CHAPTER

6

Synthesis and Perspectives

C. Jerry Nelson

Author is Curators' Professor Emeritus, Plant Sciences, University of Missouri.

Correspondence: C. Jerry Nelson, 205 Curtis Hall,
University of Missouri, Columbia, MO 65211
nelsoncj@missouri.edu

"There was good science to support most purposes and criteria, especially on factors affecting production."

Synthesis and Perspectives

6

C. Jerry Nelson

INTRODUCTION

This CEAP project aimed to determine the degree that NRCS conservation programs are supported by science and to gain perspectives of the state of science for continuing to address current and emerging problems (Maresch et al., 2008). This report on four selected conservation practice standards for pasture and hayland is part of an overall effort by USDA-NRCS to evaluate a wide range of programs. Earlier CEAP efforts resulted in assessments related to fish and wildlife (Gray et al., 2005; Haufler, 2005, 2007), wetlands (DeSteven and Gramling, 2011), cropland (Schnepf and Cox, 2006, 2007), and rangeland (Briske, 2011). This report covers four major standards for pasture and hayland. Progress reports were made on the overall CEAP (Duriancik et al., 2008) and on the pasture and hayland CEAP (Sanderson et al., 2011).

Each conservation practice standard contains information on why and where the practice is applied and sets forth minimum quality criteria at the national level for implementing the practice. The national standard is more generic, yet addresses national priorities that are relevant. National purposes focus mainly on production as a primary goal while encouraging and leading the landowner to enhance conservation of resources. Each state adapts the practice standard purposes to meet local needs that can be more restrictive than national criteria, but not less. Conservation goals are likely given more emphasis at the state level since they can be more specific, but this was not reviewed.

Evaluation teams assessed a single practice standard in a professional manner. There was good science to support most purposes and criteria, especially on factors affecting production. In agreement with Tilman et al. (2002) and Maresch et al. (2008), much research is short term and not directly coupled with on-site or off-site measures of environmental and ecosystem services. This is gradually changing since the nature of environmental and ecosystem research requires several years to collect, analyze, evaluate, and publish results. Further, ecosystem-based experiments need to be comprehensive, involve diverse scientists to collect needed data, and long term to reach a reasonable level of ecosystem stability. This chapter considers collectively these and other issues arising from the assessments.

COMPARATIVE ANALYSIS OF PRACTICE STANDARDS

A matrix was developed to compare purposes of the four standards (Table 6.1). Collectively 12 purposes or major criteria could be grouped, but no standard covered all purposes. This was expected because of differences in management practices used to meet purposes and criteria, and to publication date of the standard. The teams assumed criteria would be further expanded and prioritized at the state level. Further, each national standard is revised about every 5 yr at which time purposes and criteria are updated. Therefore, some disparity may be due partially to publication times for each standard assessed (Code 590 in 2006; Code 528 in 2007; Code 511 in 2008; and Code 512 in 2009; see Appendix I). The detailed CEAP assessments should help focus future revisions.

In general, the first listed purpose for Codes 512, 528, and 511 is on production components, including maintaining plant vigor, desired species composition, and forage

Native grasses and forbs are abundant in natural grasslands of Iowa. NRCS Photo by Lynn Betts.

"It is suggested that nutrient management standard (Code 590) be divided into one for crops and one for forage and pastures."

TABLE 6.1. Comparison of key purposes among four practice standards considered in the assessments. Slight wording differences among standards were grouped for this comparison.

Purpose and/or criterion	Code 512[1]	Code 528[2]	Code 511[3]	Code 590[4]
1. Improve forage yield and quality	X	X	X	X
2. Maintain species, vigor, and regrowth	X	X	X	X
3. Provide feedstock for biofuel	X			
4. Control insects, plant diseases, and weeds	X	X	X	
5. Improve livestock nutrition and health	X	X	X	
6. Optimize nutrient management and uptake			X	X
7. Reduce soil erosion (wind and water)	X	X		X
8. Improve quality of soil and water	X	X		X
9. Improve riparian and watershed function		X		
10. Protect air quality	X			X
11. Enhance carbon sequestration	X	X		
12. Provide fish and wildlife benefits	X	X	X	

[1]Forage and Biomass Planting, [2]Prescribed Grazing, [3]Forage Harvest Management, and [4]Nutrient Management.

quality. The standard for Code 590, nutrient management, covers all crops, so purposes are not as specific for forages and pasturelands, with a focus mainly on nutrient sources, uses, and efficiency. However, criteria within the first purpose of Code 590 can be interpreted to be similar to the other three standards, such as realistic yield goals, but with emphasis on soil management rather than animal responses. Overall, most basic purposes and criteria for production were supported by the literature, at least moderately, for each standard (see Summary Tables 2.11, 3.1, 4.1, and 5.1 in their respective chapters).

SUGGESTED REVISIONS OF CODES

Code 590 was revised (NRCS, 2012) by reordering the purposes and adding emphasis in criteria for several areas of environmental concern. For example, the 2006 standard used for assessment was based on traditional soil test results that have been replaced by nutrient risk assessments for N and P based on conditions and policies adopted in each state. Minimum application setbacks have been added for sensitive areas such as sinkholes, wellheads, and ditches, and all manure applied needs to be analyzed for N, ammonia N, total P, total K, and percent solids. In addition, nutrient application rates are defined more quantitatively and use soil erosion risk assessment tools that determine potentials for nutrient and soil loss. Revised Code 590 is more focused and better able to meet national conservation objectives in specific terms, several of which were encouraged by Wood et al. (Chapter 5, this volume).

Despite the revision of Code 590, a disparity continues between acceptable nutrient management practices for perennial pastures and hayland and those for annual grain, oilseed, or fiber crops. It is suggested that nutrient management standard (Code 590) be divided into one for crops and one for forage and pastures. Major reasons include the unique roles of nutrient management of pastures such as recycling of major nutrients, in general, and lack of uniform distribution of urine and feces. More focus will allow the forage standard to address manure and nutrient management related to losses, animal health, and provision of year-round food and habitat for several wildlife species. Most pastures and hay crops are perennials, which offer different timing opportunities for manure applications and managing strategies for improving plant survival and carbon sequestration (Izaurralde et al., 2011). Also, compared with row crops and small grains, perennial forages are often grown on soil sites with lower yield potential and more potential for runoff, situations that need to be considered in the plan.

The 2010 Revised Code 512 includes "biomass" to address a contemporary issue. Codes 511 and 590 should also include biomass in the next title and purposes, and both should add more focus on riparian and watershed function. Splitting row and grain crops from Code 590 to focus on pastures and hayland will give appropriate emphasis to nutrient management for pastures, riparian buffers, grassed waterways, and other sites where perennial plants and their management goals are primary considerations. Likewise, Code 511 should have criteria for erosion control, carbon sequestration, and improvement of soil quality. Perennial forages grown for hay and silage production are renowned for their control of erosion and restoration of eroded land (Hoveland, 2000), which are not emphasized in Code 511 criteria. If not covered, these positive attributes and long-term roles should be pointed out so the topics are not considered an oversight.

COMPATIBILITY OF CRITERIA AMONG STANDARDS

Scientific evidence was compared for best practices to accomplish purposes and criteria of the selected codes. A cross-cutting evaluation shows most beneficial management practices are consistent for each of the four practice codes, yet there are some inconsistencies in management to achieve the multiple purposes.

