NEW ADVANCES AND PRACTICES FOR PRECISION CONSERVATION

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ABSTRACT

During the next four decades soil and water conservation scientists will encounter some of their greatest challenges to maintain sustainability of agricultural systems stressed by global warming and increasing population growth, with higher food and biofuels demands. It has been reported that intensive agriculture without adequate soil and water conservation practices can potentially reduce soil quality, lowering yields and increasing off-site transport of soil particles, nutrients, and agrochemicals that impact water bodies. Precision Conservation offers an alternative to integrate the use of spatial technologies such as global positioning systems (GPS), remote sensing (RS), and geographic information systems (GIS) and the ability to analyze spatial relationships within and among mapped data to develop management plans that account for the temporal and spatial variability of flows in the environment. This paper presents several advances in Precision Conservation during the last five years, and the potential applications and uses of these developments for new modified practices that can contribute to Precision Conservation across the landscape. These new technologies and new advances can help connect flows across the landscape, and improve the evaluation and understanding of connections between agricultural and non-agricultural areas to implement the best viable management and conservation practices across the landscape for sustainability of intensive agriculture that simultaneously provides for higher yields and environmental conservation. We propose that, to maintain the necessary maximum production, a parallel increase in conservation practices must take place to sustain maximum agricultural production. We also propose that Precision Conservation will be an approach to soil and water conservation that will be necessary to synchronize best management practices that maximize yields while reducing unnecessary inputs and losses of sediment and other chemicals to the environment.

Keywords: GIS, GPS, precision conservation, precision farming, nitrogen trading tool, NLEAP GIS, and remote sensing

INTRODUCTION

Population growth continues to increase, and the world population is projected to reach 10 billion by 2050, which greatly increases the demands of world food production per arable land area (Lal, 1995). The pressure to maximize agricultural production also will increase, because of the increased demand for water resources, coupled with decreasing water availability due to overexploitation of underground water resources (Wang et al. 2002; Hu et al., 2005, Kromm and White 1992; Opie 1993). There also are concerns about the potential effects of global climate change, which might affect precipitation patterns and erosion rates (Nearing et al., 2004; Hatfield and Prueger, 2004). The new demands created by a growing biofuel industry also will increase the need for more intensive cultivation and maximization of yields. Intensive cultivation will increase the potential for erosion rates and we will need to continue advancing precision conservation technology to maximize agricultural production (Berry et al 2003, 2005) while minimizing environmental impacts. Maintenance of this balance is necessary to sustain agricultural production.

It is clear that during the next four decades practitioners and conservationists will need to work with soil scientists, agronomists, farmers and environmentalists to develop sustainable cropping systems that will maximize agricultural production while conserving soil and water resources. This will require the development of technological tools that will help inform and assess best management practices. These tools will be even more imperative if we continue to develop a biofuel industry that may increase agrichemical inputs while also removing greater proportions of crop residues. Precision conservation can help scientists and practitioners discover alternative techniques to maximize production while achieving soil and water conservation balances for agricultural lands, such as cover crop implementation, buffer strips and nutrient traps. Cover crops and management of cover crops may become necessary to continue supplying enough crop residues to soils to reduce soil erosion and minimize leaching of nutrients. Buffers strips, nutrients traps, and other precision conservation practices that reduce the movement of soil and water from fields and across the landscape also will become increasingly important (Delgado and Berry, 2008).

Berry et al. (2003, 2005) defined Precision Conservation as a set of spatial technologies and procedures linked to mapped variables, which is used to implement conservation management practices that take into account spatial and temporal variability across natural and agricultural systems. Precision conservation is different from Precision Farming, which focuses on maximized yields in agricultural fields. Precision Conservation is focused on connecting farm fields, grasslands, and range areas with the natural surrounding areas, including buffers, riparian zones, forest, and water bodies in such a way that flows are sustainably managed (Fig. 1). The goal of Precision Conservation is to use and integrate multiple layers of information simultaneously to account for surface and underground flows as a means to evaluate what management practices should be used to maximize yields while contributing to conservation of agricultural, rangeland, and natural areas. Delgado and Berry (2008) refined the definition of Precision Conservation as a technologically based approach, requiring the integration ***of one or more*** spatial technologies, such as global positioning systems (GPS), remote sensing (RS), and geographic information systems (GIS) that provide the ability to analyze spatial relationships within and among mapped data according to three broad categories: surface modeling, spatial data mining, and map analysis. The previous definition requires the complete integration of GPS, RS and GIS, but more recent papers have shown that Precision Conservation can still be achieved with the use of only one or two of these technologies.

