The Relevancy of Forage Quality to Beef Production

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ABSTRACT

Low cost and abundant fossil fuels have driven the U.S. beef industry toward greater dependence on feed grains as the major feedstuff for finished beef cattle production. Further, it has led to a centralized beef cattle feeding and processing system concentrated in the High Plains states. Low cost fuel and mechanization of harvesting of forages allowed cow-calf producers to calve in late winter, which produced older heavier calves in the fall. The stocker industry evolved as a cushion between the cow-calf producer, stabilizing the flow of cattle into the feedlots and resulting in a steady flow out of the feedlots, through the processing plants, and into the retail market. In the future, other domesticated species and biofuel demands will out bid beef cattle for feed grains and transportation cost of live and processed beef cattle will increase. As a result, a greater proportion of our finished beef supply must come from forage-based diets harvested by grazing beef cattle and the final product will be processed nearer to the consumer to lower food miles and total cost of the finished product. Improving forage quality, extending the grazing season, selecting beef cattle that are efficient converters of forages into body weigh gain, and developing sustainable forage-based grazing production systems will be imperative.

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Abbreviations: ADG, average daily gain; BW, body weight; CP, crude protein; DM, dry matter; DMI, dry matter intake; EBW, empty body weight; GHG, greenhouse gas; NIRS, near-infrared reflectance spectrometry; PAR, plant adaptation region.

The word "cattle" was derived from the Latin word "capital," meaning wealth or property. In many countries, the wealth of an individual is measured by the number of cattle they possess. Cattle were domesticated over 10,000 yr ago and were selected because they were calm, grew at a good pace, bred in captivity, lacked aggressiveness, provided a walking food reserve, and consumed a diet that could be replicated in captivity (Public Broadcasting Service, 2009). In addition, beef cattle have the ability to convert fibrous, low-energy feedstuffs into a product that is rich in protein, energy, vitamins, and minerals (Burns, 2008). However, the present U.S. beef production system has evolved away from totally forage-based production systems to one that is heavily dependent on cereal grains and competes with other, more efficient starch converters for limited cereal grain resources (Corah, 2008; Koch and Algeo, 1983). Because cereal grain production requires significant fossil fuel-based inputs, beef production practices must incorporate more forage harvested by grazing beef cattle and utilize more poor-quality, by-product feedstuffs to become sustainable (Phillips et al., 2008).

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The major segments of the U.S beef production system are (i) cow-calf, (ii) stocker, (iii) feedlot or finishing, (iv) processor and fabricator, and (v) consumer (retail, export, and institutional; Phillips et al., 2008). These components composed a system that is referred to as "industrialized beef production" and has been the production model used for the last six decades (Corah, 2008; Horn, 2006; Peel, 2003). Before World War II, grass-fed beef dominated the beef market in the United States, but a robust post-war economy increased demand for beef beyond the capacity of forage-based systems to provide a constant supply of high-quality product. With increasing demand for beef, U.S. beef cattle population began to increase. Concurrently, the inputs needed to rapidly increase corn production were readily available and beef cattle became one of the vehicles by which corn was transported to market. Grain-fed beef is a unique product and became the trademark of the U.S. beef industry (Corah, 2008). Other countries could not duplicate the U.S. grain-based beef production model because their grain supplies were limited. However, within the last decade, Argentina and Australia have been able to produce grain-fed beef for their domestic consumption. The practice of feeding grain to beef cattle in the United States has been greatly aided by federal programs that have kept the cost of cereal grains low.

Beef consumption peaked in 1976 at 58 kg carcass weight per person, as did beef cow population at 45 million cows. Although the total amount of all meat products (poultry, swine, and lamb) available continued to increase from 1976 to 2008, beef, as a proportion of total meat consumption, declined from 52% in 1976 to 34% in 2008. The decline in beef consumption was due to greater amounts of nonbeef animal protein being produced at a lower price and the addition of these products to menus that had previously been traditionally dominated by beef. Corah (2008) also listed consumer desire for low-fat and low-cholesterol products and products that were convenient and easy to prepare as factors that decreased beef demand. In general, dietary habits, including what was eaten, where it was consumed, and how it was prepared, were adjusted as the baby-boomer generation aged and media influence over consumer dietary choices grew.

