments are changing more rapidly than animal populations can adapt to such changes through natural selection[2].**

Domestication and subsequent migration created opportunities for the formation of and differentiation among many locally adapted cattle populations. Our ancestors lived in a society of small tribes at that time, with limited material and cultural exchange between groups[3]. The role of cattle was determined by the needs of each tribe- milk and meat production, power generation, the accumulation of wealth and religious or cultural iconography, for example. Tribal definition of value thus imposed a new 'environmental' challenge on cattle populations, that of fulfilling an economic role. Phenotypic selection was applied, as animals more successful in meeting the community standard of value were allowed to reproduce while less successful individuals were not[4]. Planned mating and natural selection exerted by local environmental challenges also promoted the creation of populations well adapted to local requirements. As human social organization gradually evolved from tribes to communities, communities to villages, villages to cities, cities to states and states to nations, interactions among societies increased[5], and the isolation of local cattle populations diminished. When allele frequencies and gene combinations favorable to production in a local environment were disrupted through exchange of breeding animals, adaptation to specific environments declined. National and international trade in breeding animals, gametes and embryos now allows an animal to produce offspring in environments very different from the one to which that individual is adapted. While providing many benefits to efficient livestock production, **movement of genes into new environments can reduce adaptation of a resident herd to its own unique conditions and challenges.**

***An idea whose time has come back***

*Beef cattle geneticists in the American south and west concluded in the 1970's that "genetic adaptation to local environments is important in commercial beef cattle production"[6]. Furthermore, "indiscriminate distribution of breeding stock (or their semen) to different environments" should be avoided until something is known of the adaptive merit of that stock. They advised that animals be performance tested under environmental conditions similar to those that their progeny are likely to encounter. Evidence supporting these recommendations was provided by their classical experiment to investigate genotype by environment interaction. They started with two genotypes, a line of Hereford cattle selected in and adapted to Montana and another Hereford line selected in and adapted to Florida. These states also constituted the production environments; half of each herd was transferred to the other location, where production of the cows and their descendents was monitored over an 11-year span. Genotype by environment interaction would occur if the production difference between cows of Montana versus Florida origin differed depending upon the location in which they were compared. Such was the case. At Miles City, Montana, the Montana cows and their descendents exceeded Florida cows and their descendants by an average of 14 pounds calf production per year. In Brooksville, Florida, average annual calf production of Florida cows and their descendants was 84 pounds greater than that of Montana cows and their descendants! As might have been expected, cows from each origin were most productive in the environment to which they were adapted.*

Gradual response to mild selection to increase performance for production traits, as occurred during most of the history of the co-dependence between cattle and man, generally does not detract from an animal's ability to survive and reproduce. In fact, selection to increase sustained annual production selects automatically for traits important to adaptation. In recent decades, however, refined knowledge of inheritance, improved information technology and advanced reproductive techniques has allowed dramatic increases in selection intensity and selection response. Rapid response to intense selection for increased product (as opposed to increased sustained annual production) can sequester resources formerly utilized to support reproduction and survival. **Rapidly increased genetic potential for production may be achieved, therefore, at the expense of decreased genetic merit for adaptation.**

***Hidden costs of selection***

*Among domestic food animals, broiler chickens are the poster species for rapid rate of response to selection. They are highly prolific and turn generations rapidly, allowing for a high intensity of selection. Furthermore, commercial poultry breeding companies have clear, consistent objectives, most prominently to increase growth rate, feed conversion efficiency and breast meat yield. Selection responses in these traits have not been without cost[7]. Undesirable correlated selection responses include reduced fertility of broiler breeders and increased severity and incidence of* *ascites, sudden death syndrome, distortion of long bones and tibial dyschrondroplasia throughout the life cycle. In a similar manner, progeny testing and artificial insemination have fostered rapid response to selection for increased milk yield in dairy cattle, for which undesirable correlated responses include poor rebreeding performance of young cows and increased incidence of metabolic imbalances in lactating cows[8]. In swine, intense selection to increase growth rate and feed conversion efficiency has been accompanied by increased skeletal abnormalities and impaired reproduction[9]. Such undesirable side effects should come as no surprise. Within an environment, an animal can accumulate no more than some fixed level of nutritional resources. When a higher proportion of that total is required to support performance for intensively selected production traits, a smaller proportion is available to meet all other physiological demands.*

### Who benefits from improved beef cattle adaptation?

Potential benefits from genetic improvement in beef cattle adaptation include enhanced animal well being, increased profitability for beef cattle producers, more desirable products for beef consumers, enhanced resource conservation and more effective utilization of forage resources.