The area of Precision Conservation continues to progress since the initial paper published by Berry et al. (2003). Several other papers have been published that relate to the topic of Precision Conservation and describe how these new technologies can be applied to maximize the effectiveness of Precision Conservation. For details about Precision Conservation and its relationship to geospatial technologies and identification of spatial patterns and relationships, readers should review Berry et al. (2003), Berry et al. (2005) and Delgado and Berry (2008).

This paper presents some new case scenarios published since 2003 that are examples of how Precision Conservation can be applied across the landscape. A key example that shows the importance of how variable erosion can affect field productivity was presented by Shumacher et al. (2005). They used a soil displacement of Cesium-137 and the Water and Tillage Erosion model to assess the spatial erosion losses due to water and tillage across a cultivated field. We can use the same techniques implemented by Shumacher et al. (2005) to develop a spatial management plan that accounts for the variable rates of erosions across the fields. Spatial assessment of field erosion conducted by Shumacher et al. (2005) clearly identified the highly sensitive areas of the fields.

Previous to 2003, Quine and Zhang (2002) also used a simulation approach to evaluate the long term effects of soil erosion on yield. They reported that the areas of the field with soil erosion-depleted nutrients had lower yields. Their forty-year simulation showed that the areas of the field with the higher erosion rates will be impacted and will have lower yield production if the field was managed with a uniform management practice. This long term simulation from Quine and Zhang (2002) and the recent assessment of spatial erosion by Shumacher et al. (2005) clearly show the need to consider Precision Conservation for management of spatial soil erosion to sustain agricultural productivity across the landscape. Conservation practices, such as buffers in the field, alley cropping, terraces and wind barriers could be implemented to reduce erosion across the field, using site specific information like the erosion maps developed by Shumacher et al. (2005).

The underlying premise supporting Precision Conservation is based on the potential to manage agricultural systems through Precision Conservation practices in a way that increases the sustainability of these variable field systems (Berry et al. 2003, 2005). Additionally, the connections between fields and natural areas need to be managed with consideration of both spatial and temporal information.

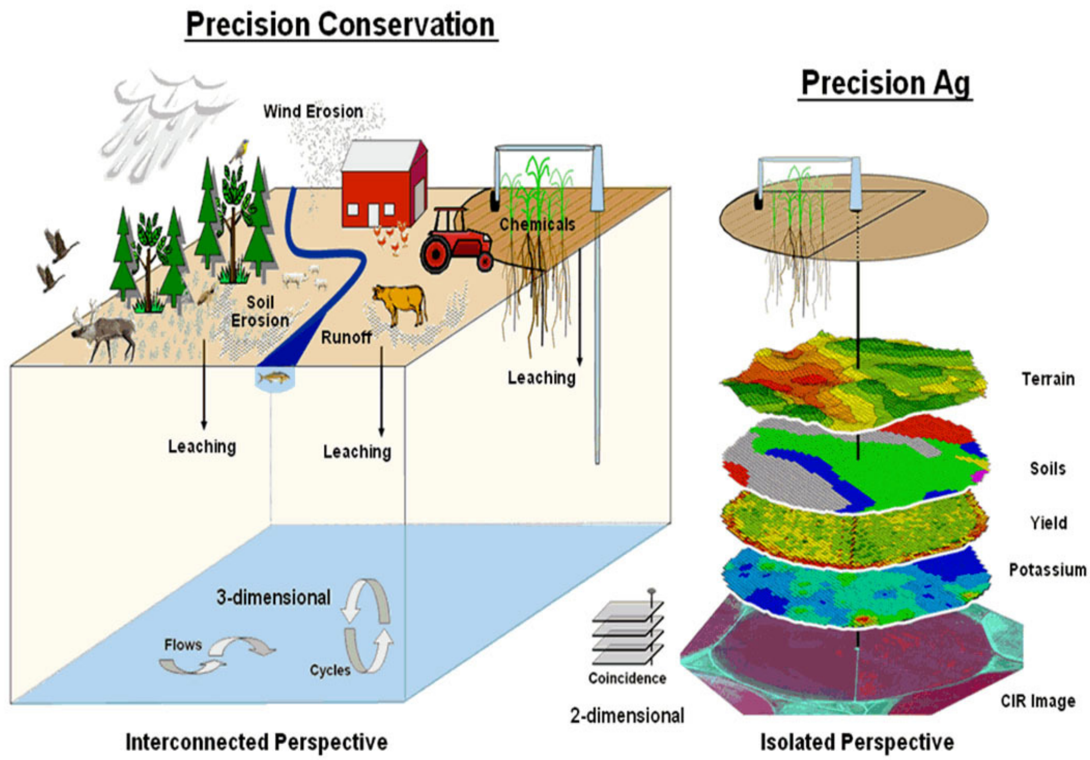

Figure 1. *The site-specific approach can be expanded to a three dimensional scale approach that assesses inflows and outflows from fields to watershed and region scales (From Berry et al. 2003).*