COW-CALF PRODUCTION COMPONENT

In the United States there are approximately 750,000 farms that have beef cows and the 2008 beef cow population was 31.7 million cows (USDA, 2008). The average number of beef cows per farm in 2008 was less than 40 head, but 10% of these farms produced 50% of the U.S. calf crop (Corah, 2008). Although beef cattle can be found in all 50 states, the number of beef cattle varies tremendously among the different states. The combined beef cow population of Texas, Oklahoma, Nebraska, South Dakota, Missouri, and Arkansas was 14 million cows in 2008, which accounted for 43% of the total U.S. beef cow population. Three states east of the Mississippi River (Tennessee, Kentucky, and Virginia) have a beef cow population of 3 million or 9% of the U.S. beef herd. Another 2.5 million cows are located within the gulf coast states of Florida, Georgia, Mississippi, and Louisiana. These three areas can account for 59% of the total 2008 beef cow population.

Beef cows are an efficient method for harvesting biomass that is either inaccessible for mechanical harvesting or is so sparsely distributed that large areas must be harvested to yield adequate tonnage. Either factor makes the beef cow the most efficient and practical method of harvesting fibrous biomass. The locations of beef cows reflect land resource allocation. As the demand for land resources for cropping and nonagricultural uses increase, beef cattle will be relegated to areas too hilly for farming, that have soil types too low in nutrients to sustain crop yields without substantial addition of inorganic fertilizer N, low economic value, or unacceptable ecological risk if developed for commercial or residential uses.

Variation in genetic potential among beef breeds has been used to devise breeding schemes to increase beef production characteristics (Dikemen, 1984: Bennett and Williams, 1994; Jenkins and Ferrell, 2007). Through genetic selection, increase in mature size, and other technological advances, the amount of product per cow has steadily increased, allowing more production from fewer cows. Genetic selection that increases calf weaning weight, mature cow frame size, milk production potential, or other production traits will also increase dietary nutrient requirements and may push animal nutritional needs beyond the capacity of forages to supply needed energy and protein (Coleman et al., 2001; Sandelin et al., 2002; Johnson et al., 2003). Supplementation strategies have been developed to meet higher nutritional requirements of beef cattle, but the majority of dietary supplements are purchased at retail prices, which increases cost of production and decreases profitability (Klopatek and Risser, 1982; Kruse et al., 2008; Huston et al., 2002). For example, hay is a major cost in beef herds that calve in late winter. Calves born in late winter will be heavier when sold in the fall and will increase gross returns to the cow-calf enterprise. However, late winter calving herds require more purchased or harvested feeds than herds that calve in late spring or early summer. Shifting the season of calving to early spring to match the cow's increased nutrient demand with the natural seasonal increase in available nutrients will lower winter feed cost and increase cow-calf enterprise profitability (Kruse et al., 2008). Although these spring-born calves are younger, have lesser weaning weights, and gross fewer dollars per calf than winter-born calves, lower feed cost more than compensates for lower returns. Fortunately, cow production in the South and Southeast can utilize both warm- and cool-season forages and well designed grazing systems that also capitalize on management tools that have shown to significantly reduce hay needs. Balancing fall and spring calving seasons has further enhanced production and economic efficiency by providing more flexibility for marketing as well as matching forages for maximum reproductive efficiency in the cow herd. Fall calving, in particular, has been one method of offsetting problems from the millions of hectares of endophyte-infected tall fescue [Lolium arundinaceum (Schreb.) Darbysh. = *Schedonorus arundinaceus* (Schreb.) Dumort] forages in the Southeast.

Cow herds are year-round ecoregion residents and they must live within the nutritional constraints of the ecoregion if they are to be economically and ecologically resilient and sustainable (Bailey, 2005; Hess et al., 2005; Dikemen, 1984). Vogel et al. (2005) proposed the development of plant adaptation regions (PAR) by merging ecoregions maps with plant hardiness zone maps. The PAR could be used to evaluate both native and introduced plants for use in beef production systems. A similar index is needed for beef cattle genotypes to ensure harmony among the plants, animals, and the climate.