Ground Cover Is Critical

Adequate ground cover favorably intercepts precipitation and reduces lateral flow to slow water runoff, in both cases reducing erosion. Grazing intensity, while retaining sufficient ground cover, has the major effect on economic return from pastures and is primary to grazing method. Rotational stocking usually provides faster regrowth to reestablish the canopy and more erosion protection than continuous stocking. Achieving ground cover rapidly is a major goal during establishment to allow the seeded species to compete with weeds and reduce runoff. Yield of alfalfa, but not quality, is increased by leaving short stubble, whereas most grasses and legumes benefit by leaving more stubble, from about 8 cm to 10 cm for upright-growing cool-season grasses, and much taller for upright warm-season grasses.

Early-season harvest of cool-season forage crops can destroy nests of some ground-nesting birds and maim turtles but lead to better nesting success when birds can see predators (Whittingham et al., 2006). Greater diversity in vegetation height occurred with continuous than rotational stocking, whereas mechanical harvest removed the topgrowth more uniformly to the detriment of many wildlife species. Grazing by mixed livestock species was often more economic but reduced variance in ground cover that affected both habitat and food sources for certain birds.

There was less research on effects of ground cover on other ecosystem services, but it was considered beneficial to use a companion crop during establishment, usually a small grain, to reduce environmental risk. The tall companion crop may attract wildlife, only to have some disrupted later by spring harvest for forage during a critical nesting period. Planting into living sods using no-till practices retains ground cover during establishment that reduces environmental risk, but, if not controlled, competition from the sod species increases establishment risk. Also, there may be options to time manure applications based on ground cover, perhaps even when plants are not growing rapidly. Very little research considered roles of ground cover of pasture or hayland to mitigate wind erosion and other air quality factors.

Retaining tall stubble helps reduce soil temperature and plant stress during summer, improve regrowth, conserve sequestered soil carbon during summer, and protect plants over winter. Yet details on stubble height are not well established for the multiple services now expected from pastures and haylands. This suggests an in-depth review of the multiple functions and trade-offs to determine and retain a threshold level of ground cover or basal biomass depending on goals. This should incorporate soil resources,

"details on stubble height are not well established for the multiple services now expected from pastures and haylands."

"it is anticipated that more environmental and other ecosystem services will be achieved from multispecies mixtures."

slope, and landscape position relative to sensitive areas. With pending global change and more severe storms, it behooves scientists and professionals to know the significance and thresholds for guiding more detailed criteria for management of ground cover as part of these standards.

In summary, achieving and maintaining adequate ground cover year-round is foundational for the four practices evaluated, but optimal quantity or height has not been determined for the entire range of grassland products and services. Best management practices for short-term economic return from pasture and hayland have been emphasized. Unfortunately there are few long-term data on how ground cover management affects performance or longevity of the conservation practice, something that should be addressed. In addition, education is needed on how basal ground cover is measured and managed over the long term to achieve multiple objectives of the practice.

Establish and Maintain Desired Species

Each standard addressed this issue based on minimizing encroachment of nonplanted species into monocultures such as alfalfa or maintaining desired mixtures of legumes and grasses. The exception is alfalfa, which is usually managed like a crop, for example, as a pure stand in a crop rotation for a scheduled number of years. With emerging issues about energy costs and environmental conservation there will be continued and even enhanced desire to achieve and maintain appropriate species mixtures, especially legumes, for a longer duration and in rotations (Russelle et al., 2007). But a major limitation is lack of commercial supplies of rhizobia inoculants for native and minor legume species. Private industry is a major player in providing inoculum for major species and should be encouraged to provide inoculum for more species.

Achieving and maintaining a desired species mixture requires management skills based on understanding basic growth principles of preferred plant species and how they interact with companion species. It is difficult to consistently establish desired legume-grass balances via seeding rates or time of seeding (Chapter 2, this volume), even when using seed treatments, causing need for adaptive management early, usually using defoliation and nutrient management. Further, there are few data on responses of other forbs and minor species. Information on forage values and growth habits of more forbs and grasses is needed including their roles in erosion control and wildlife benefits. Several methods are available for weed control to establish and maintain an alfalfa monoculture, including good herbicides, even glyphosate tolerance, allowing several options. In contrast, adaptive management of grass-legume mixtures depends largely on height and frequency of defoliation and on nutrient management to retain the desired mixture and competitiveness with weeds.

Insect control in alfalfa is well covered, but few research reports exist on insect control, economic thresholds for decision making, or long-term effects on other forage species. Conversely, it is recognized that insects in pasture and hayland are major parts of food chains for wildlife, and some are beneficial as pollinators for legumes and other forbs. Leaf diseases reduce forage quality, and root diseases reduce vigor and persistence; both are usually controlled by seed treatments and cultivar resistance. There are few public plant breeders to develop resistant cultivars, and, except for alfalfa, the private sector places little emphasis on cultivar development (Nelson and Burns, 2006) but does supply quality seed of major species. This leaves a gap in cultivar accessibility, a niche in which USDA-NRCS contributes and could expand its role.

In summary, as purposes shift from primarily production, it is anticipated that more environmental and other ecosystem services will be achieved from multispecies mixtures. This may include more forbs in mixtures and defined management strategies to enhance adaptation to variable soil sites and provide adequate food and protection for wildlife. Plant growth characteristics and compatibility among components in the mixtures need to be understood to provide adequate ground cover year-round. Regular monitoring to note changes and develop options to rebalance mixtures will contribute to experience-based knowledge.

Improve Livestock Nutrition and Health

For most domestic livestock species there is detailed research on basic principles of management of pastures and haylands to provide high nutritional value and improved livestock performance. Grazing method and nutrient management had less effect on forage quality than on forage production. In contrast, forage quality was affected strongly by harvest frequency and was favored by leaving tall stubble that has major effects on environmental and wildlife outcomes. Harvest and storage losses tend to reduce quality relatively more than yield. First harvest for hay or silage is most subject to rain damage and loss of forage quality with maturity. These quality factors also affect methane production by ruminants and their contribution to greenhouse gases and global change.

Livestock nutrition and health should be part of Code 590 because several animal conditions such as grass tetany, milk fever, nitrate poisoning, mineral imbalances in blood, and bloat (due to proportion of legumes) are related to nutrient management. Also, it is not known what and how nutrient management affects wildlife species. Forb species such as chicory and plantain have been bred for forage use and offer potential through their provision of minerals and trace elements to livestock. Mixed species of animals offer potentials in production and in providing ecosystem services because species, especially domestic ruminants, tend to select specific components of pastures. Effects of antibiotic and pathogen contaminants in manures on health of livestock, wildlife, and humans are poorly understood.

In summary, broad mechanisms by which protein, fiber and energy support livestock nutrition are well understood; however, other aspects, such as how differences in forage quality affect animal stress and animal health, are not fully known. Mounting public pressure for animal well-being and sustainability of ecosystems will require consideration of this issue.

Reduce Soil Erosion by Wind and Water

Codes 512, 528, and 590 consider wind and water erosion from different perspectives, yet ground cover is the primary protection. Erosion is not considered directly in Code 511, perhaps because harvested forage is grown on flatter, less erosive soils and is already known to provide protection. This is clearly documented by historical research data and assessment of the Conservation Reserve Program (Hughes et al., 1995). But competition for land is changing due to more biofuel crops (Blanco-Canqui, 2010) and high grain prices displacing pastures

> “Grazing method and nutrient management had less effect on forage quality than on forage production.”

Grassed waterway reduces erosion from cultivated field in Kansas. NRCS photo by Jeff Vanuga.

