Technology to complement forage-based beef production systems in the West

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ABSTRACT: Forage-based beef producers in the Western United States are faced with numerous challenges to remain sustainable and profitable. Several technologies are available to assist ranchers, but the American public must be convinced that ranchers are sound stewards of public and private lands. New coalitions to resolve environmental conflicts have been formed over the last 10 yr that seem to have helped educate the public that proper grazing management is a sustainable practice. Methods are available to help ranchers economically evaluate enterprises and aid producers in deciding which technologies to adopt. New developments in fencing, water development and placement, and supplement placement should improve cattle distribution in large pastures. The use of complementary forages remains one of the most profitable technologies available. Swath grazing technologies are being tested to decrease feeding costs. Developments in plant genetics offer a variety of applications to beef producers that could improve animal performance. In the future, molecular technologies involving transgenic organisms may offer the opportunity to produce "designer" forages, ruminal microbes, and animals, but such applications have yet to be tested. Adoption of technologies that improve environmental quality and enhance profits for forage-based beef cattle producers will influence their sustainability.

Key Words: Beef Production, Forages, Genetic Selection, Rumen Microorganisms, Transgenic Plants

 J. Anim. Sci. 81(E. Suppl. 1):E18–E26

Introduction

Forage-based beef production in the West faces an increasing number of challenges that may impact its sustainability. Many ranchers in the western US may be required to remove their livestock from public lands unless they can demonstrate that these animals do not pose an ecological threat to the landscape. Federal legislation such as the Multiple-Use Act, the Threatened and Endangered Species Act (ESA), and the Federal Clean Water Act could place additional economic pressure on already stressed beef cattle operations. Our objective is to review available or new technologies that offer solutions to some of the challenges faced by western livestock producers. We have chosen to start with examples of large-scale, whole-ranch technologies related to rangeland resources that have been successfully implemented and have had a high economic rate of return. Some of these technologies, such as fencing, water and supplement placement, have been around for a long time and have recently received renewed interest by resource managers to improve livestock grazing distribution. Then we reduced the application scale and chose examples of genetic modification of plants and animals at the gene level. These technologies have not yet been implemented on a practical basis; however, they demonstrate the wide range of possible applications of new scientific knowledge.

Conflict Resolution

The National Wildlife Federation and the Natural Resources Defense Council (2001) recently presented a white paper that charged the Bureau of Land Management (BLM) with failing to protect ecological integrity, water quality, biological diversity, and threatened and endangered species habitat. This report suggested that if the BLM failed to adopt a conservation agenda for lands under its jurisdiction, management responsibilities for those lands should be transferred to other federal agencies. The report promoted the establishment of conservation areas, Wilderness units and National Monuments, and suggested that livestock producers who use public lands in the western U.S. should be required to demonstrate that their management is ecologically sustainable. If the public fails to see that grazing is compatible with multiple values of rangelands, application of technology alone will not save the range livestock industry. Therefore, an important technology for range

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Received June 28, 2002.
Accepted March 6, 2003.

livestock operations might be categorized as conflict resolution. Changing legislation and demographics have caused ranchers and environmentalists to reexamine the current methods through which conflict is managed. For years, some environmental groups have sought to eliminate cattle grazing on public and private lands. Ranchers have viewed the ESA as an immediate threat to their livelihood. These conflicts have been reenacted in every western state, with very few constructive outcomes. Throughout the western United States, a number of organizations have been formed in response to conflicts that appeared to be unsolvable under the current social structure.

In Montana, elk numbers had been escalating steadily since the mid 1980s. Ranchers near the Beartooth Wildlife Management Area decided to seek solutions for the growing elk herds found on private lands. Chase Hibbard, Bill Milton and other ranchers formed a group that included members from the US Forest Service, Montana Department of Fish, Wildlife & Parks, BLM, Montana State Lands, and sportsman's groups. The team decided that everyone involved had to concur they were benefiting from the proposed solution, or there would be no agreement (Dagget, 1998). The group was called the Devil's Kitchen Management Team, and they agreed on a management proposal that was submitted to the Montana Fish and Wildlife Commission in 1993. The formation of this group and their management solution changed the way wildlife and public grazing resources are managed in the state of Montana. Local landowners were allowed to participate in setting wildlife harvest targets for private lands near the Beartooth Wildlife Management Area, which increased forage available for use in beef production systems.

The formation of the Malpai Borderlands Group in southwestern New Mexico in 1994 is another example of the reorganization of ranchers and conservationists to solve a resource management conflict. In a recent address, Under Secretary of Agriculture Mark Rey (2002) recognized this group for their forward thinking. Ranchers bring their cattle to the 130,000 ha Gray Ranch for a grassbank of stockpiled forage and in return, they place conservation easements on their own ranches. Ranchers use an equal amount of forage as set aside in their easement. To date, the Malpai grassbank has rested 10,000 ha on five ranches (Rey, 2002).

A number of environmental laws have made it difficult for production agriculturists to remain in business in the western US. It has become apparent that ranchers must become active participants in land policy decisions. This process will help educate environmental and ranching communities. There are numerous groups all over the western U.S. that have become active environmental educators in an effort to resolve resource management conflicts.

Whole Ranch Evaluation

Many technologies available to ranchers can increase livestock production; however, whole ranch evaluation approaches that include partial budgeting can help ranchers economically evaluate enterprises. A number of private and state entities have implemented programs to assist ranchers with economic evaluation of their business, and may also conduct workshops and sell software. Most of these programs are designed to help establish ranch goals, inventory resources, explore possible enterprises, plan changes and monitor and adjust those plans (Richards and George, 1996). Total Ranch Management, developed by a Texas Extension group, has served as the basis for the Western Integrated Resource Education (WIRE) program that involves four land-grant universities and their extension programs. This type of structured evaluation, and the use of personal computers, has helped producers examine their entire operation and has lead to the adoption of technologies that are nontraditional yet highly profitable.

