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FEATURE

Crop residue is a key for sustaining maximum food production and for conservation of our biosphere

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The Soil and Water Conservation Society (SWCS) has an extensive and productive history as a professional society, serving the science of soil and water conservation since 1944 and providing a forum where the current knowledge and latest advances in conservation can be discussed and ideas can be exchanged (SWCS 2010; Knipling 2007; Lancaster 2007; Delgado et al. 2002; Mausbach and Dedrick 2004; Knight 2005). The SWCS is a society with thousands of members from a variety of professions and academic fields who work to conserve our natural and agricultural resources (SWCS 2010). This society is constantly striving to provide a forum where conservation practitioners, scientists, and the general public can get together and present the most recent topics in conservation (SWCS 2010).

I have had the privilege of being a member of SWCS for many years. This year, I was selected by the Soil and Water Conservation Society as the recipient of the 2010 Hugh Hammond Bennett Award and was invited to give a speech at the 2010 Award Ceremony of the Soil and Water Conservation Society and to write a manuscript. This article is based on the speech delivered at that ceremony. It is an honor to receive an award like this from a society that has had such an impact, one that does so much to facilitate the transfer of conservation knowledge and that is full of members who work so hard for conservation. This honor has given me the opportunity to reflect on Bennett's contributions to conservation, as well as the challenges and opportunities we face today.

Hugh Hammond Bennett has been called the father of soil conservation. He was a national and international leader who contributed to the preservation and conservation of our natural resources. Details about his life and some of his most important quotes can be found on the USDA Natural Resources Conservation Service Web site (http://www.nrcs.usda.gov/about/history/quotes.html). After reading some of these quotes, I can more deeply appreciate how Bennett was ahead of his time. One of Bennett's famous quotes was, "From every conceivable angle—economic, social, cultural, public health, national defense—conservation of natural resources is an objective on which all should agree" (USDA NRCS 2010a). I think this quote eloquently captures the significance of what those of us working in different fields of conservation strive to do.

Bennett contributed not only thoughtful insights, but also significant changes to the field of conservation. Helms (2009, 2010) recently published a couple of articles in the *Journal of Soil and Water Conservation* about Hugh Hammond Bennett's contributions, and you can read more about Bennett and his long-lasting impacts in these articles. It is clear from these articles that Bennett was a leader and a hero for the conservation movement who contributed to the sustainability of our nation and set up the basis for our conservation systems. For example, Bennett was the first Chief of the USDA Soil Conservation Service (today called the USDA Natural Resources Conservation Service) (Helms 2009, 2010). He was a leader in convincing US leaders and the country that erosion was a severe problem that, if remained unaddressed, would negatively affect all aspects of our society (Helms 2009, 2010). His leadership and vision also contributed to science-based demonstration projects showing practices that can help to reduce erosion (Helms 2009, 2010). Given these contributions, perhaps we can all agree with a modification of the above Bennett's quote and rearrange it to say that the system that Bennett helped to develop for our nation (USDA NRCS 2010b), a system of organized science-based conservation efforts, has contributed to "every conceivable angle" of our nation: "economic, social, cultural, public health, and national defense."

These days, we face both similar and different challenges than conservationists of Bennett's times faced. We live in interesting times where our challenges in soil and water conservation can provide new opportunities for implementation and transfer of science-based conservation practices that will ensure the sustainability of our resources. Never in the history of humankind has there been so much pressure put on the biosphere to provide food, shelter, fuel, and other necessities to society on such a scale. Issues such as global warming and climate change, population growth and food security concerns, depletion of water resources and threats to water quality, soil erosion and other soil quality issues, and the need for new sources of energy, together with new technologies such as Geographic Information Systems (GIS), Global Positioning Systems (GPS), remote sensing, and advanced computer models that are being used more and more for conservation, create new challenges and opportunities for SWCS members (Lal 2004; Kümmerer et al. 2010; Berry et al. 2003, 2005). This is a great time to be an agronomist, this is a great a time to be a soil scientist, and this is a great time to be a conservation practitioner and to be at the center of professional societies where issues and new ideas in science-based conservation are presented and discussed.