Precision Conservation and Variable Erosion

There are several papers that clearly show the effect of variable erosion across the landscape and potential impact on yield production (Shumacher et al., 2005; Quine and Zhang, 2002). The variable erosion maps developed with the methods presented by Shumacher et al. (2005) and Quine and Zhang (2002) can be used to develop site-specific conservation practices that account for variable rates of erosion. Berry et al. (2005) reported that there is potential to develop Precision Conservation Management Zones (PCMZ) similar to the Site-Specific Management Zones (SSMZ) described by Flemming et al. (1999) and Khosla et al. (2002). Berry et al (2005) reported that the PCMZ and SSMZ do not necessarily need to overlap, and can be managed differently using a PCMZ map to manage conservation and a SSMZ to manage nutrients. The use of RS, GIS, and spatial technologies could facilitate and help identify the applications of specific conservation practices that account for rates of erosions for a PCMZ, while a SSMZ can be implemented for nutrient management by taking in consideration yield productivity (Berry et al., 2005; Flemming et al., 1999; Khosla et al., 2002).

Precision Conservation and Variable NO_3-N Leaching

There are several examples in the literature that report on spatial variability in nitrate leaching. Delgado (2001) and Delgado et al. (2001) studied the effects of nitrogen management under commercial field operations and spatial variability of residual soil nitrate and nitrate leaching. They reported that for center pivot irrigated barley, canola, and potatoes grown on the loamy sand zone, the NO_3-N leaching was higher than for the sandy loam zones. A similar response was found by center pivot irrigated corn grown on a sandy coarse soil of Northeastern Colorado (Delgado and Bausch, 2005). Residual soil NO_3-N was negatively correlated with the percent sand content across the field in northeastern and south central Colorado (Delgado, 2001; Delgado et al., 2001; Delgado and Bausch, 2005).

Delgado and Bausch (2005) reported that we can use Precision Conservation techniques to reduce NO_3-N leaching. Bausch and Delgado (2003) used remote sensing techniques to synchronize applied N with crop N uptake demands during the growing season, increasing the N use efficiency by almost fifty percent while sustaining yields and reducing NO_3-N leaching by 47% (Delgado and Bausch, 2005). The Bausch and Delgado (2003) approach saved 102 kg N $ha^{-1}y^{-1}$ with equivalent savings of about \$147.00 ha^{-1} per season and with current nitrogen fertilizer prices hovering around \$1.44 per kg N. Delgado et al., (2005) also reported that SSMZ can be used to reduce NO_3-N leaching while maintaining grain yields and increasing N use efficiencies and reducing N inputs.

Precision Conservation and Variable N_2O

Mosier et al. (1986) reported on the spatial variability effects of management across a catena of the shortgrass steppe. The N_2O emissions from the clay bottom soil of the catena were 2.5 ug N $m^{-2}h^{-1}$ higher than those form the coarser and sandier mid or top slope position of the catena, which averaged 1.4 and 1.3 ug N $m^{-2}h^{-1}$, respectively. Similar results were reported in Canada by Goddard (2005) and Pennock (2005). There is potential to use these spatial variability emissions rates to manage N fertilizer inputs with the potential to reduce N_2O emissions. Delgado and Mosier (1996) reported that controlled-release fertilizer and nitrification inhibitors can be used to reduce the rates of N_2O emissions. A combination of nitrogen management practices that accounts for precision conservation, SSMZ, nitrogen sources (such as controlled release fertilizers) and nitrification inhibitors might be able to be used to reduce the emissions of N_2O and even potential losses due to NO_3-N leaching (Delgado and Berry, 2008).