A number of individuals and private companies have advocated whole ranch evaluation. One of the most notable of these is Gregg Simonds. Simonds was asked by the Deseret Ranch Management Team to evaluate the economics of implementing irrigation technology, and through the use of whole ranch evaluation methods, Simonds showed the ranch management team that they would be financially better off if they did not adopt this technology (Dagget, 1998). Based on enterprise evaluation, Simonds suggested changes in production practices over a 12-y period on the Deseret Ranch that resulted in decreased total cost per pound of calf produced from over $0.90 to $0.62. Production changes implemented included moving from an early-spring calving season to a late-spring calving season, and the addition of a yearling operation to take advantage of year-round marketing opportunities (Simonds, 1991). Simonds (1991) suggested that the tremendous variability present in biological and financial environments does not make it possible for a single fixed strategy to maximize long-term profitability.

An assessment of these types of whole ranch evaluations concluded that due to the programs, ranchers had improved or protected 14% of the rangeland used in their operations, over half had increased their ranch profit and a majority had implemented at least one new technology (Richards and George, 1996).

Fencing

One of the major problems associated with grazing cattle on large pastures in the western United States is poor distribution of grazing. Grazing systems have been used to improve distribution, however, since this topic has been reviewed extensively (Launchbaugh et al., 1978), we will examine the use of fencing to manage distribution. Cattle tend to congregate near water sources and on level terrain where forage is abundant (Ares, 1953). This results in portions of the pasture that are grazed too heavily and other areas where little grazing takes place. It also contributes to erosion and poor water quality in many watersheds (Kauffman and Kruger, 1984). The use of fencing to control livestock distribution and increase forage use is usually one of the most cost effective methods used to improve cattle production on large ranches (Ohlenbusch et al., 1995). Recent developments in electric fence technology have allowed producers to employ fencing in areas where it was previously cost prohibitive. Electric fences often cost 25% to 50% of conventional fencing. Less labor is required to install electric fencing, and it can be installed at rates three to five times faster than five-strand barbed wire fencing (Lacey, 1985). The availability of low cost solar panels, energizers, and batteries has provided power to many remote areas of large ranches. This technology has also allowed producers to develop intensive grazing systems on highly productive pastures.

Water Development and Placement

Water development and placement can also be used to manipulate livestock distribution on rangelands. Very few ranch investments return higher annual rates than stockwater developments (Roberts and Wennergren, 1965).

Ganskopp (2001) evaluated the effects of moving water and salt locations to improve beef cattle distribution in large (825 ha) pastures in Oregon. Cattle were fitted with global positioning system collars to assess their location in the pasture. Mean distance to water was unaffected by location which demonstrated cattle followed the movements of the water tanks. Ganskopp (2001) concluded that cattle made less effort to remain near salt than near water and moving drinking water was the most effective tool for altering cattle distribution. Porath et al. (2002) investigated cattle distribution on pastures with off-stream water and trace mineral salt. They reported that early in the grazing season (July) cattle with access to off-stream water were located farther from the stream in the latter part of the day. There were no differences during the late season (August) in distances from the stream between cattle with off-stream water and trace mineral salt and those without.

Changing water location and providing off stream water in pastures with riparian areas is also a method to improve steambanks. McInnis and McIver (2001) conducted a study on the same pastures as Porath et al. (2002). They reported that off-stream water and salt attracted cattle into the uplands enough to reduce the proportion of uncovered and unstable streambanks from 9% to 3%. Providing off-site water can also improve animal performance. Porath et al. (2002) demonstrated that cows and calves with off-stream water and trace-mineral salt gained more than cows and calves that did not have access to off-stream water. Willms et al. (1995) found that grazing steer performance increased 23% when an alternate water source was supplied compared with steers that had access only to a dugout.

Despite recognition that water development has been one of the most effective methods to improve livestock distribution in large pastures, cost effective technologies have limited its use. Recent improvements in solar-powered pumps have led to increased use of watering sites and wells that would not have been possible due to the lack of electrical power. Nose pumps are another cost-effective recent technology that have been employed to keep cattle out of riparian areas and lure them to other adjacent locations. The U.S. Fish and Wildlife Service has encouraged the use of nose pumps as a method to keep cattle from entering riparian areas.

Supplement Placement

Another technology used to improve distribution on rangelands has been the placement of supplements. Ares (1953) demonstrated that a cottonseed meal-salt mix placed away from water could be used to reduce over-grazed areas by 50% and increase properly grazed areas by 84%. Recently, Bailey and Welling (1999) examined the use of dehydrated molasses supplements to improve grazing distribution in foothills rangelands. Three pastures that averaged 642 ha in size were divided into difficult and moderate terrain. Each terrain subunit was randomly assigned to control or supplement treatments. Dehydrated molasses supplement barrels and salt were moved every 7 to 10 d during the fall and winter. A greater proportion of cattle were observed in areas with supplement (32%) than areas without supplement (3%). Supplement placement increased forage utilization in areas with moderate terrain by 24% and by 11% in areas with difficult terrain. Bailey and Welling (1999) concluded that placement of dehydrated molasses supplements could be used to improve uniformity of grazing by beef cattle in foothill ranges although it was more effective in moderate terrain. Bailey et al. (2001) conducted a study to examine the distance cattle grazed from dehydrated molasses supplements. Three pastures were used to determine if supplement placement could increase forage utilization in underutilized areas. Forage utilization was increased 14% at distances up to 600 m from the supplement. Fifty-three percent of the cows were observed within 600 m of the supplement, and overall cows spent 37% of their time within 600 m of supplement. Supplement placement was an effective tool to modify cattle grazing distribution; however, other research has indicated that forage characteristics, such as forage quality and quantity, are the most important factors affecting cattle distribution (Harris et al., 2002).