Bennett was clearly a man ahead of his time who foresaw the need for new science-based efforts and organizations to develop and transfer conservation practices and who was a key figure in soil and water conservation at a time when the field faced great challenges such as the Dust Bowl (Helms 2009, 2010). In addressing the challenges of those times, new opportunities in conservation were established (Helms 2009, 2010). Similarly, the issues we face in conservation today encourage us to come up with new technologies and ideas to address them. As the popular expression often goes, "challenges present new oppor-

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tunities." Agricultural systems are dynamic and resilient, but as we look forward, there will be an increased need and pressure to maximize agricultural production per unit of land and to sustain high production levels into the future (Lal 1995, 2000; Berry et al. 2003, 2005; Kümmerer et al. 2010). There are new technologies, new research fields, and new concepts in conservation (e.g., precision conservation, a.k.a. target conservation; carbon (C) sequestration and trading; nitrogen (N) trading tools; ecosystem services; adaptive management). Use of satellites, computers, and models will contribute to improvements in conservation effectiveness across the land (Berry et al. 2003, 2005; Walter et al. 2007; Delgado and Berry 2008; Tomer 2010; McKinney 2010; Saleh 2010; Saleh et al. 2010). Water and air quality trading programs may also provide new opportunities for science-based conservation (Lal et al. 2009; USEPA 2007; Miami Conservation District 2008; USDA 2007; Delgado et al. 2008, 2010a). Yet, there are still many scientific questions that need to be answered; these questions will bring opportunities to learn how we can assess conservation effectiveness, as was expressed by Knipling (2007), Lancaster (2007), Mausbach and Dedrick (2004), and Richardson et al. (2008).

New tools and approaches that integrate GIS, GPS, remote sensing, and advanced computer models could contribute to assessments that evaluate the effectiveness of viable conservation practices (Berry et al 2003, 2005; Delgado and Berry 2008; Tomer 2010; Walter et al. 2007). For example, these new tools could help us determine the potential for carbon sequestration and/or reduction of reactive nitrogen losses at a given site when a conservation practice is adapted (Delgado et al. 2008, 2010a; McKinney 2010; Saleh 2010; Saleh et al. 2010). It can therefore be proposed that as these new science-based approaches and concepts are developed and improved into the future, they will contribute to future changes in the management of unknown factors, and that we may move from a nonpoint source management approach to a targeted/precision conservation approach. When paired with adaptive management, a targeted/precision approach to conservation may make it possible to adjust management decisions and thus contribute to further improvements in conservation effectiveness while maximizing yields (Blackmer 2009; Moore 2009).

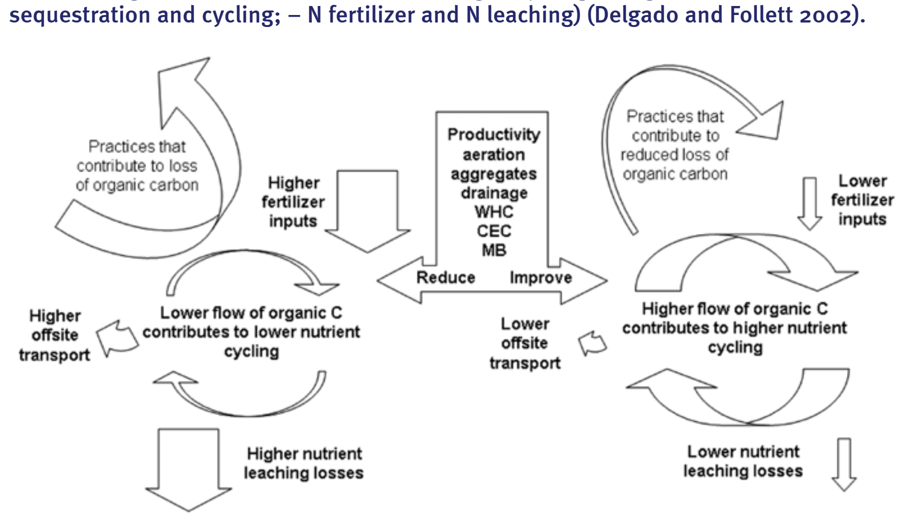
Among the new technologies and other advances in conservation are some important findings on crop residue. Crop residue is a key building block for agricultural sustainability. A lot has been said about crop residue, and readers may wish to review Lal (1995, 2000), Delgado and Follett (2002), Cruse and Herndl (2009), Karlen et al. (2009), and Newman et al. (2010) and visit Web sites such as http://www.knowledgebank.irri.org/ckb/index.php/agronomy/crop-residue-management for more information on this important topic. This paper provides a quick overview of some selected references and looks at some of the newest advances related to cover crops.

