Toward a sustainable agriculture

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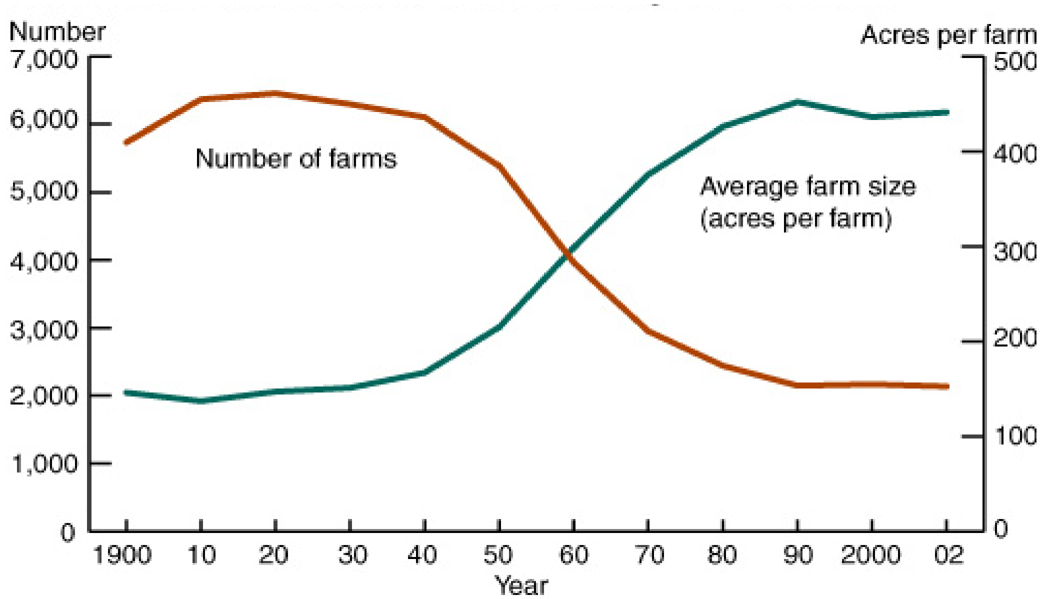
Future trends in population growth, energy use, climate change, and globalization will challenge agriculturists to develop innovative production systems that are highly productive and environmentally sound. Furthermore, future agricultural production systems must possess an inherent capacity to adapt to change to be sustainable. During the 20th century, US agriculture underwent vast transformations. Number of farmers decreased, more farmers relied on off-farm income, agriculture's proportion of the US gross domestic product (GDP) declined, and farming dependency of nonmetro counties in the United States declined and continues to decrease. Because of these transformations, new challenges have emerged in animal agriculture, including industrialization, globalization, fossil-fuel energy use, development of bioenergy, and water availability. Through a commitment of the US agricultural community, these challenges can be met and US farmers can lead the way toward a sustainable future.

Agriculture has been very successful in meeting the needs of most of the world's population. Specifically, today's agriculture feeds a population of six billion people (Tilman et al. 2002) using only 0.2 ha of land per person (Trewavas 2002). Despite such impressive achievements, there are concerns about the sustainability of modern agriculture. Intensive agriculture impacts the resource base and potentially reduces both its capacity (Huang et al. 2002) and its sustainability (Brummer 1998; Tilman et al. 2002). In the Great Plains, many cropping systems are characterized by a lack of diversity (Brummer 1998) and declining soil organic carbon (Krall and Schuman 1996). Beef production in the United States has done an excellent job of developing animals that can convert feed grains into meat (i.e., feedlots) acceptable for human consumption, but it relies heavily on fossil fuels (Heitschmidt et al. 1996).

Great changes have occurred within the US agricultural community over the past century (figure 1). From 1930 to 2002, the workforce employed in agriculture decreased from 22% to 2%, the portion of total GDP from agriculture decreased from 7.7% to 0.7%, farming dependent nonmetro counties decreased and became a minority (figure 2), and the percentage of farmers working off farm increased from 30% to 93% (Dimitri et al.