Complementary Forages

Use of complementary forages involves combining different forage species with dissimilar growth patterns to help maintain consistency in forage production and nutrient intake by cattle. In the West, rangeland forages are usually the base to which introduced forages are added. The objective often is to increase livestock production per land area in a cost efficient manner. Gray (1973) reported that complementary grazing was the single item most highly correlated with increased net profit for cow-calf producers in the Great Plains. Launchbaugh et al. (1978) described the use of improved pastures and farmed forages to reduce per animal costs and increase net returns to cattle producers. Smoliak and Slen (1974) found that complementary grazing in Canada reduced land requirements per animal unit by 77% and increased beef production by 60%. By using complementary forages, individual animal performance is usually increased due to improved forage quality, and stocking rate can be increased due to increased forage production. Other advantages of using complementary forages can include more efficient use of individual forages, improvements in range condition (Gillen and Berg, 2001), and increased resource management flexibility. Over seven calf crops, Sims (1993) compared cow-calf pairs grazing sagebrush-mixed prairie native rangeland with pairs grazing the same rangeland plus winter wheat and summer annual forage to replace 30% of the rangeland for each cow unit. Using the complementary forages increased stocking rate by 32%. Cow body weight at weaning was heavier, and Angus × Hereford cows had improved reproductive rates on the complementary forage system compared with native rangeland alone. In addition, weaning weights were 90 kg heavier for calves on the complementary forage system (Sims and Bailey, 1995). Stocking rates and total season livestock production per ha were higher when steers grazed Old World bluestem (*Bothriochloa ischaemum* L.) combined with native pasture compared with grazing native pasture alone (Gillen and Berg, 2001). Coleman et al. (2001) compared native tallgrass prairie (primarily *Andropogon gerardii* Vitman., *Schizachyrium scoparius* [Michaus] Nash, and *Sorgastrum nutans* [L.] Nash) under continuous grazing management with the addition of wheat pasture grazing or substitution of plains bluestem (*Bothriochloa ischaemum*, var. ischaemum) pasture grazing combined with wheat pasture grazing for cow-calf production. Cows grazing plains bluestem and wheat pasture lost less weight and body condition compared with cows grazing native tallgrass prairie or native prairie and wheat pasture, however, no differences were seen in calf weaning weights or in reproductive efficiency. The plains bluestem-wheat pasture system produced greater net income per hectare than either of the native tallgrass prairie systems. Gillen et al. (1999) compared two sequence grazing systems; one of native mixed grass prairie (primarily *Schizachyrium scoparium* [Michx.] Nash, *Bouteloua curtipendula* [Michx.] Torr., and *Androgpogon hallii* Hack.) and Old World bluestem, and the second of Eastern gamagrass (*Tripsacum dactyloides* [L.] L.) and Old World bluestem, for crossbred beef steers. Sequence grazing is defined as using two or more units of land containing different forage species and grazing them in succession. Steer gains during a 103-day grazing period did not differ between the two systems, however, due to a substantially greater stocking rate, the Eastern gamagrass-Old World bluestem system resulted in 150% greater beef production per hectare. Alfalfa (*Medicago sativa* L.) is commonly used as a complementary forage. Including alfalfa at as little as 35% in pasture mixtures results in improvements in animal gains (Popp et al., 2000). Yearling steers gained as much as 1.5 kg/d and total liveweight production ranged from 107 kg/ha under dryland conditions to 1946 kg/ha under irrigation when alfalfa was grazed. Grazing alfalfa can pose management difficulties due to its bloat potential. However, traditional plant breeding was used to develop AC Grazeland, a cultivar of alfalfa with reduced bloat potential when grazed (Popp et al., 2000). Many complementary forage species have been extensively evaluated including alfalfa, bermudagrass (*Cynodon dactylon* L.), Eastern gamagrass, foxtail millet (*Setaria italica* (L.) Beauv.), kochia (*Kochia scorparia*), oats (*Avena sativa* Linn.), orchardgrass (*Dactylis glomerata* L.), pearl millet (*Pennisetum glaucum* L.), perennial ryegrass (*Lolium perenne* L.), reed canarygrass (*Phalaris arundinacea* L.), rye (*Secale cereale* L.), smooth bromegrass (*Bromus inermis* Leyss.), sudangrass (*Sorghum bicolor* (L.) Moench), triticale (*Triticosecale* spp.), wheat (*Triticum aestivum* L. subsp. *aestivum*), and the wheatgrasses (*Agropyron, Elymus, Pseudoroegneria, Pascopyrum*, and *Thinopyrum* spp.). Recently, Vogel and Jensen (2001) reported survival and forage production under rangeland conditions of 105 accessions of the perennial *Triticeae* that were chosen to represent a wide range of germplasm. Species evaluated came from 8 genera and included commonly grown species as well as a large number of species not previously evaluated in the Central Great Plains. These authors identified several new species that may have potential for inclusion in rangeland forage systems, including mammoth wild rye (*Leymus racemosus*), *Leymus sabulosus*, and *Leymus chinensis.*

Swath Grazing

Swath or windrow grazing is an alternate feeding technique designed to lower production costs by allowing the cow to harvest cut forages directly. Cut hay is left in windrows through the winter, and cows graze the windrows under controlled conditions, usually with electric fencing. Ranchers from Nebraska to Canada are using this method to reduce their winter feeding costs (Surber et al., 2001). Thomson (1999) estimated that swath grazing saved an average of $36.00 per ton compared to baling, storage and feeding costs, and resulted in a savings of $0.55 per cow per day and $0.21 per calf per day. Surber et al. (2001) estimated a minimum savings of $16 per acre, assuming a harvest of 1.5 tons per acre of meadow hay. Volesky et al. (2002) baled alternating windrows of cool-season perennial species with the remaining windrows left in place for swath grazing. Forage production costs for the swath-grazing system were about $63/ha less than baling due to baling and bale moving costs. Weaned steer calves were fed baled hay or grazed windrows during each of two winters. During the 1st year, swath-grazing calves gained more than bale-fed calves, but gains were similar during the second year. Feed costs averaged $0.16·animal^{-1}·d^{-1} for swath grazing and $0.30 animal^{-1}·day^{-1} for feeding bales.