Crude protein (CP) and metabolizable energy requirements of a mature cow are variable through various stages of production (National Research Council, 1996). Immature heifers have greater nutrient requirements (as a % of dietary dry matter) than mature cows, because the heifer is adding body mass and bone while performing the same fetal growth and lactating functions as a mature cow. Dry matter intake is typically a function of body weight (BW) and, to meet increased nutrient requirements, a heifer's diet must contain more nutrient density than that of a larger mature cow (National Research Council, 1996). Bulls expend a lot of energy during the breeding season but have long periods of rest to recover and build up energy and protein reserves and can be grown at a moderate rate with diets containing moderate amounts of CP and metabolizable energy.

Commonly used warm-season and cool-season forage sources such as bermudagrass [*Cynodon dactylon* (L.) Pers.], fescue, white clover (*Trifolium repens* L.), alfalfa (*Medicago sativa* L.), and native grasses contain adequate concentrations of CP and metabolizable energy to meet the nutrient demands of most classes of beef cattle, if plant growth stage and animal production needs are synchronized. Poor-quality forages, such as corn stalks and wheat straw, can be used when animal nutrient demands are least, but some supplemental N will be needed to meet ruminal degradable N requirements for adequate dry matter (DM) digestion and microbial protein synthesis (Huston et al., 2002; McCollum and Horn, 1990).

Cow-calf production systems are heavily capitalized business enterprises and the majority of that capital is invested in land. A general business principle is that capital gravitates toward investments that offer the greatest economic return on capital. In the future, land committed to cow-calf production in subhumid ecoregions may be shifted to more nonanimal agriculture uses, that is, cereal crops, oil seed crops, and cellulosic biofuel production that can offer greater economic returns. Conversely, arid ecoregions, such as the western section of the United States, may experience a shift from crop production to a more natural and sustainable perennial pasture production system (Allen et al., 2005). This shift in the arid ecoregions may also be necessary due to dwindling underground water resources for agricultural use. Shifting cow-calf production from east of the Mississippi River to the western United States would situate beef calves closer to the next production point and decrease transportation costs associated with moving calves from the eastern United States to the southern and northern Great Plains.

STOCKER PRODUCTION SEGMENT

Unlike beef cows that are year round residents, calves not used for reproductive purposes (90% of the male and 75% of female calves) are transient and spend more of their life cycle in ecoregions apart from their places of birth (Peel, 2003; Quix, et. al., 2007). Over 70% of the beef calves produced in the United States in a 12-mo period are born in the 5-mo period of December through April (USDA, 2009). These calves are weaned in the fall and typically sold through a network of local and regional livestock auctions and special feeder and stocker calf sales. Because most cow herds are small in size, about 50% of the calves are sold in small lots of mixed gender, age, and BW. These small lots of calves are purchased by a commission buyer, transported to their facility, and sorted into larger truck load lots (20,000 to 24,000 kg of BW per load). In the process calves of various backgrounds, genetic composition, and experiences are mixed (Peel, 2003; Horn, 2006). The cost of transportation is based on dollars per km traveled. Thus, calves located further from their final destination must be discounted (dollars per kilogram BW) to compensate for transportation costs to be competitive with calves of similar quality located closer to the final destination. Transportation costs are directly related to fuel costs; each km of required transport is equal to 2.5 to 3.0 times fuel cost (dollars per liter). Recently, throughout the South and southeastern United States, local auctions are being closed. Many calves are now sold via video auction and are shipped directly from the farm or ranch to the next production point. Regional markets such as Oklahoma City, OK, and Joplin, MO, are marketing more of the regions calf crop. These changes lower marketing cost, reduce the amount of marketing and assembly stress imposed on the calf, and expand marketing opportunities. Some cow-calf producers retain ownership of calves through the stocker and feedlot phase. Regardless of the level of vertical integration, cost of transporting calves between production points must be accounted for in the price of the calf or as an expense.