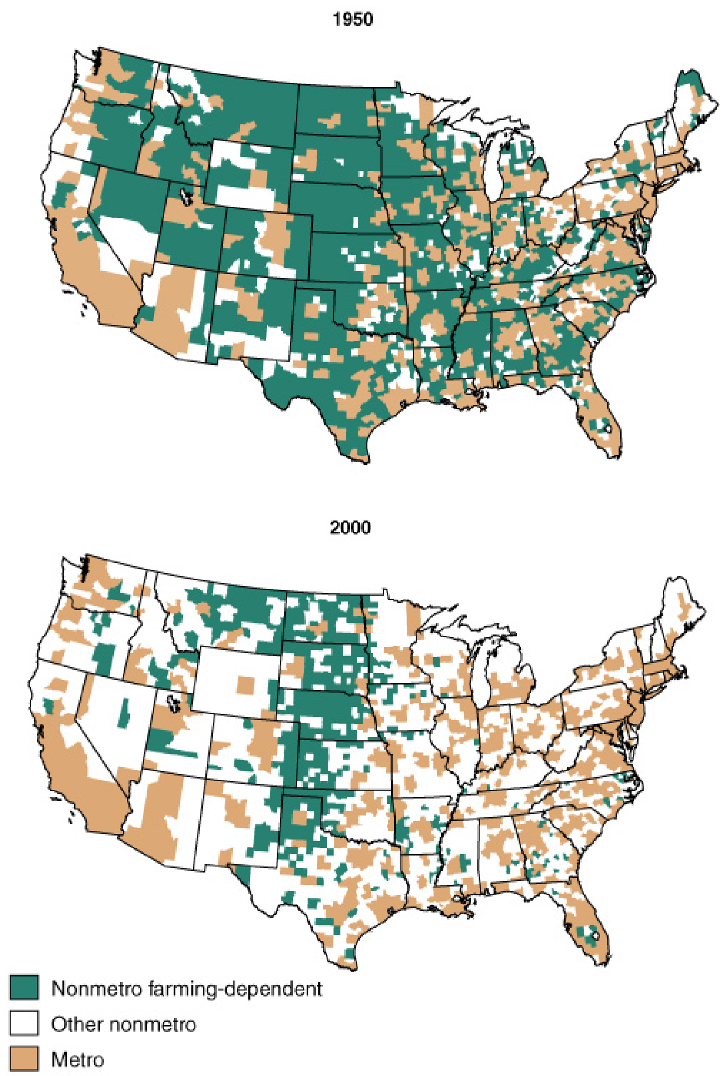
2005). These statistics are indicative of several trends in United States and world agriculture. Hanson et al. (2008) discussed eight such current trends, including (1) increased land degradation, (2) competing land uses, (3) focus on single ecosystem service, (4) increased farm size, (5) movement toward commercialization, (6) genetic engineering, (7) global markets, and (8) changing social structure.

In his discussion of the current status and future trends in American agriculture, Ikerd (2009) argued that the current industrial food system is not sustainable. His premise for animal production was that animal agriculture will be needed to help feed the world in the postindustrial 21st century, and most animals in the future will be raised on grass. His polemic that the current industrial food system is not sustainable is tenable, and it has far reaching implications for sustainable animal-based production in the United States. Other important considerations that must be dealt with to ensure a sustainable animal-based agriculture include global markets, fossil-fuel energy use, and water shortages. Before discussing these impacts, we will first address the issue of sustainability.



Source: Compiled by Economic Research Service, USDA, using data from *Census of Agriculture*, *Census of Population*, and *Census of the United States*.

Figure 1. Relationship between the number of US farms and their average size.



Source: Economic Research Service, USDA. Farming-dependent counties are defined by ERS. For 1950, at least 20% of income in the county was derived from agriculture. For 2000, either 15% or more of average annual labor and proprietors' earnings were derived from farming during 1998 to 2000 or 15% or more of employed residents worked in farm occupations. Metro/nonmetro status is based on the Office of Management and Budget (OMB) June 2003 classification.

Figure 2. Nonmetro farming-dependent counties, 1950 and 2000.