**Improved adaptation enhances animal well being.** Stress is a fact of life. Fortunately, response mechanisms have evolved to stressors commonly encountered in a population's evolutionary past. These physiological, immunological, metabolic and behavioral responses generally are sufficient to maintain biological integrity and physical well being. However, when responses are inappropriate or inadequate, stress can lead to distress, defined here as ill health or compromised well being[10]. In a maladapted population, inherent response mechanisms to prevailing environmental challenges do not maintain satisfactory well being of many individuals. An adapted population is one in which most individuals do cope successfully with those stresses most commonly encountered in their environment.

***When cows are vertically challenged.***

*Although native to and domesticated in western Asia, cattle are now raised in most semi-arid through humid, tropical through temperate and coastal through alpine regions of the world. Individuals are most likely to be poorly adapted at one or the other extreme of an environmental continuum. One such case is high altitude disease of cattle, of economic and welfare concern in mountainous regions of the American west. A synonym is 'brisket disease', named for edema which results when low oxygen pressure at high altitude induces labored respiration, increased heart rate, elevated blood pressure and fluid accumulation in the thoracic cavity of affected individuals. A tool to select breeding stock resistant to high altitude disease was developed through research at Colorado State University and elsewhere[11]. Pulmonary arterial blood pressure (PAP) measured at high elevations is heritable and is indicative of genetic susceptibility to brisket disease. Individuals with PAP below a specific benchmark produce offspring likely to be resistant to brisket disease; those whose PAP score exceeds that threshold typically produce a higher proportion of susceptible calves.*

**Improved adaptation enhances financial well being of beef cattle producers.** Beef cattle production cannot be profitable unless cattle are productive, efficient and produce a desirable end product. Selection to improve traits contributing to those ends is desirable if not required. In addition, cattle that are genetically adapted to their environment incur lower costs than un-adapted but otherwise comparable cattle. Overall profitability of beef cattle production would be enhanced by including locally-rational measures of adaptability in industry selection schemes and breeding objectives.

***When enough is just enough***

*Selenium (Se) is an essential trace mineral for animal nutrition. Its concentration in the soil varies widely across cattle producing regions of America, and in plants grown upon those soils as well. Although many cattle receive an appropriate amount of Se in their diet, some are marginally to severely deficient[12] while others experience selenosis[13] (toxicity from excess Se). Cattle at the Quinn Cow Company near Pine Ridge, South Dakota, fall into the latter category. Each year, some exhibit lameness, ill thrift and reduced calf production (the symptoms of selenosis), leading to premature culling. The Quinns believe that average resistance to Se toxicity is increasing in their herd, although slowly, as natural selection eliminates genes causing increased susceptibility. These detrimental genes could be re-introduced, however, through purchased bulls whose genetic resistance to selenosis is unknown. If a readily measurable trait indicative of ability to absorb Se from the diet could be identified, breeding animals could be selected whose genetic merit for Se* *absorption was appropriate for forages that the progeny were likely to consume. High absorber bulls could be selected for regions low in Se and low absorbers for regions in which selenosis had been a problem.*

**Improved adaptation reduces cost and enhances quality of beef.** Typically, a portion of the economic benefit of improved agricultural efficiency is passed on to the consumer as lower prices and/or better quality of product.

**Improved adaptation enhances food security.** Well-adapted populations are more resilient than poorly adapted populations to temporal variation in their environment, differences among years in weather, feed quantity and feed quality, for example. Accordingly, annual product yield from well-adapted herds will vary less than that of poorly-adapted herds. When cow herds and market animals are well adapted to their production environments, it is easier to maintain a safe, reliable and uniform supply of beef.

***When less is more***

*Just as high incidence of infectious disease may signal a poor fit between a population of cattle and its environment, low disease incidence suggests that a population is well adapted. Because adapted cattle, in general, will be healthier, they should require fewer therapeutic injections of antibiotics. Public health officials are concerned that antibiotic residues in food products may promote antibiotic resistance in organisms that are pathogenic to humans. Reducing the use of antibiotics within the production chain for beef could, therefore, benefit public health and food security as well. Economic benefits would accompany these social benefits. Each time that an animal is injected, there is a possibility that the injection site may become infected. According to the National Cattlemen's Beef Association 1995 National Beef Quality Audit, resultant blemishes reduce carcass value an average of $7.05 per steer and heifer slaughtered in America[14]. Producers of better adapted and healthier cattle would escape some proportion of this financial burden.*

**Improved adaptation lessens the need to modify production environments.** Beef cows have been called a scavenger species. Their traditional agro-ecological role has been to convert foodstuffs not directly usable by man to wholesome, nutritious meat and other valuable products. They do this best when they are well adapted to the environment in which they find themselves. When they are not well adapted to a prevalent challenge, a management option is to modify the environment to more closely satisfy their needs. Such modifications are never without monetary cost, and they may incur social costs as well. For example, recreational users of public forest and range lands prefer 'natural' to altered environments, and adapted cows are more likely than un-adapted cows to prosper on unmodified lands.