Calves that are not purchased for immediate placement in a feedlot will spend from 60 to 180 d grazing forages before moving to the feedlot segment. These calves are referred to as stocker calves. Calves moved directly from the cow-calf farm to the feedlot are referred to as feeders. Although an accurate number of stocker enterprises are not accounted for through the annual agricultural statistics survey, we estimate that there are 15,000 to 20,000 individual stocker enterprises in the United States. Peel (2003) listed the following three functions of the stocker segment of the U.S. beef cattle industry:

1. The stocker segment serves as a pool for inventory management of calves to stabilize their flow from cow-calf operations to the feedlot. Currently, the U.S. feedlot segment has a one-time feeding capacity of approximately 11 million cattle with a turnover rate of 2 to 2.5 times each year. This can only be done by warehousing the surge of fall-weaned calves as stockers;
2. The stocker segment reduces the overall cost of the calf. Cost of gain during the stocker period is normally less than during the feedlot period. Thus, the cost of the calf (dollars per kilogram BW) on entry into the feedlot is less if the calf goes through a stocker phase before entering the feedlot;
3. The stocker segment improves overall calf health, socializes the calf to a group environment and human contact, and provides learning experiences to procure feed and water. Comingling of calves from different backgrounds also exposes calves to different bacterial and viral agents. During the stocker phase, immune systems are challenged to develop immunity and calves are taught to eat from a trough and drink from a fountain.

As beef calves grow and develop, body composition changes (Coleman et al., 1995; Rohr and Daenicke, 1984). The National Research Council (1996) offers equations that describe the accumulation of fat and protein as BW increases in beef calves from 100 to 800 kg of BW. Protein accumulation is described as protein (kg) = $(0.235 \times \text{EBW}) - (0.00013 \times \text{EBW}^2) - 2.418$, in which EBW is empty body weight (kg). In cattle of "typical" genetics, protein accumulation is almost linear from birth until the animal attains an EBW of approximately 350 kg, and then the rate of accumulation slows. If nutrients are not limiting, the converse is true for fat accumulation, which the National Research Council (1996) describes as fat (kg) = $(0.037 \times \text{EBW}) - (0.00054 \times \text{EBW}^2) - 0.610$. Fat accumulation is slower early in life but increases rapidly after the animal attains an EBW of approximately 350 kg. The traditional stocker phase results in more protein being accumulated than fat. During the last 50 yr, medium frame calves were moved to the feedlot when they reached a shrunk BW of approximately 350 kg. More recently, stocker calves are kept on pasture until heavier BWs are obtained to decrease the amount of BW gain needed during the feedlot phase. In the feedlot, the energy concentration of the diet is increased to meet the physiological demand for fat synthesis. Once empty body fat content approaches 32%, the calves are harvested.

To decrease the amount of energy-rich cereal grains needed to reach the desired body fat percentage, the stocker phase could be extended. However, during the later stages of the stocker period the physiological demand for energy can exceed the energy density of traditional forages. Also the need for more energy dense diets may occur late in the growing season when plant growth is declining or underutilized plants are maturing and energy density has declined.

Similar to the discussion in the previous section, supplementation strategies have been developed for stocker calves to meet energy and protein demands for rapid BW gain or to correct N and energy density imbalances (McCollum and Horn, 1990; Elizalde et al., 1998; Huston et al., 2002). The amount and rate at which DM is fermented in the rumen and the availability of N to support ruminal microbial growth are key elements that determine the growth rate of stocker calves and efficiency of feed conversion. Cool-season grasses and legumes have greater concentrations of digestible energy and protein than warm-season grasses during the vegetative stage (Phillips et al., 2009; Coleman et al., 2010). Stocker systems based on cool-season forages typically have greater rates of average daily gain (ADG) and can support stocker calves for greater number of days than systems based on warm-season forages. Cool-season forages are also available in the fall and are at their greatest nutrient content when the majority of calves are weaned and enter the stocker phase. On the other hand, warm-season grasses that are well fertilized can frequently be stocked more intensively thus carrying more animals per hectare.

Near-infrared reflectance spectrometry (NIRS) technology for evaluating forages began almost 40 yr ago and is now widely used by researchers, consultants, and private and public forage testing laboratories (Lundberg et al., 2004). This technology has been used to analyze fecal samples for estimations of DM intake and chemical composition of the DM consumed by grazing livestock (Lyons and Stuth, 1992; Phillips et al., 2007). Starks et al. (2004, 2006) used NIRS to estimate the nutrient density of standing forage and Phillips et al. (2007) applied this technology to warm-season grass stocker production enterprises. Applying NIRS technology to standing forage or fecal samples and using that information to determine when to begin CP supplementation of stocker calves can decrease wastage of protein supplement and increased economic returns to the system (Phillips et al., 2007).