Sustainable Agricultural Systems

Agricultural systems need to be developed that are sustainable and adaptable to change, but yet maintain their productivity. Most producers do not develop and use management systems that are designed to be unsustainable. Rather, managers have difficulty discerning between sustainable systems and those that are not. A cursory search of the literature will demonstrate the vast array of what "sustainable" actually means. Such a search demonstrates there are different understandings of sustainability and different visions on how to achieve it. A multitude of definitions of sustainable agriculture exist, yet most include economic, environmental, and social/community dimension. Tinsley (2005) stated that sustainable agriculture "balances the need for essential agricultural commodities such as food, fibre, etc. with the necessity of protecting the physical environment and public health, the foundation of agriculture." A composite definition might define sustainable agriculture as an approach to growing food and fiber that is profitable, uses on-farm resources efficiently to minimize adverse effects on the environment and people, preserves the natural productivity and quality of land and water, and sustains vibrant rural communities (UCS 2005; Hendrickson et al. 2008). Regardless of the definition, the potential benefits of a sustainable agriculture should include long-term viability and resilience of farm economics, conservation and enhancement of the natural resource base, minimization of off-site environmental impacts, improvement of farm-level management skills, and enhancement of socioeconomic viability of rural communities.

Impact of Industrialization on Animal-Based Production

Industrialization in agriculture refers to increasing farm consolidation and vertical integration among stages of the food and fiber system. Emerging agricultural systems are expected to be highly competitive in global markets, more efficient, more responsive to consumer demands, less dependent on government assistance, and able to more rapidly adopt new technologies. Industrialization of the US farm has been pronounced over the past several decades. As farm numbers decreased and farm size increased, the food processing industry has concentrated into fewer commercial operations. The four-firm concentration ratio (i.e., the sales of the four largest firms as a percentage of total sales) in meatpacking increased from 26% in 1972 to 57% in 1997, with similar increases in other processing industries such as poultry slaughter and soybean processing (Ollinger et al. 2005). By 2000, the ratio was 80% in fed beef slaughter, with over 58% within the holdings of two companies. A trend is also developing toward supply-chain consolidation (Ollinger et al. 2005). In this type of consolidation, all stages of production, processing, and distribution are woven tightly together to ensure reliable, efficient product delivery (Drabenstott 1999).

Supply-chain consolidation predominates in the poultry industry and is accelerating in the pork industry. This consolidation has sweeping geographic, environmental, and economic consequences. Supply-chain consolidation shifts the base of operations from near feed production facilities to areas of lower labor costs and closer to key markets, further decoupling crop and livestock agriculture. In the pork industry for example, real growth has not occurred in the Corn Belt, but rather in the southeastern United States and in the southern Great Plains (Drabenstott 1999).

Agricultural industrialization in the United States has replaced ownership and operational control by the farmer with that of the investment community. This has restricted involvement of the farmer in the decision-making process. In the industrialization model, the predominant decision-making criterion has become the economic bottom line. To see and understand more fully the intent of industrialized farming, we must examine its philosophies: (1) nature is a resource to be exploited and variation is to be suppressed, (2) natural resources are not valued except when a necessary expense in production is incurred, (3) progress is equivalent to the evolution of larger farms and depopulation of farm communities, (4) progress is measured primarily by increased material consumption, (5) efficiency is measured by looking at the bottom line, and (6) science is an unbiased enterprise driven by natural forces to produce social good (Stauber et al. 1995). This latter statement implies that industrial agriculture relies on science and that any results from science, especially those useful to further industrialization, are assumed by proponents to be inherently beneficial. These philosophies conflict with most strategies for developing sustainable agricultural systems.

We recognize three major areas of concern regarding industrialization of agriculture. First is the ecological concern. In the industrial model, declining soil productivity, desertification, water pollution, increasing scarcity of water, increasing pest pressures, and rapid global climate change are viewed as negative impacts only if they have a direct cost to the production system. Second is the socioeconomic concern. Issues here include increased federal regulation, disparate farmer incomes, disappearance of the midsized farm, and urban sprawl. Once again, without a direct cost to the production system, or an overriding social consequence, the industrial model does not view these changes in agricultural systems as losses or problems. Third is the human health concern. These issues include overuse of antibiotics in animal production, nitrate and pesticide contamination of water and food, and release of toxic residues into our food and fiber supply (Gold 1999). Unfortunately, these negative consequences are traditionally handled by reactive rather than proactive approaches.