Overgrazed pastures promote soil erosion in Iowa. NRCS photo by Lynn Betts

and hayfields to lower soil quality and sloping land sites. More consideration should be given to ground cover, runoff, and wind erosion on these less-productive areas. This also applies to harvest management of riparian areas and grassed waterways.

Intuitively, risk from wind and especially water erosion is high during establishment of forage species following tillage when there is little ground cover. Although research on methods for erosion control during establishment of forages is very sparse, there is a relative abundance of data on no-till practices for establishing field crops that can be applicable to forages. In addition, some forage plants take more than one growing season to be fully established, so risk is prolonged. Risk of erosion is even higher on sloping soils with low productivity and slow establishment. Runoff from slopes closer to a water body increases the likelihood of decreased water quality. Once established, the canopy and stubble of hayfields and pastures can be very effective in reducing erosion. Grazing intensity was shown to be a major factor in maintaining adequate cover to minimize erosion risk.

In summary, water and wind erosion remain primary objectives of the agency and need proper attention. The ecosystem costs of lost soil and impaired water need to be quantified. In addition, a small loss of surface soil on lower productivity sites may have greater economic value than the same loss on productive sites. Great strides have been made in control methods including no-till seeding and controlled grazing intensity, and the agency has long experience in developing and implementing soil conservation plans.

Monitoring and cost-benefit data are needed to demonstrate the true value of each conservation practice with time being an integral component. From a public perspective, the question arises: "Is it more cost effective to install and maintain a practice that lasts 20 yr or to install two practices that each last 10 yr?" The answer may be intuitive but is more credible with data.

Improve Quality of Soil and Water

Soil quality is a comprehensive term that encompasses "fitness for use" or "capacity to function" and is recognized as an important criterion in three of the four standards. It has a series of core components that interact at relative weights to form a quantifiable number (NRCS; see http://soils.usda.gov/sqi/assessment/assessment.html) that allows comparative assessments of practices over a range of soils and landscapes. Quality is not easily defined or quantified, and so most measurements include several indicators that are blended (e.g., six in Karlen, 2006). For example, water erosion potential is affected by infiltration rate, soil depth, and physical properties, including bulk density, that indicate water-holding capacity. Infiltration rate and physical properties depend on more detailed components including organic matter.

Similarly, water quality, as mandated by the Clean Water Act, includes several components such as chemicals, microorganisms, soil particles, and general particulate materials. Currently most agricultural research is conducted on plots that represent hayfields or pastures to assess pesticide or nutrient content in runoff or infiltration to ground water. Water quality indicators in experiments reviewed by this CEAP effort included nutrient content, pathogen load, sediment load, turbidity, and responses of fish populations reflecting diversity of interests. This leaves little transferability among experiments to the broader aspects. Components of water to be measured as a quality index should be prioritized and based on intended use, for example, for drinking, health of an ecosystem, or safety for human contact.

In summary, most experiments reviewed were conducted before soil and water quality indices were developed or refined and included only one or a few measures to evaluate effects on soil quality or water quality. When a new conservation practice is designed and installed the use of water and type of quality assessment should be considered in the management plan. Soil and water quality goals for the site should be defined, appropriate indicators identified, and basic measurements selected for planning and adaptive management of the installation. Standardized sampling and analysis methods would facilitate data transfer and use for models.

Enhance Sustainability of Agriculture

The public has expanded expectations from agriculture, beyond food, to manage natural resources in a sustainable way that may differ from conservation goals. In some cases, best management practices to conserve soil or water, for example, planting a biofuel crop or installing a riparian buffer, may not be compatible with sustainability of economic production or enhancing diversity of wildlife species. Each practice in place has implied expectations that it will conserve resources for an acceptable time duration and was installed voluntarily. Yet there is growing public concern that farmer decisions depend mainly on markets, policies including incentives, and technical knowledge (Reganold et al., 2011). The goal of a conservation practice within an ecosystem concept should lead to a more sustainable condition that continues, but how will it be funded?

"Each practice in place has implied expectations that it will conserve resources for an acceptable time duration and was installed voluntarily."

Following a detailed report on alternative agriculture (Natl. Acad. Sci.-Natl. Res. Counc. 1989), sustainability of agriculture was addressed as a blend of components of economic return, environmental conservation, production efficiency, and social acceptance. Priorities among components were being questioned, and the public began demanding more output on environmental and social issues, gradually defining and adding more details for each component. For example, the American Society of Agronomy (1989) reached a consensus for the term: "A sustainable agriculture is one that, over the long term, enhances environmental quality and the resource base on which agriculture depends; provides for basic human food and fiber needs; is economically viable; and enhances the quality of life for farmers and society as a whole."

“Challenges will be to stay ahead of rapid changes in emphases associated with sustainability and/or ecosystem services.”

The basic concept of sustainability with slightly altered wording was included in the 1990 Farm Bill (US Congress, 1990). Gradually, the terms were refined and components categorized such that sustainability of agriculture was defined, in general, as *Economically Viable*, *Environmentally Sound,* and *Socially Acceptable* (Fig. 6.1). Achieving it required further compartmentalization, definition, and changes.

Subsidies have been used to encourage practices for conservation. It is known that when personal incomes increase, the public will pay more for food that is produced in ways that are presumed safe, such as organic, or result in better quality, such as taste (Fig. 6.2), that are not necessarily components of long-term sustainability (Natl. Acad. Sci.- Natl Res. Counc. 1989). At high income levels, price premiums for products produced with preservation of wildlife and aesthetics are emerging in Europe (Lemaire et al., 2005) and will become important in the USA. Some, but not all, sustainable production practices can be funded partially or wholly by value-added marketing.

In summary, current approaches have served the agency well as agriculture has developed to meet food needs while conserving soil and water resources. Now a wider range of ecosystem services is expected. Challenges will be to stay ahead of rapid changes in emphases associated with sustainability and/or ecosystem services. Labels such as “organic,” “natural,” “grass fed,” “healthy,” or “locally grown” entice consumers to pay a higher price to offset reduced yield or higher production costs. These are funded mainly by value-added marketing, do not involve subsidies for other ecosystem services, and differ from conservation practices that have high potential to contribute directly to sustainability.

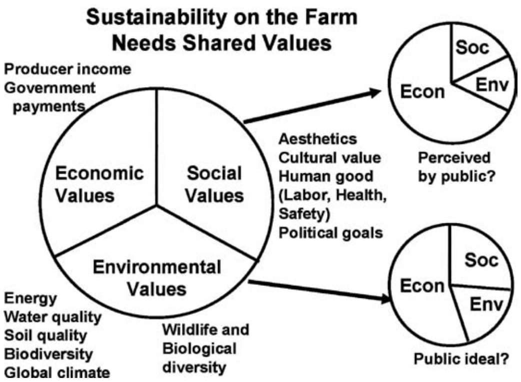

FIGURE 6.1. Sustainability has three major components, but they are arrayed in priority differently by different groups. Social and behavioral scientists are needed to accurately determine the perceptions and value judgments of what sustainability should look like for the general public. Divisions are conceptual because there are no good data for comparison. Adapted from Nelson (2007).

Use of Modeling

Each assessment suggested that comprehensive models are invaluable for handling large databases needed for effective planning and documentation of multiple functions from pastures and harvested forages. Modeling can utilize data from existing research, suggest areas for more research, point out areas where adoption of practices may be conflicting with desired outcomes, and incorporate quantifiable ecosystem services and values when that information is known (Carpenter et al., 2009). Information from models will assist in planning conservation practices and determining variables to monitor while the practice is operational. Models could also guide, but probably not direct, adaptive management toward cost-effective ways to restore or maintain the practice (Tonitto et al., 2010).

