doi:10.2489/jswc.66.6.167A

RESEARCH INTRODUCTION

Recent advances in precision (target) conservation

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Achieving food security and sustainability in the 21st century is expected to become increasingly challenging due to greater soil degradation resulting from climate change, population growth, and depletion of water resources (Delgado et al. 2011). New scientific research is critical for developing innovative soil and water conservation practices and programs that will maintain or even increase agricultural productivity. This special issue about recent advances in landscape-targeting precision conservation presents studies that investigate the impacts of precision conservation management on agricultural systems and the environment.

Technological advances in computer hardware and software, engineering, communications, and other fields have allowed crop and soil management to be integrated with geographic information systems (GIS), global positioning systems (GPS), computer modeling, and remote sensing, allowing better management. The last decade has seen the integration of these tools into precision conservation systems (Berry et al. 2003, 2005; Delgado and Berry 2008; Tomer 2010; Walter et al. 2007). Precision conservation (also called target conservation) has the potential not only to increase the sustainability of agricultural systems, but also to aid in mitigating and adapting to climate change and optimizing biofuel systems to minimize their environmental impacts (Delgado et al. 2011).

SPECIAL ISSUE PAPERS

While high-tech precision conservation may be prohibitively expensive in some developing areas, low-tech approaches can be used very effectively (Berry et al. 2003, 2005). This is important because conservation agriculture (e.g., conservation tillage, residue management to maintain soil cover, use of diverse cropping systems, and/or cover crops) is known to be critical to food security, particularly in Africa (FAO 2009; Silici 2010; Thiombiano and Meshack 2009). In this special issue, Jenrich (2011) described how precision conservation techniques could be used by farmers using low-tech approaches in Sub-Saharan Africa to improve yields and incomes without further degradation of their lands.

In a Canadian study, Lobb (2011) examined how management contributes to variable soil erosion and reduces yield. Specifically, the study examined areas where soil was moved from higher to lower landscape positions after a few decades of cultivation. Lobb (2011) reported that there is potential for precision conservation to restore soil productivity in these situations. In fact, soils can be managed to mechanically transport the eroded soil back to the areas that were severely eroded, thus reclaiming the crop productivity that was lost (see figure 1 in Lobb 2011).

In the Pacific Northeast, Williams et al. (2011) reported that precision technologies for contour planting could improve the efficiency of water capture and reduce runoff in a hilly landscape. They used digital elevation data and terrain analysis to develop precise contour planting maps for managing winter wheat. Digital elevation data enabled the development of precisely aligned deep furrows located along the contour and at strategically located positions of the fields to help capture runoff and minimize erosion. The elevation data were also used to help track the movement of the agricultural equipment.

Modeling advances are also helping us understand variable hydrology across hill slopes, improve the accuracy of model evaluations of the effects of landscape variability, and minimize environmental impacts from nonpoint sources (Sen et al. 2011). Sen et al. (2011) improved evaluation of pasture management under a hill slope in northern Alabama using a Hortonian Infiltration and Runoff model. Sen et al. (2011) reported that although hydrological models such as SWAT, PRMS, and SWIM can be used to evaluate water quality, they do not account for the complex spatial variability of hydrological processes, and they can be improved by adding routines that can evaluate the management effects of this hydrological spatial variability across the hill slopes.

Remote sensing tools such as digital aerial imagery and Light Detection and Ranging (LIDAR) can enhance precision conservation efforts by allowing better assessment, management, and targeting of precision agricultural practices across watersheds. For example, Kyveryga et al. (2011) demonstrated that aerial imagery could be used to assess the effects of nitrogen management practices across large corn fields in Iowa to help farmers implement adaptive management. Earlier, Bausch and Delgado (2003) and Delgado and Bausch (2005) demonstrated that with remote sensing and using precision conservation techniques nitrogen applications can be cut back by close to 50% in sprinkler-irrigated systems of northeastern Colorado, increasing nitrogen use efficiency and significantly reducing nitrate leaching losses without reducing yields. By integrating remote sensing with precision conservation tools, the effectiveness of conservation practices can be improved and the impact of agriculture on the environment can be reduced. Management zones can also be integrated when applying precision conservation techniques to increase nitrogen use efficiency and reduce nitrate leaching losses without decreasing yields, as shown by earlier work from Khosla et al. (2002, 2008), Delgado et al. (2005), and Inman et al. (2007, 2008).