There is an alternative to the industrialization model for animal-based producers. Many ranchers, particularly in the western United States, are implementing management models focused on keeping native grasses abundant and healthy. These managers see themselves as caretakers of the land, thus they value plants, wildlife, and even predators, but they are ranchers first. They tend to think of themselves not as commodity-producing businessmen, but rather as whole-ecosystem stewards. Cattle are not considered the sole focus of the operation, but rather tools used to manage the enterprise. This change in emphasis creates new opportunities for collaboration. For example, the Quivira Coalition in New Mexico is a collaborative effort between ranchers and environmentalists to enhance ecological, economical, and social health of western rangelands. This is a worthy goal, although the tools to achieve it are controversial (Savory 1998; Briske et al. 2008). Ideally, the objective of a grazing system is to modify the landscape by increasing soil microbial activity, enhancing soil organic carbon, and increasing water infiltration rate. Thus, under properly managed grassland, the motto becomes, "capture every drop of rain where it hits." Greater production makes for healthier cattle and ultimately impacts the economics of the enterprise. All of these improvements subsequently have obvious and positive impacts on the community.

Impact of Global Markets on Animal-Based Production

Agricultural producers in the United States are competing in an increasingly global marketplace. Boehlje (2008) reported that changes occurring in the agricultural sector are inevitable and they represent opportunities for some, but threats for others. Specifically he reported, "Twenty-first century agriculture is likely to be characterized by: more global competition; expansion of industrialized agriculture; production of differentiated products; precision (information intensive) production; emergence of ecological agriculture; formation of food supply chains; increasing risk; and more diversity" (Boehlje 2008). He concluded that in agriculture of the future, successful companies would need to be better, faster, and cheaper to have a sustainable competitive advantage.

This approach, however, only considers bottom-line economics as the measure for sustainability.

Bottom-line economics does not always favor US producers. Compared to US producers, producers in other countries can often produce agricultural commodities cheaper. For example, foreign soybean production has recently exceeded that in the United States. (Ash 2001). Even though agricultural exports remain strong, agricultural imports are increasing, and the overall US agricultural trade balance has decreased since 2001 (Hanson et al. 2008). Expansion of trade and faster information flow through the Internet are converging to create a new worldwide farm and food system. This new era is being fueled by at least five major issues (Thiermann 2001): (1) finance, technology, and information are being democratized; (2) the Internet has empowered global information dissemination and increased the speed of information dissemination; (3) the basic human desire for a better life has emerged at the root of globalization; (4) the role of world governments has increased in developing policies that allow their agricultural sectors to become competitive in the global agricultural marketplace by becoming more efficient and offering higher quality service; and (5) opportunities have evolved through international trade to improve consumer health, provide consumer choices, and increase producer income.

While this new farm era would offer great potential, there are many pitfalls. Trade liberalization and globalization are assumed to increase food production and improve the economic condition of farmers. However, in most countries, the process has resulted in a decline in food production, a decline in conditions for farmers, and a decline in food security for consumers. Globalization is intensifying food insecurity throughout the world (Shiva 1997). Bill Christison from the US National Family Farm Coalition spoke of the impact of globalization on family farm agriculture at an International Forum in Porto Alegre, Brazil. He stated, "The current farm income crisis is unprecedented in times of economic prosperity and stability" (Christison, International Forum in Porto Alegre, Brazil, July 5, 2000). Since Christison made this statement, agriculture has undergone dramatic changes. Although farm prices have increased substantially, increased price volatility and high input costs have had positive and negative impacts on farm income. Christison highlighted seven outcomes of globalization that would affect the small farm: (1) development of domestic policies that directly support international deals are in the best interest of corporate agribusiness; (2) disappearance of middle-sized farms and loss of independent ownership; (3) unprecedented mergers, acquisitions, and concentration in all stages of agricultural production, marketing, and retailing; (4) more control of agriculture by fewer representatives; (5) increased agricultural industrialization leading to water, soil, and air pollution and overproduction leading to lower prices for independent producers; (6) a shift in land ownership and land availability, particularly away from minority-owned operations; and (7) the World Trade Organization placing more power and profits into the hands of transnational corporations.