***One cow's fodder is another cow's poison***

*Hank Maxey raises cattle in the Piedmont region of Virginia. Forage grows well on his farm in spring and autumn but not during the hot and often droughty summer. In fact, tall fescue (Festuca arundinacea) is the only grass species that tolerates the climatic, nematode and insect stresses characteristic of much of the southeastern United States at that time. It does so because of its symbiotic association with the endophytic fungus, Neotyphodium coenophialum[15]. Together, fungus and grass produce toxins that are harmful not only to invertebrate consumers of the grass but to livestock as well[16]. Affected cattle experience severe discomfort from heat stress, leading to reduced forage intake, lower milk yield, slower growth and impaired reproduction. Lost production exceeds $800 million per year[17]. Farmers in the 'fescue belt' report that some cattle within each herd are particularly susceptible to fescue toxicosis while others are largely unaffected. Research suggests that inheritance is partly responsible for observed differences and that tolerance to endophyte-infected fescue could be improved by among-breed[18] and within-breed[19] genetic selection, as several southern cattle breeders are attempting to achieve.*

**Improved adaptation enhances resource conservation and utilization.** Cattle production has sometimes been criticized for contributing to environmental deterioration. It also, however, can serve to maintain or improve pastoral environments. For example, cattle are grazed in the Grayson Highlands State Park in southwestern Virginia to prevent reforestation of meadows that contribute to habitat diversity. Several European countries subsidize traditional cattle production enterprises to maintain rural economies and environments. To contribute effectively to environmental conservation, cattle must be satisfactorily adapted to the particular environment that they are assisting to conserve.

***Designing cows for resource conservation***

*When the right number of cattle consume the right amounts of the right forages at the right times, according to the physical and ecological characteristics of a specific site, range beef cattle production is a remarkably sustainable enterprise. This requires skillful and judicious management. Cattle, and the wild ungulates with which they share the range, prefer grazing near streams. Therefore, one of the most intractable problems on mountainous, semi-arid ranges has been to prevent over-utilization of riparian zones before there has been adequate utilization of upland terrain. Can beef cattle be selected for more uniform utilization of a forage resource? Researchers from Montana State University reported that Tarentaise cattle (an alpine breed) spent a higher proportion of time grazing on slopes distant from water sources than Hereford cattle (native to a farming region)[20]. They reported heritable variation within Herefords in propensity to graze steeper, drier areas of the range as well. New Mexico State University researchers reported among-breed[21] and within-breed[22] genetic variation in diet selection, an important component of utilization of native range. Perhaps cattle can be selected for improved utilization of a heterogeneous forage resource, reduced degradation of riparian habitat and reduced grazing pressure on especially palatable plant species.*

## Strategies and Tools for Genetic Improvement

Breeding objectives are critically needed that would rationally combine selection for product quality, production and adaptation. Decision support tools are needed to evaluate alternative breed choices and mating systems for adaptability and production efficiency within specific environments and their specific challenges.

A first step in designing breeding strategies is to access existing knowledge of heritability, breed differences, inbreeding depression and heterosis for adaptation to important nutritional, physical, climatic, management and economic stressors within major beef production environments in America. Less is known of genetic correlations among adaptive traits and of genetic correlations between traits contributing to adaptation and those affecting production and product. Designed experiments will be needed to estimate genetic parameters required for specific breeding goals.

Breeding value estimation procedures should be developed for specific adaptive traits and for overall adaptation to particular environments. Predictions should utilize indicator traits and marker assisted selection, as appropriate; and research to identify new information sources should be conducted.

In order to fund the research and development necessary to design programs for genetic improvement of beef cattle adaptation, it would be beneficial to quantify the expected impact of improved genetic adaptation on the cost and revenue of beef cattle production and on animal well being, sustainability of beef cattle production systems, the integrity of production environments and the health and economic well being of beef consumers.

***Achieving site-specific adaptation***

*The number of traits contributing to adaptation in any environment typically is too large to allow all of them to be optimized by selection. Rex Ranches of Ashby, Nebraska take a different approach. They define what a cow must accomplishment by her fourth birthday in order to be successfully ADAPTED to their ranch and its challenges. Such elite cows are given the opportunity to leave as many descendents as possible in future generation; while cows that fail to meet the benchmark criteria are prevented from leaving many replacement offspring. This program should improve adaptation but, because of the inherent limitations of bovine reproduction, only slowly. In 2004, National Beef Cattle Evaluation Consortium scientists used records from the Rex Ranch to test a program to increase genetic merit for site-specific adaptation. Using procedures that are routine for genetic evaluation of production and product quality traits, data from the entire herd were analyzed simultaneously to estimate genetic merit for adaptation not only of four-year-old cows but of their male and female relatives as well. Although requiring further development, the method shows promise as a tool for within-herd genetic evaluation of adaptation, as defined for specific needs and conditions.*

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