Galzki et al. (2011) found that LIDAR provides very precise terrain attributes that can be used to identify environmentally sensitive areas for targeted conservation practices (e.g., grassed waterways, buffer strips, and/or the retirement of land from cultivation or application of conservation tillage). This could effectively increase

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conservation effectiveness across an entire watershed and reduce the erosion losses from sensitive areas (Galzki et al. 2011). Previous work shows that we can also use logistic regression models incorporating precise elevation data to identify the best location across the landscape to apply conservation practices such as grass waterways and thus increase conservation effectiveness (Mueller et al. 2005; Pike et al. 2009; Luck et al. 2010).

Advances in modeling allow site-specific conservation practices to be tracked in order to evaluate off-site nutrient transport (Saleh et al. 2011). Delgado et al. (2008, 2010) proposed a Nitrogen Trading Tool for assessing the effects of management practices on reducing nitrogen losses to the environment, which can help provide an opportunity to farmers to sell these savings in nitrogen losses as ecosystem services. Saleh et al. (2011) expanded the Nitrogen Trading Tool concept to also evaluate how management practices can reduce erosion and phosphorus losses. Their Nutrient Tracking Tool follows the losses of nutrients and aids assessment of how precision conservation practices can be applied to reduce these losses and potentially sell the savings as ecosystem services (e.g., water and air quality trading markets).

McConnell and Burger (2011) reported on a geospatial decision support system that can be a valuable precision conservation tool for identifying environmental and economic benefits from management and targeted conservation practices. The tool can help determine economic benefits from strategically targeted conservation practices (e.g., use of conservation buffers, conversion of sensitive agricultural lands to natural vegetation) and assess the agricultural and environmental tradeoffs. McConnell and Burger (2011) reported that we can use precision conservation to implement better spatial management, contributing to the maximization of economic and environmental returns. Dosskey et al. (2011) also reported on advances in computer modeling that can contribute to better assessment of hydrological variability (infiltration–excess runoff), which can help us improve the targeting of sensitive locations within a watershed with buffers.

Delgado et al. (2011) reported that effective application of conservation practices and/or programs will increase the chances of achieving and/or maintaining food security. They reported that without efforts in soil and water conservation programs to mitigate and adapt to climate change, food security will be harder to achieve. They listed a series of conservation principles that need to be applied, including the following principles related to surface crop residue: surface residue protects, soil function improves with soil carbon, and surface needs to be covered. These three principles are directly related to the management of surface crop residue and its relationship with erosion and soil organic matter, which are both related to soil quality and productivity. Johnson et al. (2007, 2010) reported that, in order to ensure that soil quality is maintained, crop residue should not be removed from agricultural systems for bioenergy unless soil protection goals are achieved. Delgado and Berry (2008) and Cruse and Herndl (2009) proposed precision harvesting to reduce erosion potential and maintain soil quality. If residue is not removed from areas that are sensitive to erosion and/or negative impacts on soil organic matter, and is only removed from those areas where there will not be a significant effect on erosion and soil quality, conservation effectiveness could be increased.

This special issue presents advances in how to use tools for site-specific crop residue management. Thomas et al. (2011) conducted precision conservation studies that evaluated the effects of corn residue removal at different rates (38%, 52.5%, and 70%) on different soils and tillage management on erosion rates. They used the GLEAMS-NAPRA model to conduct their assessment across corn fields of Indiana. They found that even with no-till practices, removing crop residue will increase erosion rates compared to no residue removal. Thomas et al. (2011) reported that it is important to continuously assess the effects of residue management across different soil types, slopes, and management to help promote sustainability. They concluded that future studies are necessary to assess the effects of biofuel production systems on water quality (e.g., erosion, surface transport, nitrate leaching).

Meki et al. (2011) also conducted simulation studies to evaluate the effects of corn residue removal on environmental impacts. They used the APEX model to assess the effects of corn residue removal across 3,703 farm fields from the Upper Mississippi River Basin. Similar to findings by Thomas et al. (2011), they found that the effects of corn stover removal are site specific and vary with soils and management practices. Their simulation evaluation showed that the sandier soils are the most susceptible to crop residue removal, contributing to lower soil productivity and lower yields. They also found that for some soils and site-specific factors, removal of crop residue will significantly lower soil organic matter and that residues should not be harvested from those areas.