Wheat pasture is a primary forage resource for beef stocker calf enterprises in the southern Great Plains region (Peel, 2003; Horn, 2006; Phillips et al., 1996). The CP concentration of winter wheat pasture during the winter grazing period ranges from 230 to 280 g kg^{-1} DM (Gallavan et al., 1989; Mader et al., 1983), which is more than twice the dietary protein requirement of a 227 kg calf grazing winter wheat (National Research Council, 1996). Based on intensive trials with lambs, we concluded that stocker calves grazing winter wheat pasture retain less than 15% of the N consumed and excreted approximately 60% in the urine as urea (Phillips et al., 1995). Urea N is highly susceptible to hydrolysis by soil and fecal microbes to produce ammonia that can rapidly volatilize (Todd et al., 2008; Archibeque et al., 2007; van Groenigen et al., 2005).

Vogel et al. (1987, 1989) reported a decrease in the amount of wheat forage consumed by stocker calves when wheat or sorghum silage was fed ad libitum. In these studies, silage dry matter intake (DMI) increased as forage mass—the amount of standing biomass available for grazing—decreased, thereby producing a gradient between the quantity of wheat forage and silage consumed and between dietary CP concentration and the estimated amount of N excreted across the winter grazing season. A combination of limiting access to winter wheat pasture to reduce wheat forage intake and providing a low-CP high-energy supplemental feed would balance CP and energy intake to improve the efficiency of dietary CP utilization and decrease urinary N losses (Alton and Schmedt, 1984; Horn et al., 2005). However, in some cases economic returns to the enterprise can be reduced because of costs for supplemental feed. The producer is forced to choose between profitability or N utilization efficiency.

Performance response of stocker calves on winter wheat pasture to supplemental feeding is dependent on the amount fed and the nutrient density of the supplement (Horn et al., 2005; Vogel et al., 1989). Scaglia et al. (2009a, b) concluded that time of supplementation could decrease grazing activity, total DMI, and animal performance of calves grazing high-quality ryegrass pastures. Daily feeding increases labor cost and may increase cost per kilogram of BW gain, whereas feeding every other day or 3 times per week often results in the same rate of gain as feeding protein supplements every day (Aiken and Brown, 1996; Huston et al., 2002; McCollum and Horn, 1990;. Therefore, before applying any supplementation program to grazing beef cattle, the impact of supplementation on grazing behavior should be considered.

Nitrogen is a highly dynamic and mobile element and significant losses of N can occur within grazing systems as a result of nitrate leaching and gaseous emissions of ammonia and nitrous oxide (Zaman et al., 2009). As previously noted, the majority of N in urine is found as urea, which can be quickly hydrolyzed to ammonia and emitted as a gas (Cole et al., 2005; Uchida et al., 2008). Ammonia itself is not a greenhouse gas (GHG), but it is a secondary source of N for conversion to nitrous oxide. The N concentrations of urine patches can be equivalent to applying 700 to 1000 kg N ha^{-1} (Zaman et al., 2009). Yan et al. (2007) correlated N intake and the quantity of N excreted in the urine and feces of beef cattle. Fecal excretion of N ranged from 22 to 53% of the N consumed and urinary N excretion ranged from 22 to 77% of the N consumed. The most effective strategy to reduce N excretion by beef cattle is to manipulate dietary N concentration (Cole et al., 2005, 2006; Yan et al., 2007), which is much easier if calves are confined and fed a mixed diet rather than grazing pastures.

FEEDLOT AND PROCESSOR SEGMENTS

The third and final segments of the U.S. beef production system are the feedlots and the beef processors. These segments are not directly dependent on forages as a production input. While cow-calf operations are spread across the United States, beef cattle feedlots and processors are concentrated in the Great Plains states (Nebraska, Kansas, Oklahoma, Colorado, New Mexico, and Texas). Feedlots in theses states account for more than 80% of the cattle fed in the United States. Beef cattle processing plants are located in close proximity to the feedlots to decrease transportation costs and time. Finished cattle are delivered to packing plants only hours before being processed. Carcasses are typically retained and chilled for 72 h before being disassembled and fabricated into wholesale components, boxed, and shipped to retail, institutional, and export outlets. The majority of the beef calves that began their lives on one of 750,000 U.S. farms are now processed by one of only four major beef processors.