Plant Genetic Selection

Genetic improvements in forage quality can result in reductions in supplementation, reductions in acreages of complementary forages or enhanced flexibility in livestock and enterprise management (Casler and Vogel, 1999), and the development of improved cultivars can improve livestock productivity (Moore and Jung, 2001). Although improvement of forage quality through traditional plant breeding and genetic selection can be successful, very few new cultivars with improved forage quality have been developed and released (Vogel and Sleper, 1994). Improving forage quality characteristics such as digestibility may not be beneficial to a species, while anti-quality factors in plants that reduce animal performance appear to improve the survivability and vigor of a species. However, substantial genetic variation in digestibility has been reported for a wide variety of forages including alfalfa, bermudagrass, crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), indiangrass (*Sorghastrum nutans* (L.) Nash), intermediate wheatgrass (*Elytrigia intermedia* (Host) Nevski subsp. *intermedia*), orchardgrass, perennial ryegrass, smooth bromegrass, and switchgrass (*Panicum virgatum* L.; Vogel and Sleper, 1994). Ranges in IVDMD as large as 10% within a forage species have been reported, and heritabilities have been estimated to be 0.3 or higher. Documented progress has been made in improving digestibility via genetic selection in at least 7 forage species, and the reported rates of change of 0.7 to 2.5% per year are similar to long term gains for grain yield in many cereal crops (Casler and Vogel, 1999). Genetic progress in selection for reduced NDF content has been reported in smooth bromegrass (Casler, 1999) and reed canarygrass (Surprenant et al., 1988). However, these reductions in NDF content were associated with reduced forage yield.

It is possible to dissociate yield and nutritive value. Belanger et al. (2001) reported success in improving the nutritional value of timothy without reductions in forage yield. Forage yield and digestibility have both been improved in a number of species. Vogel and Sleper (1994) reported a 34% increase in yield, 12% increase in IVDMD, 42% increase in ADG, and a 132% increase in gain/ha for bermudagrass. In addition, the improvements made in IVDMD have been repeatable across a wide range of environments and management systems, including on-farm tests (Vogel and Sleper, 1994). Selection for increased Mg content has been successful in Italian ryegrass (*Lolium multiflorum* Lam.) with a 56% increase in forage Mg, a 10% increase in gains by grazing ewes and lambs, and a reduction in incidence of hypomagnesaemia in ewes (Mosely and Baker, 1991). Similar results have been obtained in tall fescue (*Festuca arundinacea* Schreb.; Sleper et al., 1989; Crawford et al., 1998). Variation in UIP content and minor success in increasing UIP has been demonstrated in alfalfa (Broderick and Buxton, 1991).

Plant toxins often give a competitive advantage to plants, and the resulting toxicity to cattle is merely a secondary effect. Reed canarygrass cultivars have been developed with reduced levels of alkaloids (Kalton et al., 1989), sudangrass with decreased potential to cause prussic acid poisoning (Haskins et al., 1990), and sweetclover cultivars with lower levels of coumarin (Gorz et al., 1992). Most anti-quality compounds are the result of specific pathways found in plants, and many are not necessary for growth or development. With increased understanding and characterization of these pathways, "blocking" genes or down-regulation of these pathways might prove a useful way of reducing the levels of toxin compounds.

Genetic Modification of Plants

New technologies, which complement improvements made in pasture science, include advances in DNA and molecular genetics (Vercoe, 1996). Molecular approaches offer the opportunity to produce "designer forages." Opportunities to design forages with beneficial characteristics include forages containing specific antibodies or vaccines (Ma et al., 1995; Mason et al., 1996), expression of UIP (McSweeney et al., 1999), or enhanced fiber digestion (Carpita et al., 2001). McSweeney et al. (1999) stated that there are two strategies to improve forage quality prior to ingestion. One is maximizing the content of desirable compounds such as amino acids presented to the small intestine, and the second is reducing the content of undesirable compounds such as lignin and secondary products that are toxic.

Tabe et al. (1995) suggested that there are two major biotechnological approaches to improving forage protein quality for ruminants; introducing condensed tannins into forages such as alfalfa to increase the UIP fraction, and enriching forages with specific proteins that have a reduced ruminal degradability. When condensed tannins and polyphenolic secondary plant products are found at high levels (40 to 50 g/kg DM) in forages, CP and DM digestibility are reduced (McMahon et al., 2000). However, tannins at moderate levels (5 g/kg DM) have been shown to reduce the degradation of leaf protein in the rumen, increase duodenal nonammonia N flow, increase absorption of essential amino acids from the small intestine (Baba et al., 2002), increase milk production, prevent bloat in cattle and sheep (Barry and McNabb, 1999; McMahon et al., 2000), and reduce parasite infections in grazing sheep (Butter et al., 2001). Research efforts are currently underway to genetically modify alfalfa to reexpress its tannin biosynthetic pathway or to move genes encoding steps of this pathway into alfalfa (McMahon et al., 2000).