Impact of Fossil-Fuel Energy Use on Animal-Based Production

The use of fossil fuels in agriculture has greatly impacted agriculture. Escalating price of fuel has increased everything, from transportation costs to fertilizer costs, and to feed costs. At the same time, high transportation costs have limited some attributes of industrialization because high fuel costs mean that large firms cannot simply ship feed or product to areas of low labor costs. In response, the United States is turning in a cyclonic manner to develop renewable energy systems. Future agricultural production will no longer be focused solely on food and feed markets, but will include other outlets like energy and industrial uses. For example, corn and soybean will not only be used as livestock feed, but will also be sold for generation of biofuels (ethanol and biodiesel). Use of a biofuel crop within an integrated system adds not only to farm diversity, but also contributes to the rural community. Selling starch (corn or dry peas) or lignocellulosic material (switchgrass or big bluestem) certainly gives the producer an added economic incentive. However, facilities must be developed to manage and use these materials. Thus, developing a bioenergy program helps enhance the local economy by providing jobs and an increased tax base; although, it also directly impacts the cost to produce animal-based products. Greater value of corn due to demand for ethanol production will limit use of corn as animal feed. This subsequently provides a hidden trigger for animal-based production to rely more on grass farming.

Switchgrass has been evaluated for cellulosic energy development (Schmer et al. 2008). Two primary concerns of using switchgrass as a biofuel crop are its net energy efficiency and its economic feasibility. In this base-line project conducted on marginal cropland, switchgrass was found to produce 540% more renewable energy than nonrenewable energy consumed. Managed correctly, average greenhouse gas emissions from cellulosic ethanol derived from switchgrass were 94% lower than estimated emissions from gasoline. Thus, incorporation of biomass crops for cellulosic ethanol production into a portfolio of enterprises for ranchers could become a viable alternative component of a holistic management system. In fact, some 83% of the average US household's carbon footprint for food consumption comes from production, while only 11% and 5% come from transportation and retailing, respectively (figure 3).

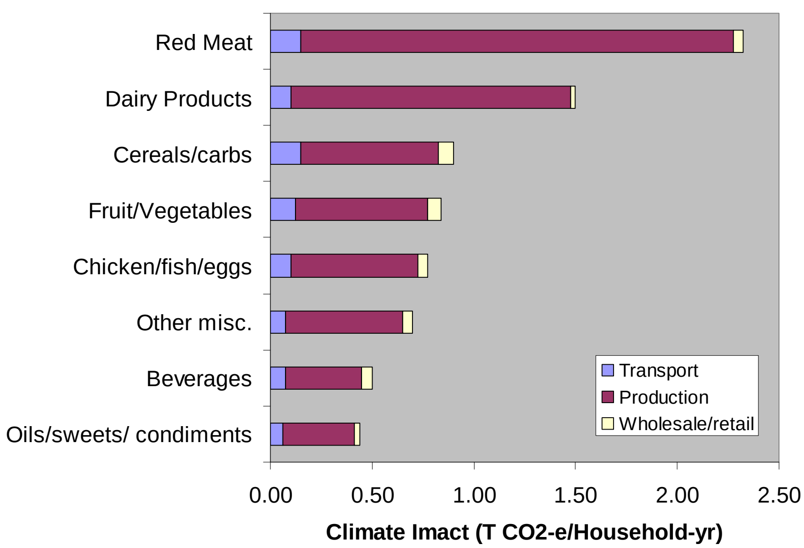


Figure 3. Estimates for the carbon dioxide equivalents (metric ton CO_2 equivalents produced per household-year) for a variety of agricultural products (Weber and Matthews 2008).