Doran and Jones (1996) described in detail the benefits derived from improving soil quality with good management practices that increase carbon sequestration, and crop residue is at the center of improving and/or sustaining this desirable soil quality. Management of crop residue can contribute to increased nutrient cycling and greater crop yields (Al Sheik et al. 2005; Delgado et al. 2007; Cruse and Herndl 2009). Management of crop residue also has an important role in reducing soil erosion and maintaining yields (Cruse and Herndl 2009; Lal 1995, 2000). By selecting a crop rotation and/or management practices such as minimum tillage to reduce soil disturbance and/or increase the amount of residue returned to the soil, we can minimize erosion and increase soil organic carbon and nitrogen in the system (Havlin et al. 1990; Christenson 1997; Hussain et al. 1999; Black and Tanaka 1997; Lal 2000; AL Sheik et al. 2005).

Delgado and Follett (2002) reported that carbon management should be part of nutrient management plans and that systems that increase cycling of carbon (sequestering carbon and nitrogen) while reducing nitrogen inputs contribute to greater nutrient cycling and reduced losses of nitrogen to the environment (figure 1). Crop residue offers significant benefits for agricultural systems, and the removal of crop residue from an agricultural system will increase the potential for increased soil erosion and/or negative effects on environmental quality (Karlen et al. 2009; Newman et al. 2009; Johnson et al. 2010; Lal 2004; Cruse and Herndl 2009). Several scientists have suggested that before crop reside is removed, it is important to identify how much residue can be harvested from the land before any adverse effects are caused (Karlen, et al. 2009; Newman et al. 2010; Johnson et al. 2010; Lal 2004; Cruse and Herndl 2009). Recently, precision harvest

Figure 1

Potential organic carbon contribution to nitrogen cycling (+ organic C and N sequestration and cycling; – N fertilizer and N leaching) (Delgado and Follett 2002).



of crop residue across the field accounting for the spatial potential for erosion and carbon sequestration has also been recommended as a method for managing crop residue to increase conservation effectiveness with spatial variability (Delgado and Berry 2008; Cruse and Herndl 2009).

Nitrogen is the major nutrient used in agricultural systems worldwide, and it contributes greatly to the economic viability and sustainability of cropping systems. By contributing to higher yields, nitrogen also contributes to food security and global sustainability and stability. There is no question that nitrogen is the most important nutrient used in agriculture and that it is an essential fertilizer for worldwide food production. We need nitrogen to continue producing food and to ensure future food security. However, there is also the need to increase nitrogen use efficiencies; doing so will reduce the potential for nitrogen losses to the environment. For example, Randall et al. (2008) showed that nitrogen losses average at about 34% across 22 studies over several regions that used isotopic ^{15}N. These nitrogen losses may potentially increase the off-site transport of N and contribute to billions of dollars lost globally each year (Baligar et al. 2001; Delgado 2002). They may also impact groundwaters and surface waters (Follett and Hatfield 2001; Follett and Delgado 2002).

While it is difficult to assess the effects of management practices on nitrogen losses quantitatively, we can use isotopic ^{15}N techniques to trace the fate of nitrogen and accurately measure the magnitude of its losses to the environment (Delgado 2002). There is potential to develop best management practices that would reduce atmospheric greenhouse gas concentrations through management of agricultural emissions, carbon sequestration, and use of crop residue N inputs. Crop residue is important for nutrient cycling, and the potential to cycle macronutrients and micronutrients varies with residue type (Delgado and Follett 2002). Delgado et al. (2010b) reported results from unique crop residue exchange studies with ^{15}N that show that N losses from the inorganic fertilizer inputs were significantly higher than the N losses from the crop residue inputs—31% for inorganic fertilizer compared to 13% for crop residue inputs. The greater N retention in the soil with crop residue inputs (73%) than in the soil with fertilizer N (26%) suggests that the slower cycling pool of crop residue protects against nitrogen losses.