Their analysis, however, predicted that using "acceptable planning criteria," there is potential to harvest residue while taking site-specific information into account to minimize impacts. They concluded that by using computer models, management practices, land type, and other site-specific factors of the landscape can be evaluated in such a way that there is potential to identify sites where the harvesting of crop residue will have minimal environmental impacts. Work from Meki et al. (2011) suggests that site-specific evaluations could be used to implement precision conservation practices by identifying areas where the harvesting of crop residue will have minimal impacts on erosion and soil organic matter content. Whatever management decisions are made, recent research suggests that leaving crop residue in place yields many benefits for conservation of our biosphere and/or for climate change mitigation and adaptation (Delgado 2010; Delgado et al. 2011; Lal et al. 2011). If residue is going to be harvested, the results of these new precision conservation evaluations suggest that models could be used to conduct independent evaluations that could help in planning criteria for identifying those areas where harvesting of residue, together with site-specific management (e.g., no-till), will have minimal impacts on the environment (Thomas et al. 2011; Meki et al. 2011).

CONCLUSION

Research conducted during the last five to ten years is helping us better understand some of the processes that are contributing to spatial and temporal variability of erosion and soil productivity and how to use field and off-site practices for precision conservation of agricultural and natural areas. These advances are accelerating the development of new tools that integrate concepts from engineering, chemistry, physics, and remote sensing. These new tools are becoming more user friendly and are using GIS and GPS platforms to help us make better management decisions that target management practices at the most sensitive areas of a watershed and/or at a given site-specific field. These new tools are helping us connect and integrate management of agricultural and natural areas (e.g., fields, buffers, native grasses, trees, wetlands). These new tools are facilitating a more precise identification of the landscape locations where grass waterways, buffers, filter strips, and water collection furrows, for example, should be applied. The significance is that we can now use models that integrate more complex layers of information, such as variable hydrology, variable soil properties, and more accurate topographies, to help us identify, calibrate, and validate flows and surface terrain, thus increasing the efficiency conservation practices by identifying better locations to apply them.

This special issue shows that we can now more precisely apply planting furrows at contour to minimize erosion. We can now develop precise digital elevation maps that, together with modern GPS techniques and agricultural machines, could find the locations where the conservation practices were implemented year after year. Precision conservation and computer models are helping us integrate multiple layers of information across this variability to assess how site-specific conservation practices could potentially reduce the off-site transport of nutrients to water treatment plants. The cost of removing nitrate from sources of drinking water in the United States is estimated to be US$4.8 billion per year, and it is estimated that it costs US$1.7 billion to remove the nitrate coming from agriculture alone (Ribaudo et al. 2011). There are now tools capable of assessing the benefits of precision conservation practices across watersheds. For example, these tools can provide information for ecosystem trading markets about how the implementation of site-specific conservation practices can reduce the losses of nitrogen from agricultural systems. There is potential for farmers to implement conservation practices and sell the savings in nitrogen losses as ecosystem services in water and air quality trading markets.

This special issue has several papers that report on the advancement of modeling to assess variable hydrology and even assess how to potentially manage crop residue removal to minimize environmental impacts. There have also been advances in applying precision conservation agriculture across the Sub-Saharan region of Africa using low-tech approaches, increasing conservation and even productivity. Additionally, precision conservation research from Canada shows that if we understand the factors that contribute to spatial variability of erosion and how it reduces yields, we can use precision conservation practices to reclaim some of the soil productivity lost due to erosion. These papers clearly show that we can target conservation across watersheds to increase efficiency in managing natural and agricultural areas. Precision conservation will be a key tool in helping us achieve food security in the 21st century.

REFERENCES

Bausch, W.C., and J.A. Delgado. 2003. Ground-based sensing of plant nitrogen status in irrigated corn to improve nitrogen management. *In* Digital imaging and spectral techniques: Applications to precision agriculture and crop physiology, eds. T. VanToai, D. Major, M. McDonald, J. Schepers, and L. Tarpley, 151-163. Agronomy Society of America Special Publication No. 66. Madison, WI: Agronomy Society of America, Crop Science Society of America, Soil Science Society of America.

Berry, J.K., J.A. Delgado, R. Khosla, and F.J. Pierce. 2003. Precision conservation for environmental sustainability. Journal of Soil and Water Conservation 58(6):332-339.