Transgenic subterranean clover (*Trifolium subterraneum* L.), white clover (*Trifolium repens*) and alfalfa have been produced which contain genes which encode delta-zein, ovalbumin and albumin; proteins that are resistant to ruminal degradation but are readily degraded by intestinal proteases (Tabe et al., 1995; Khan et al., 1996; Christiansen et al., 2000). Christiansen et al. (2000) introduced genes encoding sunflower seed albumin into white clover to increase the content of cysteine and methionine. They were able to increase the level of albumin to 0.1% of total protein in the leaves, and demonstrated that the ability to synthesize albumin was inherited in successive generations. Khan et al. (1996) introduced a gene encoding sunflower seed albumin into subterranean clover, and the expression of the gene was stable in the first and second generation progeny. Tabe et al. (1995) introduced sunflower seed albumin into Australian commercial cultivars of alfalfa, and were able to obtain expression of the foreign protein, however, the levels of albumin achieved were presumably not high enough to affect animal production.

Ferulic acid crosslinks xylans and links them to lignin in grasses, and this reduces digestibility of the plant cell wall. Hatfield et al. (1999) speculate that targeting the enzymes that attach ferulic acid to polysaccharides could be the key step in reducing cross-linkages and improving forage grass digestibility. Other options to manipulate cell wall digestibility include altering lignin concentration and lignin composition using both genetic selection and molecular approaches. In forage legumes, selection for increased pectin content could lead to increased digestibility (Hatfield et al., 1999).

Current transformation efforts involve down-regulating enzymes in the lignin biosynthetic pathway in alfalfa and stylo (*Stylosanthes* spp.) that have resulted in reduced lignin content and increased digestibility compared with control plants (Casler and Vogel, 1999). Guo et al. (2001) produced transgenic alfalfa lines that had decreased lignin content and changed lignin composition by down-regulating two O-methyltransferase enzymes in the lignin biosynthesis pathway. Compared with control alfalfa plants, these transgenic alfalfa plants exhibited no gross changes in stem morphology as assessed by examination of stained cross sections, and no changes in pectin, cellulose and hemicellulose content. Alfalfa in vitro NDF digestibility was increased by 1 to 5.5% in the transgenic alfalfa lines compared with control alfalfa, and NDF digestibility of the stems was improved by 8% in one transgenic line. In *Arabidopsis thaliana*, a plant species that has been used extensively as a model for genetic studies, it is estimated that approximately 15% of the more than 25,000 genes identified are involved in cell wall synthesis, reorganization and turnover (Carpita et al., 2001). Tremendous progress has already been made, but for molecular breeding and transformation technology to be successful, detailed knowledge of the exact genes to manipulate, and of any possible negative consequences of genetic manipulation are necessary (Vogel and Jung, 2001).

Genetic Modification of Ruminal Microbes

Using genetically engineered ruminal microbes and microbial enzymes offers the possibility of eliminating anti-nutritional factors and toxins in plants, enhancing fiber digestion, and improving amino acid composition of ruminal bacteria (Wallace, 1994; Bonneau and Laarveld, 1999). Over 100 different genes encoding enzymes for fiber digestion have been identified and cloned from ruminal bacteria such as *Butyrivibrio fibrisolvens, Fibrobacter succinogenes, Prevotella ruminicola, Ruminococcus albus* and *Ruminococcus flavefaciens*. At least 30 genes from ruminal fungi have been isolated that encode cellulase, xylanases, mannanases, and endoglucanases. These are of particular interest due to their powerful fibrolytic activity and ability to break down very resistant cell wall polymers. In addition, cellulase and xylanase genes from ruminal protozoa have been cloned. Almost 50% of the fibrolytic genes cloned have been sequenced (Selinger et al., 1996). Protein engineering has been used to increase the catalytic activity and substrate diversity of fibrolytic enzymes from ruminal microbes. This has resulted in enzymes with up to 10 times higher specific activity, changed pH and temperature optima and increased substrate binding activity than the enzymes from which they originated (Selinger et al., 1996). Some ruminal bacterial species such as *Butyrivibrio fibrisolvens* and *Prevotella ruminicola* are found widely in ruminant animals on varied diets and are found in significant numbers regardless of the ruminal environment. These species therefore are logical choices to introduce new or enhanced genetic material into the rumen (Selinger et al., 1996).

Streptococcus bovis is tolerant to O_2 and depressed rumen pH unlike most cellulolytic bacterial species in the rumen. In addition, there are convenient gene transfer methods available for this species that make it a candidate as a host for the expression of genes from other organisms. Ekinci et al. (2002) were able to use a beta-glucase promoter found in *S. bovis* to express a cellulase gene from the anaerobic rumen fungus *Neocallimastix patriciarum* that is found in very low levels in the rumen, and is important for the degradation of crystalline cellulose. The resulting enzyme product was active against a wide variety of cellulosic substrates. The advantages of using fungal enzymes are their stability to low pH and their extremely high activity level (Ekinci et al., 2002).

Xue et al. (1997) were successful in introducing a xylanase gene from the anaerobic ruminal fungus *Neocallimastix patriciarum* into *Butyrivibrio fibrisolvens*, and achieving secretion of the enzyme. Krause et al. (2001) constructed a recombinant *Butyrivibrio fibrisol-*

vens that expressed a xylanase enzyme from the ruminal fungus *Neocallimastix patriciarum*. The recombinant *Butyrivibrio fibrisolvens* did have an increased ability to digest fiber, but it did not persist in the rumen past 22 d.