The Delgado et al. (2010b) paper supports an earlier proposal by Delgado and Follett (2002) that increasing soil organic matter and nitrogen cycling will contribute to lower nitrogen inputs and lower nitrogen losses to the environment. Vigil et al. (2002) reported that an average of 49 kg N ha^{-1} (44 lb N ac^{-1}) are mineralized with every one percent of organic matter. If we increase the soil organic matter, we are increasing the potential for nitrogen cycling, enabling lower nitrogen inputs to be used and decreasing nitrogen losses (Delgado and Follett 2002).

Delgado et al. (2010b), based on findings from using ^{15}N isotopes and modeling, respectfully recommended that the Intergovernmental Panel on Climate Change (IPCC) methodology that assigned the nitrous oxide (N_2O) emissions and nitrate leaching coefficients from crop residues be reevaluated and be adjusted to coefficients that are in closer agreement with these findings. The current IPCC methodology assumes that 1% of fertilizer N, crop residue N, manure N, and mineralization N added to cropland is emitted to the atmosphere as direct emissions of N_2O and that 30% are lost as nitrate nitrogen (NO_3-N) leaching and/or surface runoff to streams and waters. The IPCC methodology assigned an N_2O–N emissions coefficient of 0.75% to the nitrogen that is lost to the water bodies via leaching and/or surface runoff pathway. This methodology has the potential to affect domestic and international policies because it is used to report the N_2O emissions from agricultural systems to the United Nations Framework Convention on Climate Change (UNFCC). The Delgado et al. (2010b) ^{15}N data and modeling simulations suggest that the methodologies with respect to crop residues (especially high C/N residues) are not correct and are overestimating the N_2O emissions contributed by crop residues. The Delgado et al. (2010b) data suggest that the IPCC crop residue N_2O–N emissions coefficients of one percent and thirty percent for NO_3-N leaching and/or surface runoff should be lowered to represent the lower losses from crop residues, especially if the residues have a higher C/N ratio. The results and recommendations by Delgado et al. (2010b) are in agreement with studies from other scientists that suggest that N_2O emissions from crop residues are lower than the one percent reported by IPCC (Malhi and Lemke 2007; Toma and Hatano 2007; Jantalia et al. 2008).

Greenhouse gas emissions from agriculture have been documented as being among the anthropogenic factors driving climate change (USEPA 2002; Del Grosso and Walsh 2008; USEPA 2008). It has been reported in peer-reviewed journals that climate change could potentially affect weather patterns, and changes in these patterns could affect agricultural production, soil erosion, and soil and water conservation (Nearing et al. 2004; Hatfield and Prueger 2004).

Delgado et al. (2010b) showed that nitrogen cycling (e.g., cover crops) can ensure a significant and viable contribution of N from crop residue, and the N losses to the environment from soils with cover crops are much lower than losses from soil with inorganic nitrogen fertilizer. The Delgado et al. (2010b) study, which integrates the use of isotopic chemistry and modeling, shows that N management based on crop residue has the potential to improve agricultural management systems and increase nitrogen use efficiencies, reduce N losses to the environment, and reduce N_2O emissions and nitrate leaching. This is especially the case if we reduce the N applications to account for higher nitrogen cycling. Crop residue management can thus be a practice that helps to mitigate climate change.

Eroded soils have lower yield potentials (Lal 1995, 2000; Cruse and Herndl 2009). Thus, crop residue, by virtue of its contribution to lowering of soil erosion, also indirectly contributes to the sustainability of higher yield (figures 2 and 3). In other words, crop residues are contributing to more sustainable increases in food production per unit of area. Therefore, just as Lal (2004) reported, crop residue is not simply a waste left over from harvest. Kümmerer et

Figure 2

Field studies with cover crops at farmers fields.