Berry, J.K., J.A. Delgado, F.J. Pierce, and R. Khosla. 2005. Applying spatial analysis for precision conservation across the landscape. Journal of Soil and Water Conservation 60(6):363-370.

Cruse, R.M., and C.G. Herndl. 2009. Balancing corn stover harvest for biofuels with soil and water conservation. Journal of Soil and Water Conservation 64(4):286-291.

Delgado, J.A. 2010. Crop residue is a key for sustaining maximum food production and for conservation of our biosphere. Journal of Soil and Water Conservation 65(5):111A-116A.

Delgado, J.A., and W.C. Bausch. 2005. Potential use of precision conservation techniques to reduce nitrate leaching in irrigated crops. Journal of Soil and Water Conservation 60(6):379-387.

Delgado, J.A., and J.K. Berry. 2008. Advances in precision conservation. Advances in Agronomy 98:1-44.

Delgado, J.A., P.M. Groffman, M.A. Nearing, T. Goddard, D. Reicosky, R. Lal, N.R. Kitchen, C.W. Rice, D. Towery, and P. Salon. 2011. Conservation practices to mitigate and adapt to climate change. Journal of Soil and Water Conservation 66(4):118A-129A.

Delgado, J.A., C.M. Gross, H. Lal, H. Cover, P. Gagliardi, S.P. McKinney, E. Hesketh, and M.J. Shaffer. 2010. A new GIS nitrogen trading tool concept for conservation and reduction of reactive nitrogen losses to the environment. Advances in Agronomy 105:117-171.

Delgado, J.A., R. Khosla, W.C. Bausch, D.G. Westfall, and D. Inman. 2005. Nitrogen fertilizer management based on site-specific management zones reduces potential for NO3-N leaching. Journal of Soil and Water Conservation 60(6):402-410.

Delgado, J.A., M.J. Shaffer, H. Lal, S. McKinney, C.M. Gross, and H. Cover. 2008. Assessment of nitrogen losses to the environment with a Nitrogen Trading Tool. Computers and Electronics in Agriculture 63:193-206.

Dosskey, M.G., Z. Qiu, M.J. Helmers, and D.E. Eisenhauer. 2011. Improved indexes for targeting placement of buffers of Hortonian runoff. Journal of Soil and Water Conservation 66(6):362-372.

FAO (Food and Agriculture Organization of the United Nations). 2009. Agriculture and Consumer Protection Department. Conservation Agriculture. Food and Agriculture Organization of the United Nations. http://www.fao.org/ag/ca/.

Galzki, J.C., A.S. Birr, and D.J. Mulla. 2011. Identifying critical agricultural areas with three-meter LiDAR elevation data for precision conservation. Journal of Soil and Water Conservation 66(6):423-430.

Inman, D., R. Khosla, R. Reich, and D.G. Westfall. 2007. Active remote sensing and grain yield in irrigated agriculture. Journal of Precision Agriculture 8(4-5):241-252.

Inman, D., R. Khosla, R. Reich, and D. G. Westfall. 2008. Normalized difference vegetation index and soil color-based management zones in irrigated maize. Agronomy Journal 100:60-66.

Jenrich, M. 2011. Potential of precision conservation agriculture as a means of increasing productivity and incomes for smallholder farmers. Journal of Soil and Water Conservation 66(6):171-174.

Johnson J.M.F., M.D. Coleman, R. Gesch, A. Jaradat, R. Mitchell, D. Reicosky, and W.W. Wilhelm. 2007. Biomass-bioenergy crops in the United States: A changing paradigm. The Americas Journal of Plant Science and Biotechnology 1:1-28.

Johnson, J.M.F., D.L. Karlen, and S.S. Andrews. 2010. Conservation considerations for sustainable bioenergy feedstock production: If, what, where, and how much? Journal of Soil and Water Conservation 65(4):88A-91A.

Khosla, R., K. Fleming, J. A. Delgado, T. M. Shaver, and D. G. Westfall. 2002. Use of site specific management zones to improve nitrogen management for precision agriculture. Journal of Soil and Water Conservation 57(6):513-518.

Khosla, R., D. Inman, D.G. Westfall, R. Riech, W.M. Frasier, M. Mzuku, B. Koch, and A. Hornung. 2008. A synthesis of multi-disciplinary research in precision agriculture: Site-specific management zones in the semi-arid western Great Plains of the USA. Journal of Precision Agriculture 9 (1-2):5-100.