Need for modeling was also highlighted in the Cropland CEAP (Lowrance et al., 2006) and the Rangeland CEAP (Bestelmeyer et al., 2011) with similar issues, yet different approaches based on current efforts and needed results. The Pastureland CEAP suggests a hybridized approach, first, similar to the Rangeland CEAP, to understand mechanisms and interactions of management with purposes for perennials in pastures and haylands at a local level, and, second, similar to the Cropland CEAP, to understand contributions of services when scaled to the landscape level that contains fields of annual crops and other vegetation. The amount of modeling research at the local and landscape levels is more advanced for range and crops than for pastures and hayland. It appears some plant models for rangeland at the local level could be adapted and tested for perennial forage plants. Similarly, landscape models for crops could be supplemented with data and models for woodland (Heard et al., 2000) and expanded for inclusion of pastures and haylands. Maps and management units are already defined. Adaptation areas for many forage crops are described (Hannaway et al., 2006).

Some models have been developed to understand roles of pastures and forage crops at the farm level such as DAFOSYM (Rotz et al., 1989) and its major submodels and improvements. Russelle et al. (2007) pointed the direction toward models at larger scales. However, most research evaluated by the CEAP teams was short term and covered some on-site environmental responses, but usually no off-farm responses to the management practices were evaluated. Yet, as public expectations change and solidify, there will be greater need for quantitative data at different levels to capture contributions or impacts of various local management practices beyond the field or farm level. The shear magnitude of data needed to understand main treatments and interactions requires modern computers and sophisticated models that are becoming available.

In summary, pastures and haylands in the eastern USA are usually associated with annual cropland and/or woodland. Many factors are involved in comprehensive analyses and outcomes are not always consistent across locations for each practice. Models will help understand interactions and give guidance to optimum solutions. Cost-benefit analyses from models will help prioritize programs and generate public support.

VALUES OF EDUCATION AND MONITORING

Developing and implementing a practice at a given site requires fundamental knowledge supplemented by experience of personnel involved. Local data and agent experience about soil types, topography, species adaptation, and responses to management assist in fine-tuning the practice and predicting outcomes. Interviews of 26 ranchers from a single watershed demonstrated valuable experiences complimented scientific knowledge for site-specific decisions on management and

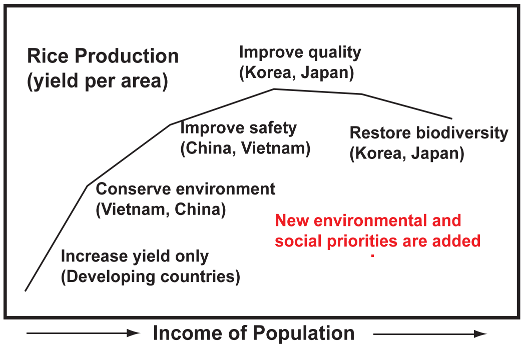

FIGURE 6.2. Relationship between income and rice yield. Country names indicate where on the relationship they fit. Yield increases are lower than potential due to trade-off to provide other desired benefits; for example, rice quality is reduced by high N rates and use of cultivars selected for high yield. Comparable data are not available for pasture and haylands, but the general effect of income on consumer preferences of products is likely similar. Developed by C. Jerry Nelson from several sources including Tilman et al. (2002) and Fischer and Edmeades (2010).

ecological responses (Knapp and Fernandez-Gimenez, 2009). Regular monitoring of practices to note their condition and function adds experience that will be increased further by recommending adaptive management and documenting and evaluating the responses. Outcomes will optimize effectiveness and longevity of the practice.

Currently there is minimal monitoring to determine if the ecosystem goal has been met in terms of its function and longevity. Further, there is no assessment of the long-term costs if the needed conservation practice is not implemented. Evaluation and assessment data are critical in an overall evaluation in terms of what the landowner and the public expects. Periodic monitoring of ecosystem benefits will aid the agency by adding experience, understanding the value of adaptive management, identifying research needs, and determining the collective value of practice lifespan.

In summary, experience is a valuable asset and is needed in local decision making. Monitoring and adaptive management based on combinations of research data and agent experience will help fulfill the

"Models will help understand interactions and give guidance to optimum solutions."

Discussion about pasture management for rotational stocking. NRCS photo

conservation goals, extend the life of the practice, help maintain credibility, and improve cost effectiveness to demonstrate fiscal responsibility.

POINTING OUT RESEARCH DEFICIENCIES

A major contribution from each assessment team was recognition of critical scientific data required to make quality decisions on planning and implementation of conservation practices, transfer information, and make comparative analyses among experiments. Usually the main focus of research could be augmented by a few basic measures to address multiple objectives and interactions. Critical reviews on basic experimental measures for nonproduction outcomes are needed to identify key data for improving quality and utility of research. A similar recommendation for standardizing measurements arose regarding fish and wildlife benefits from the Wildlife Habitat Incentives Program (WHIP) (Gray et al., 2005). Needs appear to be greatest for measuring management effects associated with nutrient sources, air quality, global change, measures of plant and wildlife diversity, and basic protocols for monitoring practices.

More research needs to be long term, probably for more than 10 yr. For example, in a crop rotation study on soil quality in Iowa the experiment included rotations of forage and grain crops that extended over 20 yr (Karlen and others, 2006). In a study at three Australian sites (annual rainfall of 554 mm, evenly distributed) accumulation of soil carbon under pastures was not linear; after an initial decrease and lag periods of up to 7 yr, organic carbon increased linearly but had not reached equilibrium in 13 yr (Chan et al., 2011). Nearly all carbon accumulated in the upper 15 cm, with most treatment variation occurring in the upper 5 cm, making sampling depth a major consideration.

A few comprehensive, detailed, and long-term experiments are needed at strategic locations in the USA to form a national framework that incorporates crops and woodland/forest into the farm and landscape effort. The recent development of a Long-Term Agroecosystem Research Network (LTAR) by the USDA-ARS is a step in this direction (Walbridge and Shafer, 2011; http://www.ars.usda.gov/research/Docs.htm?docid=22480). The purpose of the network is to address questions related to the condition, trends, and sustainability of agricultural systems and resources on large scales of space and time.

There are continuous changes in science at the national and international levels as new analytical procedures and management technologies become available while major external issues emerge to affect agriculture and public priorities. With modern means of communication and social media the public and agricultural community will redefine priorities continuously and rapidly, often before sufficient research has been conducted to evaluate the responses and interactions. Without research as a guide, the time disconnect will require compromises and decisions by professionals designing conservation practices based mainly on intuition from component studies and early personal experiences that can be questioned.

In summary, research funding and management need to be long term and place more emphasis on broad aspects of pasture and hayland research. Both public and private funding will be needed. International connections will assist with methodologies and data acquisition but require refinement for use in specific and variable sites. Strong partnerships among state universities and federal agencies will add comprehensiveness and help justify long-term investments. Understanding the methods and translating interdisciplinary research into useful education programs will be essential.

FUTURE PARAMETERS FOR CONSERVATION PRACTICES

There are a myriad of emerging issues that will need attention of NRCS and the new generation of Conservation Practice Standards. Some are already well developed. Most require the agriculture community to be involved with a broad range of disciplines and new partners. Each has its own timeline, level of public support, relative importance, and uniqueness that will require it be dealt with in its own way. International relations on trade (for example, mad cow disease or hay marketing), role of genetically modified plants, and residue effects from pharmaceuticals, probiotics, and *E. coli* could be on an exhaustive list.