Impact of Water Shortages on Animal-Based Production

Humans use about 26% of terrestrial evapotranspiration and about 54% of available runoff (Postel et al. 1996). With increasing global population, water availability is decreasing throughout the world, and models suggest that a large portion of the world's population is currently experiencing water stress (Vörösmarty et al. 2000). In some countries, reduction of water tables is critical. For example, in Yemen, the water table is falling by roughly 2 m per year as water use far exceeds replenishment of aquifers. Iran is also facing a severe water deficit problem. Its water table is falling by 2.8 m per year. Similar situations exist in Egypt, Mexico, and the United States. In the United States, irrigation in the southern Great Plains is dependent on the Ogallala Aquifer, which is largely a fossil aquifer. Such water shortages are leading to vast areas being affected by desertification. CNN (2008) reported that desertification costs China $6.5 billion per year; Lake Chad has shrunk in size by 95% since the 1960s; in Kazakhstan, desertification has resulted in nearly 50% of cropland being abandoned since 1980; Africa may only be able to feed 25% of its population by 2025; and in Iran, fierce sandstorms are believed to have buried over 100 villages in 2002. As the population of urban centers continues to grow, water that otherwise would have been available for agricultural uses will be diverted for urban uses. In addition, agriculture is the leading source of impairments in US rivers and streams (Ribaudo and Johansson 2006) because of fertilization, pesticide use, sedimentation, and animal activity (through manure impacts on nitrogen [N], phosphorus [P], and pathogen loads). Animal-based production enterprises need to manage for water conservation and healthy vegetation.

Potential Solution for Animal-Based Production

Full integration of livestock and cropping systems may help in slowing or reversing some of the detrimental environmental and sustainability issues associated with agriculture. Traditionally, farms with livestock used animal manure in crop production and feed grains in animal production (Honeyman 1996). Integration of livestock and cropping systems had benefits of enhancing nutrient cycling efficiency, adding value to grain crops, and providing a use for forages and crop residue (Brummer 1998). Crop producers with livestock traditionally raised a greater diversity of crops in rotation (Honeyman 1996), and livestock could convert low-quality crop residues or failed crops into higher value protein (Oltjen and Beckett 1996). Despite these advantages, many farms in the Great Plains have not achieved integrated land use (Krall and Schuman 1996).

Use of forages and other crops in rotation can reduce energy-intensive inputs required by agriculture (Brummer 1996; Entz et al. 2002; Schiere et al. 2002), enhance yield of subsequent crops (Entz et al. 1995, 2002), enhance and intensify nutrient cycling (Brummer 1998; Schiere et al. 2002), and improve soil quality (Krall and Schuman 1996). Use of legumes in rotation can add significant amounts of organic N to soil (Krall and Schuman 1996; Entz et al. 2002), which can be used by subsequent crops. However, the ability of perennial forages to increase yield is dependent on precipitation, and in more semiarid areas, perennial forages may actually reduce yield of subsequent crops (Entz et al. 2002).

The future will present new challenges as well as opportunities for developing and integrating forages, crops, and livestock into production systems. With producers under increasing economic constraints, one of the major benefits of integrating forages, crops, and livestock systems would be spreading production risks over several very different enterprises, thereby taking advantage of a variety of agricultural markets (Krall and Schuman 1996; Brummer 1998). As an example, incorporation of forages into a cropping system reduced risk more than government programs (Entz et al. 2002). Under dryland conditions, integrating crop and livestock systems would appear to be both economically and ecologically sustainable (Krall and Schuman 1996).

Closing Remarks

One often overlooked aspect of sustainability is the ability of producers and land managers to adapt to change (Holling 2001; Hendrickson et al. 2008). Agricultural producers need to respond to rapid changes occurring in the agricultural environment by reducing risk, while retaining management flexibility. Holistic management and integrated agricultural systems are approaches by which whole-farm strategies and technologies are organized to help producers manage enterprises in a synergistic manner for greater profitability and natural resource stewardship. In the past, US agriculture was focused solely on its ability to produce sufficient food and fiber to meet national and global demands. Agriculture has been largely successful in meeting these production demands. While productivity will continue to be a major factor in food production systems, increased societal demands for environmentally sound management, use of agriculture for fuel production, the need for rural community viability, and a rapidly changing global marketplace are now shaping the evolution of more integrated and sustainable agricultural systems.

Environmentally sustainable agriculture emphasizes the need to mix complementary crops and animals in appropriate times and places, keeping the soil covered with growing crops and mulches, including crops and practices that maintain the productivity of the farm, and using detailed knowledge of ecological relationships to reduce the use of purchased inputs, such as pesticides and fertilizers, and to solve problems. Nutrient-use efficiency is a major concern when environmental sustainability is a goal. A range of solutions for improving nutrient-use efficiency exist and they range from simple to complex. Government policies, including subsidies, farmer/rancher innovation, research and technology, and public acceptance of farming practices all combine to create these solutions.