Monofluoroacetate is a toxin found in many Australian shrubs and trees that results in substantial animal deaths. Gregg et al. (1996) reported the successful introduction and in vitro expression of a gene encoding a toxin-degrading enzyme (fluoroacetate dehalogenase) into *Butyrivibrio fibrisolvens*. The recombinant *Butyrivibrio fibrisolvens* established and persisted in the rumen of sheep for over 5 mo; however, the successful colonization of a genetically modified species in the rumen is still the most difficult barrier to cross. Currently, the biggest problem is the ability to introduce and maintain the new strain in the mixed rumen population, and survival of new strains is not well understood. Other options include using nonruminal organisms such as *Saccharomyes cerevisiae* because yeast is already used as a feed additive and its genetics are well understood (Wallace, 1994).

Genetic Modification of Animals

The technology of developing transgenic animals with modified characteristics offers the opportunity to increase production efficiency, modify digestion and end products, improve metabolic efficiency, and partition nutrients (Vercoe, 1996). Bacteria appear to be a convenient reservoir of useful functional genes to introduce into animals. Several efforts in this area are currently ongoing. The one that has made the most progress involves inserting a biosynthetic pathway for cysteine, a rate-limiting amino acid for wool production, into sheep. Genes from *Escherichia coli* encoding the two enzymes necessary to convert the amino acid serine into cysteine were introduced into mice. These transgenic mice expressed the enzymes for the synthesis of cysteine, and when placed on a low sulfur amino acid diet continued to grow normally. Control mice without the enzymes for cysteine synthesis suffered considerable weight loss on the same diet. These same genes have been placed into transgenic sheep, but although low-level expression of the enzymes has occurred, not enough cysteine has been synthesized to be useful (Ward, 2000).

Another attempt at manipulating animal metabolism is the introduction into ruminants of a glyoxylate pathway that synthesizes glucose from acetate. Ruminant metabolism is unique in that there is very limited glucose absorption and only one gluconeogenic VFA, propionate. Saini et al. (1996) introduced genes encoding bacterial glyoxylate cycle enzymes into mammalian cells in vitro, and into transgenic mice. In both cases, the appropriate enzymes have been expressed. Introducing this pathway into ruminants presumably would improve metabolic efficiency. However, all efforts so far to insert these genes and achieve expression of the glyoxylate pathway enzymes in sheep have failed (Ward, 2000).

Implications

Forage-based beef cattle producers in the Western United States face two large challenges in the future. First, they must demonstrate that their production methods are compatible with the desires of the American public, especially when public land grazing is involved, and second, they must remain economically viable in times of increased competition. A number of technologies that are simple and relatively inexpensive are currently available to help meet these challenges. Advances in electric fencing, water development and supplement placement offer practical solutions to improve distribution problems. The use of complementary forages has proven to be one of the most profitable improvement practices for livestock producers in the Western US. Other technologies such as genetic modification of plant and ruminal microbial species are not currently available, but they may substantially change the way livestock producers operate in the future.

Literature Cited

Ares, R. N. 1953. Better cattle distribution through the use of meal-salt mix. J. Range Manag. 6:341–346.

Baba, A.S.H., F. B. Castro, and E. R. Orskov. 2002. Partitioning of energy and degradability of browse plants in vitro and the implications of blocking the effects of tannin by the addition of polyethylene glycol. Anim. Feed Sci. Technol. 95:93–104.

Bailey, D. W., and G. R. Welling. 1999. Modification of cattle grazing and distribution with dehydrated molasses supplement. J. Range Manag. 52:575–582.

Bailey, D. W., G. R. Welling, and E. T. Miller. 2001. Cattle use of foothills rangeland near dehydrated molasses supplement. J. Range Manag. 54:338–347.

Barry, T. N., and W. C. McNabb. 1999. The implications of condensed tannins on the nutritive value of temperate forages fed to ruminants. Br. J. Nutr. 81:263–272.

Belanger, G., R. Michaud, P. G. Jefferson, G. F. Tremblay, and A. Bregard. 2001. Improving the nutritive value of timothy through management and breeding. Can. J. Plant Sci. 81:577–585.

Bonneau, M., and B. Laarveld. 1999. Biotechnology in animal nutrition, physiology and health. Livest. Prod. Sci. 59:223–241.

Broderick, G. A., and D. R. Buxton. 1991. Genetic variation in alfalfa for ruminal protein degradability. Can. J. Plant Sci. 71:755–760.

Butter, N. L., J. M. Dawson, D. Wakelin, and P. J. Buttery. 2001. Effect of dietary condensed tannins on gastrointestinal nematodes. J. Agric. Sci. 137:461–469.

Carpita, N., M. Tierney, and M. Campbell. 2001. Molecular biology of the plant cell wall: searching for the genes that define structure, architecture and dynamics. Plant Molecular Biol. 47:1–5.

Casler, M. D. 1999. Structural responses to selection for reduced fiber concentration in smooth bromegrass. Crop Sci. 39:1435–1438.

Casler, M. D., and K. P. Vogel. 1999. Accomplishments and impact from breeding for increased forage nutritional value. Crop Sci. 39:12–20.

Christiansen, P., J. M. Gibson, A. Moore, C. Pedersen, L. Tabe, and P. J. Larkin. 2000. Transgenic *Trifolium repens* with foliage accumulating the high sulphur protein, sunflower seed albumin. Transgenic Res. 9:103–113.

Coleman, S. W., W. A. Phillips, J. D. Volesky, and D. Buchanan. 2001. A comparison of native tallgrass prairie and plains bluestem forage systems for cow-calf production in the Southern Great Plains. J. Anim. Sci. 79:1697–1705.

Crawford, R. J., M. D. Massie, D. A. Sleper, and H. F. Mayland. 1998. Use of an experimental high-magnesium tall fescue to reduce grass tetany in cattle. J. Prod. Agric. 11:491–496.