Consumer preferences for beef products are communicated to the processor via the retailer. Through economic incentives or disincentives, the processor passes product information to the feedlot. Information trickles down to the stocker component and finally the cow-calf operator. Unfortunately, these signals are not tied directly to an animal or to a group of animals but are general marketing trends for classes and grades of calves. Early in the production chain, the connection between the cow-calf producer and their final product is lost. Also, the lag time between implementing a decision at the farm level and impacting the final product can be from 16 to 48 mo.

The U.S. feedlot industry uses more than 10 million tons of feed grains annually and feed grain production is highly dependent on fossil fuels, including N fertilizer inputs. Therefore, beef cattle finishing systems that depend on feed grains and grain-based beef production have been depicted as ecologically unsustainable. However, the amount of grain fed to beef cattle for finishing represents less that 10% of total amount of grain produced. A recent life cycle assessment of beef production in Australia (Peters et al., 2010) reported that dry lot feeding of beef cattle generated fewer greenhouse gas emissions than grass-based systems because the additional effort of producing and transporting feeds was offset by the increased efficiency of meat production in feedlots.

Beef cattle are less efficient than nonruminants at utilizing starch and thus are frequently viewed as more sustainable and more ecologically sound when less grain was used in the beef production system. Beef cattle convert 1 kg of feed into 0.11 kg of gain, which is much less than that reported for 0.25, 0.48, and 0.61 kg^{-1} of feed reported for swine, poultry, and fish, respectively (Damron, 2006). Each year beef cattle in U.S. feedlots are fed millions of tons of byproducts from corn milling (e.g., gluten feed and distiller's grains), vegetable oil (e.g., cottonseed meal and soybean meal), and other industries. Beef cattle can play a prominent role in recycling by-products that would other wise be considered waste and sent to a landfill. Therefore, cattle will compete with unconventional energy generation plants for these products.

For the foreseeable future, feedlots will be needed to ensure consistency of the final product and to provide a steady supply of cattle for packers. However, if the number of days a calf spends in the feedlot is reduced, fewer feedlots will be needed.

ADDITIONAL FED BEEF COMPONENTS

To distinguish beef products in the market place and to exploit niche markets, many times descriptors such as "natural," "grass-fed," "grain-fed," "all natural," "organic," "farm-raised," and "pasture-finished" are attached to the final product. These descriptors are used to convey to the consumer a sense of how the product was produced and/or processed, but many descriptors are not clearly defined and have widely different meanings. For example, a beef product may be identified as hormone and antibiotic free. This tells the consumer that no antibiotics or hormones were given to the animal that produced the product but does not inform the consumer about the other production practices (diet fed, pasture or dry lot produced, etc.). Some descriptors have clear and definable meaning and their use in the labeling of the product are regulated by the federal government. Certified Organic Beef has a fully verifiable production system and is managed in accordance with the Organic Foods Production Act of 1990 and the regulations found in Title 7, Part 205 of the Code of Federal Regulations. Consumers can be assured that beef products labeled as Certified Organic Beef have been produced and processed under a strict set of guidelines.

The USDA defines "natural" beef as beef raised without additives and with minimal processing, which can include a wide range of production practices and diets. Natural beef can be produced under dry lot feeding management using a grain based diet as well as on pasture. Beef cattle grown on pasture with no or very limited grain inputs have nutritional and social attributes perceived to be important to many consumers. These attributes include greater concentration of conjugated fatty acids, improved animal well being, and minimal use of production-enhancing compounds. It is worth noting here that pastures may consist of legumes and grasses in mixtures, pure stands of legumes, or pure stands of grasses with a component of desirable forbs as well as weeds. Harvested beef can be marketed as grass-fed beef if the animals consumed only grass and/or forages for its lifetime, with the exception of milk consumed before weaning. The animal cannot be fed grains or grain by-products and must have access to pasture during the growing season (Agricultural Marketing Service, 2007). Harvested forages can be fed during periods when grazable forage is not available. Niche markets for grass-fed beef do exist, but the infrastructure required to expand production and to market grass-fed beef on a large scale is not available because the amount of grass-fed beef produced or consumed is not available. To ensure consumer safety, state and federal regulations have been established for the proper harvesting and processing of animal products for human consumption. These regulations have limited the number of regional meat processors, because infrastructure is expensive and the product output is low. An additional hurdle is the seasonal nature of grass-fed production, which further complicates the steady supply of market ready animals for harvesting and marketing. Grass fed beef production systems need high-quality forage and competes with beef cows for grazing lands and cash crops for higher classes of land.