The question now is, “What does the future have in store for US agriculture?” The driving factors for the near future in agriculture have been put in place. The US Farm Bill has historically dictated the types of crops farmers produce and thereby drives the production practices employed. Despite changes in legislation over the past decade, the Farm Bill will probably maintain its major role to drive agricultural production. Crop insurance appears to stifle diversity, but it has been helpful to stabilize market signal demands for specific crops. Ultimately, this leads to competition between agricultural producers and other programs for federal funds. Increased competition for limited federal funds in combination with international trade issues are likely to result in changes to farm programs.

The majority of the current US population is one or more generations removed from farming. This means the public has less direct connection to issues involved in agricultural production; however, they still have a strong demand for perceived benefits from environmental stewardship. Consumers may not be well informed, but they are discerning. This will bring to the forefront such issues as product identity preservation, designer crops (i.e., biotechnological crops developed to meet specific criteria defined by the consumer), improved quality (especially in relation to health issues), organic production (reduced use of chemical pesticides and fertilizers), and further industrialization of food. These demands for environmental stewardship and food quality characteristics are likely to shape future agricultural policy and to be reflected in the marketplace.

Concurrently, producers are looking for additional economic opportunities and are becoming more market astute. This may cause a movement away from standard agricultural products to include such items as biomass for renewable energy production, long perennial phases in cropping systems, use of crop residue for animal feed, and recycling animal manure to meet N demands. This could result in an increase in multiple farm enterprises within a single farm operation, development of other forms of income-generating operations (i.e., hunting, fishing, site-seeing, etc.), and flexibility to generate an alternative array of products. Thus, changes in agriculture and public demand will benefit grazing and integrated crop-livestock operations, in addition to other aspects of sustainable agriculture, by providing an environmentally sustainable agriculture that provides multiple income streams to the producer, while providing socially acceptable land management.

References

Ash, M. 2001. Soybeans: Background and Issues for Farm Legislation. OCS-0701-01. Washington, DC: Economic Research Service, USDA.

Boehlje, M. 2008. Globalization and Agriculture: New Realities. Strategic Business Planning for Commercial Producers. http://www.agecon.purdue.edu/extension/sbpcp/ resources/ GlobalizationandAg.pdf.

Briske, D.D., J.D. Derner, J.R. Brown, S.D. Fuhlendorf, W.R. Teague, K.M. Havstad, R.L. Gillen, A.J. Ash, and W.D. Willms. 2008. Rotational grazing on rangelands: Reconciliation of perception and experimental evidence. Rangeland Ecology and Management 61:3-17.

Brummer, E.C. 1998. Diversity, stability and sustainable American agriculture. Agronomy Journal 90:1-2.

CNN (Cable News Network). 2008. http://edition.cnn.com/2008/WORLD/asiapcf/04/25/es.desertification/index.html.

Dimitri, C.A. Effland, and N. Conklin. 2005. The 20th Century Transformation of U.S. Agriculture and Farm Policy. Electronic Report from the Economic Research Service. Economic Information Bulletin Number 3.

Drabenstott, M. 1999. Consolidation in U.S. agriculture: The new rural landscape and public policy. Economic Review (First Quarter 1999):64-71.

Entz, M.H., W.J. Bullied and F. Katepa-Mupondwa. 1995. Rotational benefits of forage crops in Canadian prairie cropping systems. Journal of Production Agriculture 8:521-529.

Entz, M.H., V.S. Baron, P.M. Carr, D.W. Meyer, S.R. Smith, Jr. and W.P. McCaughey. 2002. Potential of forages to diversify cropping systems in the Northern Great Plains. Agronomy Journal 94:240-250.

Gold, M.V. 1999. Sustainable Agriculture: Definitions and Terms. Special Reference Briefs Series no. SRB 99-02. Washington, DC: National Agricultural Library.

Hanson, J.D., J.R Hendrickson, and D. Archer. 2008. Challenges for maintaining sustainable agricultural systems in the United States. Renewable Agriculture and Food Systems (in press).