Dagget, D. 1998. Beyond the rangeland conflict: toward a West that works. Good Stewards Project, Flagstaff, AZ.

Ekinci, M. S. J. C. Martin, and H. J. Flint. 2002. Expression of a cellulase gene, celA, from the rumen fungus *Neocallimastix patriciarum* in *Streptococcus bovis* by means of promoter fusions. Biotechnol. Lett. 24:735–741.

Ganskopp, D. 2001. Manipulating cattle distribution with salt and water in large arid-land pastures: a GPS/GIS assessment. Appl. Anim. Behaviour Sci. 73:251–262.

Gillen, R. L., and W. A. Berg. 2001. Complementary grazing of native pasture and Old World bluestem. J. Range Manage. 54:348–355.

Gillen, R. L., W. A. Berg, C. L. Dewald, and P. L. Sims. 1999. Sequence grazing systems on the southern plains. J. Range Manage. 52:583–589.

Gorz, H. J., F. A. Haskins, G. R. Manglitz, R. R. Smith, and K. P. Vogel. 1992. Registration of N28 and N29 germplasms. Crop Sci. 32:510.

Gray, J. R. 1973. Characteristics of superior management for efficient calf production. Pages 1–1 to 1–15 in Proc. Great Plains Beef Symposium, Great Plains Agric. Council, Univ. Lincoln, Nebraska.

Gregg, K., G. Allen, and C. Beard. 1996. Genetic manipulation of rumen bacteria: From potential to reality. Aust. J. Agric. Res. 47:247–256.

Guo, D., F. Chen, J. Wheeler, J. Winder, S. Selman, M. Peterson, and R. A. Dixon. 2001. Improvement of in-rumen digestibility of alfalfa forage by genetic manipulation of lignin O-methyltransferases. Transgenic Res. 10:457–464.

Harris, N. R., D. E. Johnson, M. R. George, and N. K. McDougald. 2002. The effect of topography, vegetation, and weather on cattle distribution at the San Joaquin Experimental Range, California. USDA Forest Service Gen. Tech. Rep. PSW-GTR-184:53–63.

Haskins, F. A., H. J. Gorz, and K. P. Vogel. 1990. Registration of NP31 and NP32, two populations of sudangrass selected for low dhurrin content. Crop Sci. 30:759–760.

Hatfield, R. D., J. Ralph, and J. H. Grabber. 1999. Cell wall structural foundations: Molecular basis for improving forage digestibilities. Crop Sci. 39:1–11.

Kalton, R. R., P. Richardson, and J. Shields. 1989. Registration of 'Venture' reed canarygrass. Crop Sci. 29:1327–1328.

Kauffman, J. B., and W. C. Krueger. 1984. Livestock impact on riparian ecosystems and streamside management implications: a review. J. Range Manag. 37:430–438.

Khan, M.R.I., A. Deriotti, L. Tabe, A. Aryan, W. McNabb, A. Moore, S. Craig, D. Spenser, and T.J.V. Higgins. 1996. Accumulation of a sulphur-rich seed albumin from sunflower in the leaves of transgenic subterranean clover (*Trifolium subterraneum* L.). Transgenic Res. 5:179–185.

Krause, D. O., R. J. Bunch, B. D. Dalrymple, K. S. Gobius, W.J.M. Snith, G. P. Xue, and C. S. McSweeney. 2001. Expression of a modified *Neocallimastix patriciarum* xylanase in *Butyrivibrio fibrisolvens* digests more fibre but cannot effectively compete with highly fibrolytic bacteria in the rumen. J. Appl. Microbiol. 90:388–396.

Lacey, J. R. 1985. An introduction to high tensile, smooth wire electric fence. Bull. No. 1324. Montana Coop. Ext. Serv., Montana State Univ., Bozeman, MT.

Launchbaugh, J. L., C. E. Owensby, F. L. Schwartz, and L. R. Corah. 1978. Grazing management to meet nutritional and functional needs of livestock. Pages 541–550 in Proc. 1st Int. Rangeland Cong., Denver, CO.

Ma, J. K., A. Hiatt, M. Hein, N. D. Vine, F. Wang, P. Stabila, C. Van Dolleweerd, K. Mostov, and T. Lehner. 1995. Generation and assembly of secretory antibodies in plants. Science 268:716–719.

Mason, H. S., I. M. Ball, J. J. Shi, X. Jiang, M. K. Estes, and C. J. Arntzen. 1996. Expression of Norwalk virus capsid protein in transgenic tobacco and potato and its oral immunogenicity in mice. Proc. Natl. Acad. Sci. 93:5335–5340.

McInnis, M. L., and J. McIver. 2001. Influence of off-stream supplements on streambanks of riparian pastures. J. Range Manag. 54:648–652.

McMahon, L. R., T. A. McAllister, B. P. Berg, W. Majak, S. N. Acarya, J. D. Popp, B. E. Coulman, Y. Wang, and K. J. Cheng. 2000. A review of the effects of forage condensed tannins on ruminal fermentation and bloat in grazing cattle. Can. J. Plant Sci. 80:469–485.

McSweeney, C. S., B. P. Dalrymple, K. S. Gobius, P. M. Kennedy, D. O. Krause, R. I. Mackie, and G. P. Xue. 1999. The application of rumen biotechnology to improve the nutritive value of fibrous feedstuffs: pre- and post-ingestion. Livest. Prod. Sci. 59:265–283.

Moore, K. J., and H.J.G. Jung. 2001. Lignin and fiber digestion. J. Range Manag. 54:420–430.