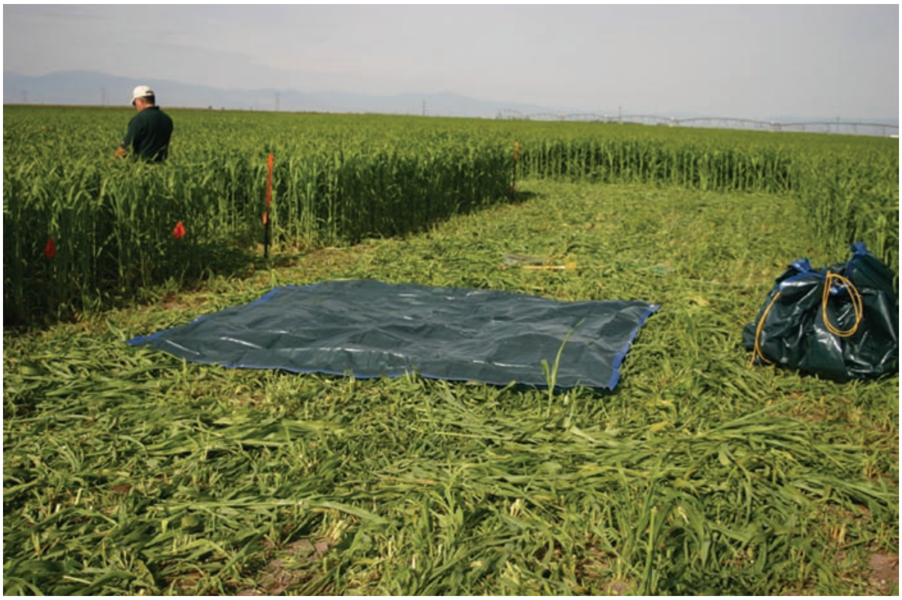


Figure 3

Cover crop studies show higher tuber yield and quality than fallow systems.

al. (2010) discusses the importance of soils and sustainability for humankind, and soil carbon is at the center of it. Crop residue is an important block in the foundation for building a sustainable system that supports and benefits the human population. Crop residue (e.g., cover crops) is food for soil microorganisms, and indirectly crop residue is also important for sustainable food production for humankind.

Crop residue has a critical role in sustainability, maximized food production, and, more generally, environmental conservation. With this in mind, I would like to conclude with another respectful modification of the Hugh Hammond Bennett quote that began this article. If we slightly reword his quote, I think it can be fairly said that, "From every conceivable angle—economic, social, cultural, public health, national defense—we should all agree that crop residue is key for sustaining maximum food production and for conservation of our biosphere."

As I mentioned at the beginning of this paper, this is a great time to be a soil scientist, this is a great time to be an agronomist, and this is a great time to work in soil and water conservation. The challenges that the world is going to have in the next five decades are going to be new, and the societies of the world will need the best science to continue improving management practices and agricultural production across key world agroecosystems. The challenges in these areas, such as global climate change, weather variability, and the interaction of these factors with energy (e.g., energy cost, energy sources), soil management, crop production, and water use for an ever-growing world population, will create new opportunities for science and research to help us achieve higher yields and sustainability.

Professional societies, peer-reviewed journals, workshops, and national and international meetings and conferences are excellent ways to maximize these opportunities and help bring scientists, conservation practitioners, farmers, ranchers, and the general public together to exchange ideas and technologies, as well as discuss different methodologies. They are also great platforms for discussing areas of common agreement or areas where there are disagreements, and they provide a safe place where all points of view can be represented. This scientific collaboration contributes to the advancement of soil science and to soil and water conservation.

It is clear that we need to make a commitment to maintaining and improving conservation practices and working towards the sustainability of our biosphere. We as soil scientists, agronomists, and conservationists are going to be in the middle of these important activities in the decades to come, and crop residue should be considered an essential component of nutrient management plans and our efforts to move towards sustainable agricultural systems. A part of this nutrient management, if crop residue is going to be harvested, should include an analysis of how much residue can be harvested from the land before any negative effects result (Karlen et al. 2009; Newman et al. 2010; Johnson et al. 2010; Lal 2004; Cruse and Herndl 2009). Including this analysis for such cases, and, more generally, recognizing the role of crop residue in conservation, is one way to help us move in the right direction towards both sustainability and productivity goals.

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