Integrate Sustainability and Resilience. Sustainability has been an issue for a long time beginning with public interest in low-input sustainable agriculture (LISA), but the scientific community believed low input meant "organic," which was too restrictive, and argued that agriculture could be sustainable with high inputs. There was some thought about "multifunctional," a term used in Europe and Asia, but functions were broad in scope and not clearly defined. Finally, the US agricultural community agreed on *sustainable agriculture,* which included three general components: (1) economically viable, (2) environmentally sound, and (3) socially acceptable (Fig. 6.1). The definition was used mainly for land resources and applied primarily at the farm level, although many thought it should be landscape or watershed based (Gold, 1999, revised 2007).

Economic production could be evaluated, but mechanisms for measuring and valuing the other two components are not clear. Public perception is farmers place greatest emphasis on economic production with little consideration of environmental and social effects during long-range planning and daily decision making (Fig. 6.1). As society develops and personal income increases there is public demand for more and better contributors to sustainability and the human condition (Nelson, 2007). Similar to developing countries, the primary focus of low-income consumers is on increased supply of affordable food (Fig 6.2). As incomes rise, more emphasis is placed on environmental issues, which often results in reduced rate of yield increase. As incomes continue to increase, the public demands food safety, followed by food quality and finally by increased biodiversity of plants and animals. Each service reduces the rate of production gain due to "fitness penalties" and altered management that is needed to achieve goals.

"As society develops and personal income increases there is public demand for more and better contributors to sustainability and the human condition"

In the USA and other developed countries, current public pressure is on food safety, such as the *E. coli* challenges, and food quality, which is associated with freshness and taste. Emphasis is on eating *healthy,* which includes purchase of locally grown food that is fresh and often organic. Following the lead of Europe and developed countries in Asia, more emphasis on wildlife and other forms of biodiversity are expected to be provided by agriculture. High-income consumers will pay more for organic food that is pesticide free and assumed to be healthy. The trend for healthy food has been accompanied by dietary shift to more vegetables and fruits as well as fewer red meats

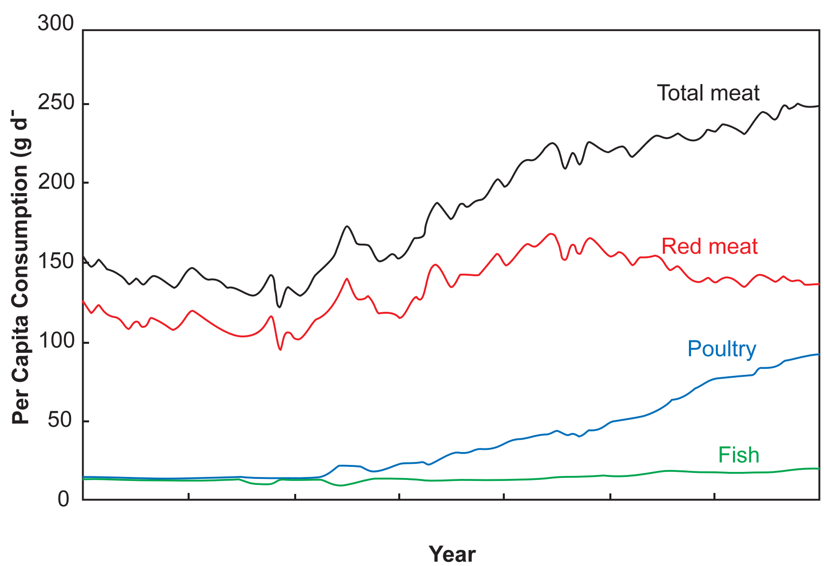

FIGURE 6.3. Consumption of meat and meat products is increasing, but that of red meat is decreasing. Reasons include health consciousness and relative cost. Data are from USDA-ERS and Daniel et al. (2011).

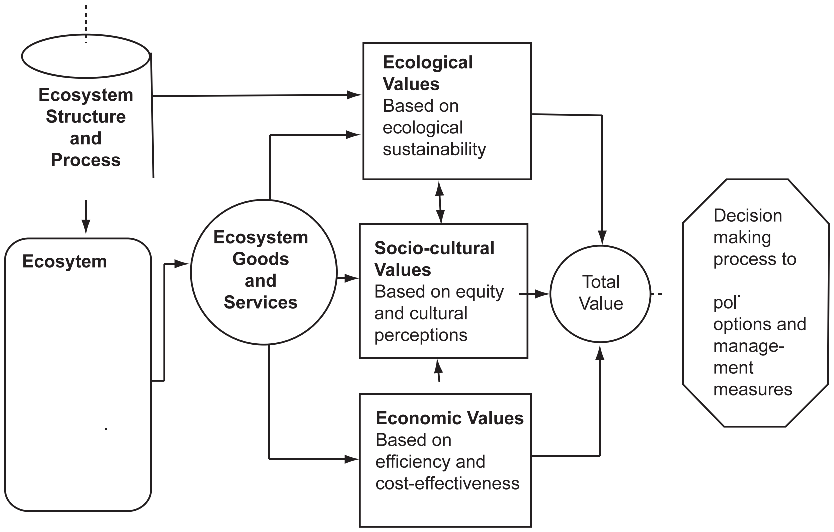

FIGURE 6.4. Proposed flow chart of management decisions (right) and the resulting changes in ecosystem function and resulting ecosystem goods and services as they relate to sustainability. Adapted from de Groot et al. (2002).

and other foods that have high fat content (Fig. 6.3). Meat consumption per capita in the USA continues to gradually increase, mainly due to preferences for poultry, while beef consumption is decreasing (Daniel et al., 2011), which has effects on pasture and hayland. Pork consumption has remained relatively steady.

Current emphasis is now adding *resilience*, the ability to produce consistently every year (Allen and Brown, 2006; Hoffmaister, 2009; Woolley and Douthwaite, 2011). This is partially in response to more variable weather events associated with global climate change and to international and national priorities on food security, especially stable grain prices. Cultivars and crop management systems will need to *consistently* provide the quantity and quality of food in a sustainable manner along with increased efforts to increase provision of other goods and services. Potential drastic events involve weather variables, disease, or insect outbreaks against vulnerable cultivars, and even calamities such as wars and terrorism (Rosa et al., 2012). These drastic changes are often abrupt and localized.

In summary, it will be difficult for new cultivars to maintain consistent yields while overcoming the fitness penalty needed for resilience to stresses. Using defensive measures in crop management to gain resilience will likely result in short-term yield reduction as more conservative practices are used. To date, there has been little research on how increasing resilience of agriculture will fit into the larger picture of environmental stewardship in a socially acceptable way. Regardless, the older, three-component model for sustainability is being replaced by an emerging concept that requires high output of sustainable production with resilience while providing even more environmental and social services.

Technologies to Address Ecosystem Services. Based on needs for addressing ecological and social issues the concept of *ecosystem services* emerged as an ecological approach to describe desired outputs from natural ecosystems. Several attempts to relate sustainability and ecosystem services were attempted. For example, one detailed conceptual framework and typology proposed 24 specific functions that could be allocated among four services to describe, classify, and value ecosystem goods and services that link with sustainability (Fig. 6.4). Later these approaches were coalesced by the Millennium Ecosystem Assessment project (Carpenter et al., 2009) into a set of four major outputs or services from natural (production remaining on-site) or managed (production moving off-site) ecosystems. These include the following:

- Supporting services (including primary production, nutrient cycling, and soil formation)
- Provisioning services (including food, fresh water, wood, fiber, and fuel)
- Regulating services (including regulation of climate, quantity and quality of water, and diseases)
- Cultural services (including aesthetics, spiritual issues, education and recreation).