Systems that incorporate more forages in producing the final product have been proposed to decrease the amount of grain needed to produce a finished beef carcass and to harvest and market forages more effectively (Phillips et al., 2004, 2006a, b). The propose system incorporates intensive early stocking of warm season grasses with feeding a cereal grain based diet in self-feeders for the last half of the finishing period. Calves from Arkansas, Texas, Montana, and Florida were used in these studies. Breed of calf was confounded with state of origin, but temperate, tropical, and continental breeds were tested. Calves were born in late winter or early spring, weaned in the fall, and grazed annual and perennial pastures before beginning the finishing phase at approximately 16 mo of age. Under the conventional system calves were placed in dry lot and fed a grain-based diet until finished (fat thickness over the 12th and 13th rib was ≥10 mm). Calves assigned to the pasture finishing system grazed warm-season grass pastures under intensive early stocking management (twice the normal season-long stocking for 30 or 40 d). When approximately 80% of the standing forage had been removed, a self-feeder containing the same diet as that fed in the conventional system was placed in each pasture. Calves in pasture finishing system were fed to the same endpoint as the conventional system. Carcasses from the calves finished on pasture tended to be leaner as compared to carcasses produced under the conventional system. Because all calves were fed to the same endpoint, carcass characteristics were similar between the two systems. By the end of the 136-d finishing period (range 120–167 d), calves finished on grass had consumed an average of 107 kg less feed than calves assigned to the conventional system. Feed savings ranged from 0 to 232 kg per calf and were dependent on initial BW, breed, and length of the finishing period. The finished product can be marketed locally to consumers who are interested in knowing where and how their beef is produced or it can be sold to a commercial processor. In addition to the feed savings, waste material is distributed over the pasture by the animals each day and organic N is added to the pasture. The authors estimated that 145 kg ha^{-1} was added to the pastures each year.

ENVIRONMENTAL ISSUES

Grazing livestock produce three greenhouse gasses: carbon dioxide, methane, and nitrous oxide. Methane, a byproduct of rumen fermentation, has 20 to 30 times the global warming potential of carbon dioxide (Johnson et al., 1996). The amount of enteric methane produced per unit of energy consumed is variable and is impacted by the interaction of the chemical composition of feedstuffs, site, and rate of digestion. The amount of feed consumed is also important. Johnson et al. (1996) estimated that 6.2% of the gross energy consumed by beef cows grazing pastures was emitted as methane. In comparison, 3.5% of the gross energy consumed by cattle in feedlots fed grain-based diets was lost as GHG. These differences in energy losses reflect the differences in ruminal fermentation processes in cattle consuming forage-based diets in comparison to cattle consuming grain-based diets. Therefore, grazing systems that increase the number of days cattle are on pasture may increase the amount of enteric methane per animal.

Improving the efficiency of beef cattle production decreases enteric methane production (Nkrumah et al., 2006). Factors such as dietary nutrient concentration, genetic selection, and animal management that enhance ruminant productivity are tools that can be used to reduce the amount of methane produced per unit of product produced (Johnson et al., 1996). Casey and Holden (2006) evaluated 15 case studies of Irish beef production units to assess the GHG emissions from convention (n = 5), rural environmental protection scheme (n = 5), and organic production (n = 5). Life cycle assessment methods were used to estimate the GHG emissions as CO_2 equivalents per kilogram of live weight and per hectare. They reported a reduction in GHG emissions per unit of live weight and per hectare by shifting from a conventional to an organic-based production system, but live weight production per hectare was reduced. The authors pointed out that greater emphasis is being placed on the aesthetic quality and the environmental role of agriculture rather than just production. However, a growing world population demands more food production.