Kyveryga, P.M., T.M. Blackmer, R. Pearson, and T.F. Morris. 2011. Late-season digital aerial imagery and stalk nitrate testing to estimate the percentage of areas with different nitrogen status within fields. Journal of Soil and Water Conservation 66(6):373-385.

Lal, R., J.A. Delgado, P.M. Groffman, N. Millar, C. Dell, and A. Rotz. 2011. Management to mitigate and adapt to climate change. Journal of Soil and Water Conservation 66(4):276-285.

Lobb, D.A. 2011. Understanding and managing the causes of soil variability. Journal of Soil and Water Conservation 66(6):175-179.

Luck, J.D., T.G. Mueller, S.A. Shearer, and A.C. Pike. 2010. Grassed waterway planning model evaluated for agricultural fields in the western coal field physiographic region of Kentucky. Journal of Soil and Water Conservation 65(5):280-288.

McConnell, M., and L.W. Burger. 2011. Precision conservation: A geospatial decision support tool for optimizing conservation and profitability in agricultural landscapes. Journal of Soil and Water Conservation 66(6):347-354.

Meki, M.N., J.P. Marcos, J.D. Atwood, L.M. Norfleet, E.M. Steglich, J.R. Williams, and T.J. Gerik. 2011. Effects of site-specific factors on corn stover removal thresholds and subsequent environmental impacts in the Upper Mississippi River Basin. Journal of Soil and Water Conservation 66(6):386-399.

Mueller, T.G., H. Cetin, R.A. Fleming, C.R. Dillon, A.D. Karathanasis, and S.A. Shearer. 2005. Erosion probability maps: Calibrating precision agriculture data with soil surveys using logistic regression. Journal of Soil and Water Conservation 60(6):462-468.

Pike, A.C., T.G. Mueller, A. Schorgendorfer, S.A. Shearer, and A.D. Karathanasis. 2009. Erosion indicies derived from terrain attributes using logistic regression and neural networks. Agronomy Journal 101:1068-1079.

Ribaudo, M., J.A. Delgado, L. Hansen, M. Livingston, R. Mosheim, and J. Williamson. 2011. Nitrogen in Agricultural Systems: Implications for Conservation Policy. Economic Research Report No. (ERR-127). Washington, DC: USDA.

Saleh, A., O. Gallego, E. Osei, H. Lal, C. Gross, S. McKinney, and H. Cover. 2011. Nutrient Tracking Tool—a user-friendly tool for calculating nutrient reductions for water quality trading. Journal of Soil and Water Conservation 66(6):400-410.

Sen, S., P. Srivastava, T.P. Clement, J.H. Dane, and H. Meng. 2011. Simulating hydrologic response of a pasture hillslope in North Alabama using the Hortonian Infiltration and Runoff/On model. Journal of Soil and Water Conservation 66(6):411-422.

Silici, L. 2010. Conservation Agriculture and Sustainable Crop Intensification in Lesotho. Rome, Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/012/i1650e/i1650e00.pdf.

Thiombiano, L., and M. Meshack. 2009. Scaling-up Conservation Agriculture in Africa: Strategy and Approaches. Addis Ababa, Ethiopia: Food and Agriculture Organization of the United Nations Sub Regional Office for Eastern Africa. http://www.fao.org/ag/ca/doc/Kenya%20Workshop%20Proceedings.pdf.

Thomas, M.A., B.A. Engel, and I. Chaubey. 2011. Multiple corn stover removal rates for cellulosic biofuels and long-term water quality impacts. Journal of Soil and Water Conservation 66(6):431-444.

Tomer, M.D. 2010. How do we identify opportunities to apply new knowledge and improve conservation effectiveness? Journal of Soil and Water Conservation 65(4):261-265.

Walter, T., M. Dosskey, M. Khanna, J. Miller, M. Tomer, and J. Weins. 2007. The science of targeting within landscapes and watersheds to improve conservation effectiveness. *In* Managing Agricultural Landscapes for Environmental Quality: Strengthening the Science Base, eds. M. Schnepf and C. Cox, 63-89. Ankeny, IA: Soil and Water Conservation Society.

Williams, J.D., D.S. Long, and S.B. Wuest. 2011. Capture of plateau runoff by global positioning system–guided seed drill operation. Journal of Soil and Water Conservation 66(6):355-361.