Supporting and regulating services are considered fundamental for natural processes and set parameters for human intervention effects on provisional and cultural services. Production factors of agriculture are located mainly in provisioning services. The shift in classification from three services for sustainable agriculture to four ecosystem services makes it more difficult for the agriculturalist to assign priorities and use the correct measures. It would be impossible to measure all services in one experiment, so researchers need to identify key indicators for each component. This is similar in concept to measures of soil quality or water quality and will eventually lead to models that are capable of integrating many variables.

In summary, public agencies such as NRCS should evaluate and consider conservation standards that incorporate sustainability, resilience, and delivery of ecosystem services. Alternatively the decision may be to remain within the realms of conservation and make connections and cooperation with agencies that focus on other services. Regardless, the issue should be addressed and be reflected in the next generation of conservation standards.

Determining Values of Ecosystem Services. Economic returns for forages or pastures depend on input costs and output values in monetary terms, but currently there is no good way to value issues such as water, air or soil quality, an aesthetic view or improved wildlife biodiversity. Early attempts to evaluate cost benefits for forage management practices have used market pricing (e.g., Caddel et al., 1995) or nonmarket estimates to evaluate program outcomes (e.g., Hughes et al., 1995, for CRP). But these methods are not comprehensive over all services. For example, it is known that delay of first harvest of hay and silage crops will improve nesting success (Chapter 4, this volume). Can this be interpreted to mean that the calculated dollar loss in quality and yield of forage can be assumed to be the true value of the wildlife conserved?

Ecological economists are developing methods to evaluate ecosystem services for decision making. One or more evaluation methods may be needed to gain information that is compatible for comparisons and models, each depending on inputs from a comprehensive database (Villa et al., 2002). Current databases are inadequate except for a few locations, one being the San Pedro Riparian National Conservation Area in California. Based on that comprehensive database for a small natural stream, scientists modeled changes in vegetation, water flow, and bird abundance after grazing was stopped (Brookshire et al., 2010). They are now determining economic values for services based on *choice modeling,* i.e., preferences based on public surveys, and *contingent evaluation*, i.e., public preferences based on statements of willingness and amounts they would pay for each service.

Values of ecosystem services at the national level have been considered "well-being" of the populace and could be "measured" from the gross domestic product (GDP); that is, as the GDP increases it is assumed well-being also increases. To evaluate this aspect relative to a range of sites, including the Chesapeake Bay, the Genuine Progress Indicator (GPI) or a derivative called the Index of Sustainable Economic Welfare was based on multiple indicators including parts of the GDP that directly measure benefits to people. The index then corrects the number by adding or subtracting economic, environmental, and social factors, all expressed in monetary values (McGuire et al., 2012). The indices have been tested in more than 20 countries and document that GDP is not a good measure of improved welfare or values of ecosystem services. This is consistent with Fig. 6.2, which shows factors are prioritized and respond independently.

In summary, there are many ways to participate in the emerging "biodiversity science" (Larigauderie and Mooney, 2010). The NRCS could contribute to integration of conservation practices as a positive human intervention that adds valued ecosystem services. The long-term support for biodiversity science will also compete with other agencies for public funding, especially for long-term programs of environmental or social value. Models based on interagency cooperation may be the desirable outcome.

Climate Change. The gradual increases in atmospheric concentrations of CO_2 and methane are predicted to increase average air temperature, lengthen the growing season, accelerate phenological development, lead to variable precipitation and more violent storms, and increase pest problems (Izaurralde et al., 2011). Higher CO_2 concentration will increase photosynthesis and growth of most C_3 species to partially offset the reduction due to higher temperatures. Pastures and haylands will be expected to contribute to mitigation by using less fossil fuel in producing and using these resources. Minimum tillage for establishment,

> "Ecological economists are developing methods to evaluate ecosystem services for decision making."

"water is rapidly becoming a scarce natural resource and will demand more efficient use from agriculture."

legumes in rotations for nitrogen fixation, and grazing to harvest the forage, perhaps even to time of animal harvest, will help. Manure management on pastures will be a priority for efficient use, and good nutrition of ruminants will be emphasized to reduce methane production.

These practices will save fuel costs, help sequester and retain carbon in the soil, and reduce labor costs. Adding forages as winter cover in crop rotations will reduce soil loss, improve water quality, and provide wildlife habitat. Most of these technologies have had partial research to form the foundation. Biotic and abiotic stresses on plants will increase because temperatures are expected to be higher (Howden et al., 2007). Higher temperatures may increase virulence of pathogens and activity of insect pests that reduce production and quality of pasture and hayland species. Activity of pollinators may be decreased to alter seed costs and food supplies for wildlife. In addition, increased year-to-year variability will require emphasis on resilience as well as sustainability as conditions change. If change is relatively slow, plant and animal communities can adjust naturally. In summary, there are many unknowns regarding the magnitude and effects of climate change.

Water Quality and Water Supplies. Agriculture accounts for nearly 80% of the total water use in the USA and is being strongly encouraged to reduce amounts and increase use efficiency (Howden et al., 2007; Maresch et al., 2008). Growth of cities and communities will increase demand for high-quality, dependable supplies that are free of sediment, pharmaceuticals, microorganisms, and other contaminants, many of which come from agriculture. Simultaneously, predicted climate change will place even more pressure on soil conservation, general water supplies, water quality, and the public quest to reduce flooding and restore wetlands. Water use will be an issue as the Ogallala aquifer and other sources are reduced, leading to reversion of some land to grasslands for animal or biofuel production.

The roles and management of forages in waterways, riparian areas, and other sensitive landscape positions will increase, as will watershed "cooperatives" that allow rural and urban citizens to address water quality and other problems at landscape levels instead of the field or farm level.

Restoring forages and pastures into rotations and cropping systems may best mitigate these changes (Russelle et al., 2007; Izaurralde et al., 2011). Regardless of the degree of climate change, the nation must be prepared with technology and be flexible in its use to effectively manage available water resources.

In summary, water is rapidly becoming a scarce natural resource and will demand more efficient use from agriculture. Solutions will likely depend on public support, use of community-based efforts, and integration of several disciplines for research and education while strengthening the interface with decision makers. This should be assisted by better use of weather forecasting and models to reduce risk.

Energy Issues and Biofuels. There is strong national interest to develop biofuels and mitigate global climate change without competing for use of food and feed crops such as corn or soybean (Sanderson and Adler, 2008). Perennial grasses are potential sources for direct combustion or biological conversion of cellulose for useful forms. Less fossil fuel energy is needed to maintain perennial crops, making them more efficient based on input/output energy balances. In addition, they conserve soil year round, improve soil hydraulic properties, and can sequester large amounts of CO_2 equivalents into soil organic matter (Blanco-Canqui, 2010). Wildlife benefits depend on when the crop is harvested mechanically and may be best when harvesting leaves a mosaic of harvested and nonharvested patches (Fargione et al., 2009).

Bulky energy crops will be grown near conversion facilities to conserve transport energy, but it is unclear in what locations these crops will have a comparative advantage. Some biofuel grasses take 2 yr or more to become established, so they do not fit short-term rotations. Basic principles for growth and composition of energy crops are often similar to forage grasses, so there will be reciprocal benefits from biofuel research to forage-livestock situations. Fields used for biofuel crops may be very suitable and/or preferred sites for manure applications. Significant land use change due to converting grasslands to bioenergy production to meet national biofuels targets and favorable economics may pressure land used currently for hay, silage, and pasture.