Mosely, G., and D. H. Baker. 1991. The efficacy of a high magnesium grass cultivar in controlling hypomagnesaemia in grazing animals. Grass Forage Sci. 46:375–380.

National Wildlife Federation and Natural Resources Defense Council. 2001. Conservation Management of America's Public Lands: An Assessment and Recommendations for Progress 25 Years After FLPMA. Natl. Wildlife Fed. Boulder, Colorado.

Ohlenbusch, P. D, S. L. Satterthwaite, and S. L. Watson. 1995. Managing Kansas grazinglands for water quality. MF-2086. Coop. Ext. Serv., Kansas State Univ., Manhattan, KS.

Popp, J. D., W. P. McCaughey, R.D.H. Cohen, T. A. McAllister, and W. Majak. 2000. Enhancing pasture productivity with alfalfa: A review. Can. J. Plant Sci. 80:513–519.

Porath, M. L., P. A. Momont, T. DelCurto, N. R. Rimby, J. A. Tanaka, and M. McInnis. 2002. Offstream water and trace mineral salt as management strategies for improved cattle distribution. J. Anim. Sci. 80:346–356.

Rey, M. 2002. Federally owned rangelands: are there new grounds for common ground? Paper presented at 67th N. Am. Wildlife Natural Resources Conf., Dallas, TX, April 4, 2002.

Richards, R. T., and M. R. George. 1996. Evaluating changes in ranch management practices through extension education. J. Range Manag. 49:76–80.

Roberts, N. K., and E. B. Wennergren. 1965. Economic evaluation of stockwater developments. J. Range Manag. 18:118–123.

Saini, K. S., C. R. Byrne, Z. Leish, C. A. Pruss, N. W. Rigby, A. G. Brownlee, C. D. Nancarrow, and K. A. Ward. 1996. Introduction and expression of the bacterial glyoxylate cycle genes in transgenic mice. Transgenic Res. 5:467–473.

Selinger, L. B., C. W. Forsberg, and K. J. Cheng. 1996. The rumen: A unique source of enzymes for enhancing livestock production. Anaerobe 2:263–284.

Simonds, G. 1991. Matching cattle nutrient requirements to a ranch's forage resource, or "Why we calve late". Proc. Range Beef Cow Symp., Fort Collins, CO, XII:209–216.

Sims, P. L. 1993. Cow weights and reproduction on native rangeland and native rangeland-complementary forage systems. J. Anim. Sci. 71:1704–1711.

Sims, P. L., and D. W. Bailey. 1995. Calf production by Angus-Hereford and Brahman-Hereford cows on two native rangeland forage systems. J. Anim. Sci. 73:2893–2902.

Sleper, D. A., K. P. Vogel, K. H. Asay, and H. F. Mayland. 1989. Using plant breeding and genetics to overcome the incidence of grass tetany. J. Anim. Sci. 67:3456–3462.

Smoliak, S., and S. B. Slen. 1974. Beef production on native range, crested wheatgrass, and Russian wildrye pastures. J. Range Manag. 27:433–436.

Surprenant, J., D. K. Barnes, R. H. Busch, and G. C. Marten. 1988. Bidirectional selection for neutral detergent fiber and yield in reed canarygrass. Can. J. Plant Sci. 68:705–712.

Surber, G., T. Fisher, D. Cash, P. Dixon, and J. Moore. 2001. Swath/Windrow Grazing. Montguide MT200106AG, MT Coop. Ext. Serv., MT State Univ., Bozeman, MT.

Tabe, L. M., T. Wardleyrichardson, A. Ceriotti, A. Aryan, W. McNabb, A. Moore, and T.J.V. Higgins. 1995. A biotechnological approach to improving the nutritive-value of alfalfa. J. Anim. Sci. 73:2752–2759.

Thomson, W. V. 1999. Reducing harvesting costs using windrow grazing. Proc. The Range Beef Cow Symposium, Greeley, CO, XVI:61–66.

Vercoe, J. E. 1996. Pastures for prosperity. 5. The role of animal science. Tropical Grasslands 30:58–72.

Vogel, K. P., and K. J. Jensen. 2001. Adaptation of perennial *Triticeae* to the eastern Central Great Plains. J. Range Manag. 54:674–679.

Vogel, K. P., and H.J.G. Jung. 2001. Genetic modification of herbaceous plants for feed and fuel. Crit. Rev. Plant Sci. 20:15–49.

Vogel, K. P., and D. A. Sleper. 1994. Alternation of plants via genetics and plant breeding. Pages 891–921 in Forage Quality, Evaluation and Utilization. G. C. Fahey, Jr., ed. ASA, CSSA, SSSA, Madison, WI.

Volesky, J. D., D. C. Adams, and R. T. Clark. 2002. Windrow grazing and baled-hay feeding strategies for wintering calves. J. Range Manag. 55:23–32.

Wallace, R. J. 1994. Ruminal microbiology, biotechnology, and ruminant nutrition—progress and problems. J. Anim. Sci. 72:2992–3003.

Ward, K. A. 2000. Transgene-mediated modifications to animal biochemistry. Trends Biotechnol. 18:99–102.

Willms, W. D., O. Kenzie, Z. Mir, and D. Quinton. 1995. Effects of water supplied from old dugouts on the performance of cattle. Pages 606–607 in Proc. 5th Int. Rangeland Cong., Salt Lake City, UT.

Xue, G. P., J. S. Johnson, K. L. Bransgrove, K. Gregg, C. E. Beard, B. P. Dalrymple, K. S. Gobius, and J. H. Aylward. 1997. Improvement of expression and secretion of a fungal xylanase in the rumen bacterium *Butyrivibrio fibrisolvens* OB156 by manipulation of promoter and signal sequences. J. Biotechnol. 54:139–148.