Heitschmidt, R.K., R.E. Short, and E.E. Grings. 1996. Ecosystems, sustainability and animal agriculture. Journal of Animal Science 74:1395-1405.

Hendrickson, J.R., J.D. Hanson, D.L. Tanaka, and G. Sassenrath. 2008. Principles of integrated agricultural systems: Introduction to processes and definitions. Renewable Agriculture and Food Systems (in press).

Holling, C.S., 2001. Understanding the complexity of economic, ecological, and social systems. Ecosystems 4:390-405.

Honeyman, M.S. 1996. Sustainability issues of U.S. swine production. Journal of Animal Science 74:1410-1417.

Huang, J., C. Pray, and S. Rozelle. 2002. Enhancing the crops to feed the poor. Nature 418:678-684.

Ikerd, J.E. 2009. Current status and future trends in American agriculture: Farming with grass. *In* Farming with Grass: Achieving Sustainable Mixed Agricultural Landscapes, ed. A.J. Franzluebbers, 12-25. Ankeny, IA: Soil and Water Conservation Society.

Krall, J.M., and G.E. Schuman. 1996. Integrated dryland crop and livestock production systems on the Great Plains: Extent and outlook. Journal of Production Agriculture 9:187-191.

Ollinger, M., S.V. Nguyen, D. Blayney, B. Chambers, and K. Nelson. 2005. Structural Change in the Meat, Poultry, Dairy, and Grain Processing Industries. Economic Research Report 3. Washington, DC: Economic Research Service, USDA.

Oltjen, J.W., and J.L. Beckett. 1996. Role of ruminant livestock in sustainable agricultural systems. Journal of Animal Science 74:1406-1409.

Postel, S.L., G.C. Daily, and P.R. Ehrlich. 1996. Human appropriation of renewable fresh water. Science 271:785-788.

Ribaudo, M. and R. Johansson. 2006. Water Quality: Impacts of Agriculture. *In* Agricultural Resources and Environmental Indicators, 2006 edition. Washington, DC: Economic Research Service, USDA.

Savory, A. 1988. Holistic Resource Management: A Model for a Healthy Planet. Washington, DC: Island Press.

Schiere, J.B., M.N.M. Ibrahim, and H.van Keulen. 2002. The role of livestock for sustainability in mixed farming: Criteria and scenario studies under varying resource allocation. Agriculture, Ecosystems and Environment 90:139-153.

Schmer, M.R., K.P. Vogel, R.B. Mitchell, and R.K. Perrin. 2008. Net energy of cellulosic ethanol from switchgrass. Proceedings of the National Academy of Science 105:464-469.

Shiva, V. 1997. The Threat of the Globalization of Agriculture. Voluntary Services Overseas. http://www.hartford-hwp.com/archives/25a/007.htm.

Stauber, K.N., C. Hassebrook, E.A.R. Bird, G.L. Bultena, E.O. Hoiberg, H. Ma cCormick, and D. Menanteau-Horta. 1995. The promise of sustainable agriculture. *In* Planting the Future – Developing an Agriculture that Sustains the Land and Community, ed. E.A.R. Bird, G.L. Bultena, and J.C. Gardner, 3-15. Ames, IA: Iowa State University Press.

Thiermann, A.B. 2001. Sustainable Animal Production: Conference, Workshops, Discussion. 2001 Research Consortium Sustainable Animal Production. http://www.agriculture.de.

Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor, and S. Polasky. 2002. Agricultural sustainability and intensive production practices. Nature 418: 671-677

Tinsley, R.L. 2005. Reflections on sustainable agriculture. http://www.fadinap.org/Nib/Reflections.htm.

Trewavas, A. 2002. Malthus foiled again and again. Nature 418:668-670.

UCS (Union of Concerned Scientists), 2005. http://www.ucsusa.org/food_and_environment/antibiotics_and_food/terms-frequently-used-in-discussions-of-antibiotic-resistance.html.

Vörösmarty, C.J., P. Green, J. Salisbury, and R.B. Lammers. 2000. Global water resources: Vulnerability from climate change and population growth. Science 289:284-288.

Weber, C. L., and H.S. Matthews. 2008. Food-miles and the relative climate impacts of food choices in the United States. Environmental Science & Technology 42(10):3508-3513.