In summary, need for mechanical harvest of biofuel crops favors their use on flatter soil sites, further forcing forage and pastureland production onto more marginal lands. At the time of this writing, however, crop commodity prices are also high, causing further economic pressure to convert pasture and haylands to annual crop production.

Changing Food Consumption Patterns. Obesity of US citizens is increasing, especially for children and youth, leading to policies and expanded educational attempts to mitigate this trend. Fruits and vegetables, low-fat meats and milk, and substitutes for some dairy products are being encouraged. There is movement toward more "natural" and organically produced food, including meat and milk, which rely heavily on forage and pasture use. In addition, growing demand for locally produced foods for freshness and quality will require more forage and pastureland to provide diversity of animal products from farms that market directly to urban populations.

Consumption of beef and milk, which depend largely on pastures, hay, and silage, is decreasing. Conversely, grass-finished beef is considered to be healthier, and demand for "healthy beef" may require extended time on pasture and stored forage before animals are harvested or supplemented with grains. Additional time on pasture will affect manure management and reduce odors often associated with confined livestock. Grass-fed beef and pasture-based milk production will likely continue to grow in demand based on animal rights, healthiness, and being more natural. Thus, reduced consumption of beef and milk may actually be associated with an increase in area used for pasture and hayland.

CONCLUSIONS

The USDA-NRCS is entering a new era with CEAP, a rich and unparalleled assessment of the science foundation for its products and services that offers credibility for the present and insight for the future. The new paradigm indicates that the science base for implementing practices is only part of the long term because the audience and public expectations for what agriculture can and should provide have expanded and continue to expand. To date, research has usually focused on managing to optimize economic return to the landowner with some measurements of environmental, social, or other ecosystem factors. Very rarely have there been attempts to perform economic analyses of the responses; in fact, it is very difficult to

Monitoring water quality in a tributary stream in Iowa. NRCS photo by Lynn Betts

“The collective worth of an installed practice will be well beyond the subsidy the landowner receives.”

determine the value, intrinsic or actual, of nearly all environmental or ecosystem services. This is complicated further by mounting public pressures for provision of even more ecosystem services from agriculture.

Procedures are needed for monitoring implemented practices and providing effective educational programs about key outcomes expected and how to utilize adaptive management. Educational and planning efforts at the local level involving communities, and individuals could set realistic goals and estimate values for the blend of ecosystem services expected at a larger scale. These values will likely differ from location to location. Then goals of each landowner can be quantifiably used to estimate that contribution to the whole.

The collective worth of an installed practice will be well beyond the subsidy the landowner receives, and the return value of services needs to be communicated to policy makers and the public. This new agenda will require interdisciplinary research and education efforts by teams, including soil scientists, agronomists, animal scientists, ecologists, economists, and sociologists.

Throughout, the CEAP project has been working on a moving target. The CEAP effort is based on assessment of previous research for support of the current practice standards. Fortunately the review teams were charged to consider broader aspects, recognizing the change in public expectations will be critical for the next generation of practices. The futuristic approach also is helpful in planning to meet shortfalls in the amount, style, and comprehensiveness of research. Clearly a major issue is “how does the agricultural community move forward at an accelerated pace to meet the changing expectations in a credible manner?”

In summary, most purposes and criteria are supported by published research, but the level of support differs among criteria. In several cases there is insufficient research to be fully confident of support. In others, research is sound and supportive but limited in geographic area, so transferability to other environments and landscapes is limited. Clearly the landowner goals and compliance will be key to continued use of volunteer programs, yet desires of the public and credibility of programs need to be considered in how landowners manage the practice for effectiveness and longevity. Above all, the agency and the scientific community need to anticipate new challenges and be prepared to address emerging issues in a manner that is science based and socially acceptable. Public confidence that the system is functioning to conserve resources and provide diverse services in a credible way must always remain a primary goal.

Literature Cited

Allen, V.G., and C.P. Brown. 2006. Using grazing animals to restore resilience in our agricultural systems. *In* Proc. John M. Airy Symp. Visions for animal agriculture and the environment, Kansas City, MO. Available at http://www.agron.iastate.edu/courses/agron515/grazingresilience.pdf (verified 20 Jan. 2012).

American Society of Agronomy. 1989. Decision reached on sustainable ag. *Agron. News,* Jan., p. 15. ASA, Madison, WI.

Bestelmeyer, B.T., J.R. Brown, S.D. Fuhlendorf, G.E. Fults, et al. 2011. A landscape approach to rangeland conservation practices. p. 337–370. In D.D. Briske (ed.) Conservation benefits of rangeland practices: Assessment, recommendations, and knowledge gaps. Allen Press, Lawrence, KS.

Blanco-Canqui, H. 2010. Energy crops and their implications on soil and environment. *Agron. J.* 102:403–419.

Briske, D.D. (ed.) 2011. Conservation benefits of rangeland practices: Assessment, recommendations, and knowledge gaps. Allen Press, Lawrence, KS.

Brookshire, D.S., D. Goodrich, M.D. Dixon, L.A. Brand, et al. 2010. Ecosystem services and reallocation choices: A framework for preserving semi-arid regions in the Southwest. *J. Contemp. Water Res. Educ.* 144:1–14.

Caddel, J., J. Stritzke, P. Mulder, R. Huhnke, et al. 1995. Alfalfa harvest management: Discussions with cost-benefit analysis. Oklahoma Coop. Ext. Center Circ. E-943.

Carpenter, S.R., H.A. Mooney. J. Agard, D. Capistrano, et al. 2009. Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proc. Natl. Acad. Sci.* 106:1305–1312.

Chan, K.Y., M.K. Conyers, G.D. Li, K.R. Helyar, et al. 2011. Soil carbon dynamics under different cropping and pasture management in temperate Australia: Results of three long-term experiments. *Soil Res.* 49:320–328.

Daniel C.R., A.J. Cross, C. Koebnick, and R. Sinha. 2011. Trends in meat consumption in the USA. *Public Health Nutr.* 14:575–583.

de Groot, R.S., M.A. Wilson, and R.M.J. Boumans. 2002. A typology for the classification, description and valuation of ecosystem functions, good and services. *Ecol. Econ.* 41:393–408.

DeSteven, D., and J.M. Gramling. 2011. Assessing wetland restoration practices on southern agricultural lands: The Wetlands Reserve Program in the Southeastern Coastal Plain. Available at http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046724.pdf (verified 20 Mar. 2012).

Duriancik, L., D. Bucks, J.P. Dobrowolski, T. Drewes, et al. 2008. The first five years of the Conservation Effects Assessment Project. *J. Soil Water Conserv.* 63:185A–197A.

Fargione, J.E., T.R. Cooper, D.J. Flaspohler, J. Hill, et al. 2009. Bioenergy and wildlife: Threats and opportunities for grassland conservation. *BioScience* 59:767–777.

Fischer, R.A., and G.O. Edmeades. 2010. Breeding and cereal yield progress. *Crop Sci.* 50:S85–S98.

Gold, M.V. 1999; revised 2007. Sustainable agriculture: Definitions and terms. USDA-Natl. Agric. Lib. Spec. Ref. Briefs (Call no. aS21. D27S64 no. 99-02). Available at http://www.nal.usda.gov/afsic/pubs/terms/srb9902.shtml#toc2 (verified 13 Mar. 2012).

Gray, R.L., S.J. Benjamin, and C.A. Bacon. 2005. Fish and wildlife benefits of the wildlife habitat incentives program. Wildlife Society, Washington, DC. Available at http://digitalcommons.unl.edu/usdafsfacpub/98 (verified 21 Jan. 2012).