Reductions in GHG emissions by grazing livestock can be achieved by different methods and must be balanced with productivity per hectare. Applying N fertilizer to increase forage production can result in a greater stocking rate, greater ADG, more BW gain per hectare, and greater quantities of beef product but can also result in a greater absolute amount of enteric methane produced. Liebig et al. (2010) reported that moderately grazed native pastures in the northern Great Plains were a GHG sink, whereas highly fertilized, heavily grazed crested wheatgrass pastures were a GHG source. Implementation of grazing management techniques such as rotational grazing management can increase harvesting efficiency and the rate at which forage is converted to BW gain. As more forage is converted to BW gain greater amounts of GHG would be produced, but GHG per kilogram of product would be decreased.

Nitrous oxide has 296 times the global warming potential of carbon dioxide (Steinfield et al., 2006). Ruminants only retain about 20% of the N that is consumed and excrete the remaining 80% in the urine and feces (Phillips et al., 1995). Fecal N is degraded more slowly than urinary N and is therefore not quickly lost to the atmosphere. However, once incorporated into the soil both fecal and urinary N goes through nitrification (conversion from ammonia to nitrates) or denitrification (conversion to N_2 and N_2O) and release to the atmosphere. Balancing dietary energy and protein concentration will reduce urine N and thus lessen the release of reactive N to the atmosphere.

Pasture and rangelands are frequently carbon sinks that can sequester large amounts of carbon and reduce the amount of GHG in the atmosphere (Liebig et al., 2010). Because the amount of biomass produced above the soil surface is proportional to the amount of biomass below ground, any techniques employed by grazing land managers that increase the amount of forage biomass produced will increase the amount of carbon sequestered. As below-ground biomass increases so does the amount of carbon sequestered. If these grazing-management techniques also increase animal productivity, then through live-cycle assessment of the system, a positive impact on net GHG production may be congruent with increased BW gain per hectare.

SUMMARY

In the future agricultural production systems will be asked to produce more tonnage of high-quality products to feed a growing world population. Beef production can be greatly influenced by government policies, environmental regulations, and financial incentives to achieve societal goals. These factors, plus global climate change, makes predicting the future risky. However, the number of researchers and educators involved in developing and transferring technology to improve forage-livestock production efficiency has decreased (Reynolds, 2009; Rouquette et al., 2009). The decline in human resources is a reflection of the shifts in funding allocation at the state and national level.

Competition for land and water resources by nonagricultural entities will force agricultural systems to utilize marginal lands and to increase conversion efficiency of solar energy into food, fiber, and fuel. In the future, beef production may shift from a cereal-based production system to one that is more dependent on forages. Beef cow numbers may stabilize, but the location of cow herds could shift to marginal lands. Cow frame size and BW will need to be moderated to balance nutrient demands with nutrient supply. Calving season may be modified within regions to best match animal demands and forage supply. Season of calving can be shifted not only to decrease feed cost but to stabilize the annual supply of calves. Body weight of weaned calves may decrease and more weigh gain will be required during the stocker phase, thus the number of days calves spend as stockers will increase. Genetic selection may be used to develop beef cattle that are more efficient in converting forage fiber to body mass.

Dietary manipulation and supplementation are tools used to decrease N losses via urine and feces. Beef cattle may become tools to harvest and transport nutrients from one area to another and to deposit N, P, and C on the soil surface for incorporation and recycling through plants. Legumes will become an important forage resource for beef production in the future, both as a high-quality forage and as an economical source of N for plant growth. Establishing and maintaining mixtures of grasses and legumes or pure stands of legumes under grazing management will be a challenge. Legumes will play an important role in producing more beef from forages. Because of their greater cost, niche markets for grass-fed, organic, and natural beef will be determined in part by the general economy. Beef production east of the Mississippi River will become more specialized to meet consumer demands.

Land managers will be challenged with establishing both perennial grasses and legumes that can persist under greater grazing pressures. Some irrigation may be used in forage production, but it will be too expensive for routine use. However, industrial and municipal waste water may become more available for forage production. Development of forages that can persist and produce biomass of sufficient quantity and quality for beef production will continue to be a challenge. Heitschmidt et al. (2004) concluded that the long-term sustainability of rangeland agriculture is dependent on the ability of agriculturalists to respond to the ever-changing social values and to address the ecological and social consequences of resource management decisions. The opportunities and challenges faced by rangelands may be thrust on all grazing lands.

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