Hannaway, D.D., C. Daly, L. Coop, D. Chapman, et al. 2006. GIS-based forage species adaptation mapping. p. 305–329. *In* S.J. Reynolds and J. Frame (ed.) Grasslands: Developments, opportunities, perspectives. FAO, Rome. Available at http://www.hechoenperu.org.pe/fao/docs/Biodiversity/hannaway.pdf (verified 21 Jan. 2012).

Haufler, J.B. (ed.) 2005. Fish and wildlife benefits of Farm Bill conservation programs: 2000–2005 update. Tech. Rev. 05-2. Wildlife Society, Bethesda, MD.

Haufler, J.B. (ed.) 2007. Fish and wildlife response to Farm Bill conservation practices. Tech. Rev. 07-1. Wildlife Society, Bethesda, MD.

Heard, L.P., A.W. Allen, L.B. Best, S.J. Brady, et al. 2000. A comprehensive review of Farm Bill contributions to wildlife conservation: 1985–2000. *In* W.L. Hohman and D.J Halloum (ed.) USDA, NRCS, Wildl. Habitat Manage. Inst., Tech. Rep., USDA/NRCS/WHMI-2000.

Hoffmaister, J. 2009. Resilience: More than a trendy word. Third World resurgence No. 223 (March 2009). Available at http://www.twnside.org.sg./title2/susagri/susagri081.htm (verified 21 Jan. 2012).

Hoveland, C.S. 2000. Achievements in management and utilization of southern grasslands. *J. Range Manage.* 53:17–22.

Howden, S.M., J.-F. Soussana, F.N. Tubiello, N. Chhetri, et al. 2007. Adapting agriculture to climatic change. *PNAS* 104:19691–19696.

Hughes, J.S., D.L. Hoag, and T.E. Nipp. 1995. The conservation reserve: A survey of research and interest groups. Counc. Agric. Sci. Tech. Spec. Publ. 19. Ames, IA.

Izaurralde, R.C., A.M. Thompson, J.A. Morgan, P.A. Fay, et al. 2011. Climate impacts on agriculture: Implications for forage and rangeland production. *Agron. J.* 103:371–381.

Karlen, D.L., E.G. Hurley, S.S Andrews, C.A. Cambardella, et al. 2006. Crop rotation effects on soil quality at three northern corn/soybean belt locations. *Agron. J.* 98:484–495.

Knapp, C.N., and M.E. Fernandez-Gimenez. 2009. Knowledge in practice: Documenting rancher local knowledge in Northwest Colorado. *Rangel. Ecol. Manage.* 62:500–509.

Larigauderie, A., and H.A. Mooney. 2010. The international year of biodiversity: An opportunity to strengthen the science-policy interface for biodiversity and ecosystem services. *In* A. Larigauderie and H.A. Mooney (ed.) Terrestrial ecosystems. *Current Opinion Environ. Sustain.* 2:1–2.

Lemaire, G., R. Wilkins, and J. Hodgson. 2005. Challenges for grassland science: Managing research priorities. *Agric. Ecosyst. Environ.* 108:99–108.

Lowrance, R., T.M. Isenhart, W.J. Grured, F.D. Shields, Jr., et al. 2006. Landscape management practices. p. 269–317. *In* M. Schnepf and C. Cox (ed.) Environmental benefits of conservation on croplands: The status of our knowledge. Soil Water Conservation Society, Ankeny, IA.

Maresch, W., M.R. Walbridge, and D. Kugler. 2008. Enhancing conservation on agriculture landscapes: A new direction for the Conservation Effects Assessment Project. *J. Soil Water Conserv.* 63(6):198A–203A.

McGuire, S., S. Posner, and H. Haake. 2012. Measuring prosperity: Maryland's Genuine Progress Indicator. *Solutions* 3(2):50–58.

Natl. Acad. Sci.-Natl. Res. Counc. 1989. Alternative agriculture. National Academy Press, Washington, DC.

Nelson, C.J. 2007. Sustainability of agriculture: Issues, observations and outlook. p. 1–24. *In* M.S. Kang (ed.) Agricultural and environmental sustainability: Considerations for the future. Hayworth Press, New York.

Nelson, C.J., and J.C. Burns. 2006. Fifty years of grassland science leading to change. *Crop Sci.* 46:2204–2217.

NRCS. 2012. Nutrient management: Natural Resources Conservation Service conservation practice standard code 590. Available at http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/landuse/crops/npm/?&cid=nrcs143_026849 (verified 9 March 2012).

Reganold, J.P., D. Jackson-Smith, S.S. Batie, R.R. Harwood, et al. 2011. Transforming U.S. agriculture. *Science* 332:670–671.

Rosa, E.A., T. Dietz, R.H. Moss, S. Altran, and S. Moser. 2012. Managing the risks of climate change and terrorism. *Solutions* 3(2):59–65.

Rotz, C.A., J.R. Black, D.R. Mertens, and D.R. Buckmaster. 1989. DAFOSYM: A model of the dairy forage system. *J. Prod. Agric.* 2:83–91.

Russelle, M.P., M.H. Entz, and A.J. Franzluebbers. 2007. Reconsidering integrated crop-livestock systems in North America. *Agron. J.* 99:325–334.

Sanderson, M.A., and P.R. Adler. 2008. Perennial forages as second generation bioenergy crops. *Int. J. Mol. Sci.* 9:768–788.

Sanderson, M.A., A. Franzluebbers, S. Goslee, J. Kinary, et al. 2011. Pastureland conservation effects assessment project: Status and expected outcomes. *J. Soil Water Conserv. Soc.* 66:148A–153A.

Schnepf, M., and C. Cox (ed.) 2006. Environmental benefits of conservation on croplands: The status of our knowledge. Soil Water Conservation Society, Ankeny, IA.

Schnepf, M., and C. Cox (ed.) 2007. Managing agricultural landscapes for environmental quality: Strengthening the science base. Soil Water Conservation Society, Ankeny, IA.

Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor, et al. 2002. Agricultural sustainability and intensive production practices. *Nature* 418:671–677.

Tonitto, C., C. Li, R. Seidel, and L. Drinkwater. 2010. Application of the DNDC model to the Rodale Institute farming systems trial: Challenges for the validation of drainage and nitrate leaching in agroecosystem models. *Nutr. Cycl. Agroecosyst.* 87:483–494.

US Congress. 1990. Food, agriculture, conservation, and trade act of 1990. Public law 101-624. Title XVI, Subtitle A, Section 1603. U.S. Government, Washington, DC.

Villa, F., M. Wilson, R.S. de Groot, S. Farber, et al. 2002. Designing an integrated knowledge base to support ecosystem services valuation. *Ecol. Econ.* 41:445–456.

Walbridge, M.R., and S.R. Shafer. 2011. A Long-Term Agro-Ecosystem Research (LTAR) network for agriculture. Fourth Interagency Conference on Research in the Watersheds, 26–30 September 2011, Fairbanks, AK.

Whittingham, M.J., C.L. Devereux, A.D. Evans, and R.B. Bradbury. 2006. Altering perceived predation risk and food availability: Management prescriptions to benefit farmland birds on stubble fields. *J. Appl. Ecol.* 43:640–650.

Woolley, J., and B. Douthwaite. 2011. Improving the resilience of agricultural systems through research partnership: A review of evidence from CPWF projects. CPWF Impact Assessment Series 10. CGIAR Challenge Program for Water and Food, Colombo, Sri Lanka.