Precision Conservation and Variable Manure Management

There also is potential to use advanced manure management practices to improve manure rate applications (Cabot et al., 2007; Sharpley et al., 2007). Cabot et al. (2007) used Precision Conservation technology for improving the application of manure. Sharpley et al. (2007) reported that this type of approach can contribute to improved manure management and reduce off-site transport. Sharpley et al. (2007) also recommended the application of manures using a Phosphorous Index that evaluate site specific properties that can indicate how much manure is applied. The P Index can indicate if a field should receive variable application rates across the farm by considering the site specific properties across the field (Sharpley et al., 1999). It also is necessary to consider the simultaneous evaluation of nitrogen and phosphorous (Delgado et al., 2006, 2008; Heathwaite et al. 2000).

Precision Conservation and a New Nitrogen Trading Tool to Assess Reactive N Losses to the Environment

The new NLEAP model (Shaffer et al., *In Press*) includes a stand alone Nitrogen Index, GIS capabilities and a stand alone Nitrogen Trading Tool (Figure 2, Delgado and Shaffer *In Press*). Delgado et al. (2008) defined the Nitrogen Trading Tool difference in reactive N losses (NTT-DNL_{reac}) as the comparison between a baseline and new management scenarios. For a detailed description of the new concept of NTT-DNL_{reac}, see Delgado et al. (2008) and Gross et al. (2008). Delgado et al. (2008) presented the stand alone Nitrogen Trading Tool (Figure 2) and Gross et al. (2008) presented the web-based version of the nitrogen trading tool (Figure 3).

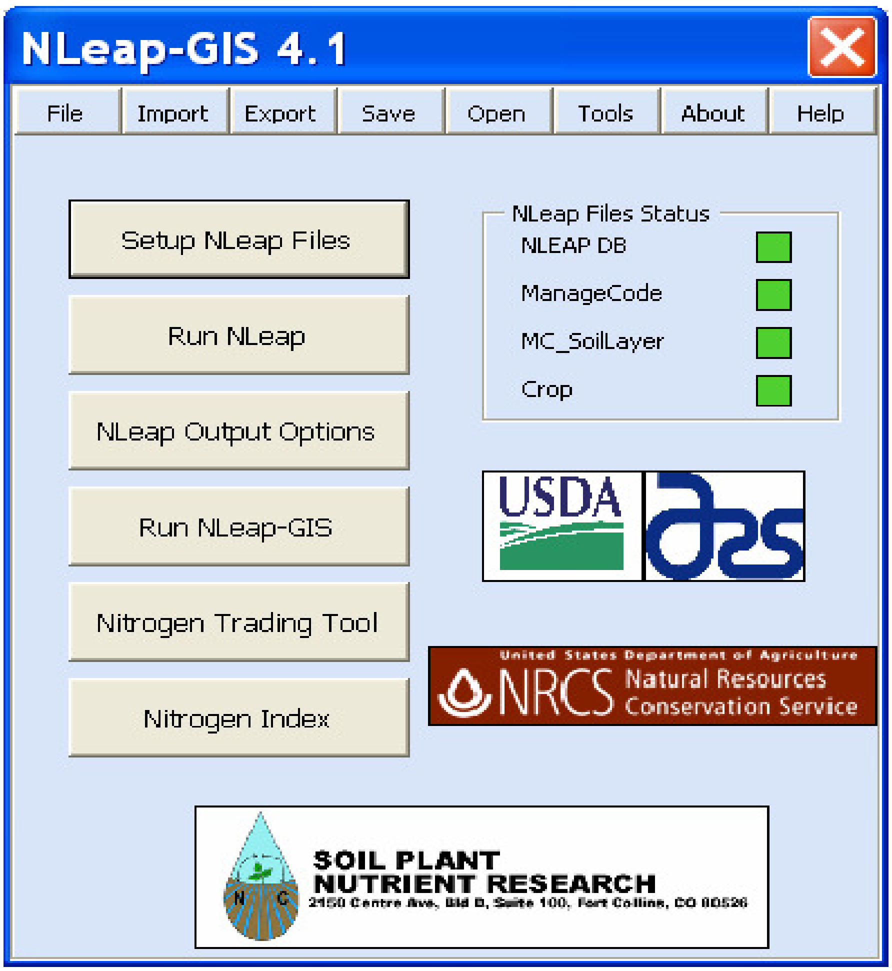

Figure 2. *A stand alone version of the NLEAP Nitrogen Trading Tool interface prototype (From Delgado et al. 2008).*

Delgado and Shaffer (*In Press*) developed a GIS NTT using the NLEAP GIS 4.2 software. The Nitrogen Trading Tool GIS prototype can evaluate the reactive nitrogen losses through different pathways, such as ammonia volatilization, nitrate leaching, runoff, and nitrous oxide emissions across risky cropping systems and landscape combinations (Figure 4).

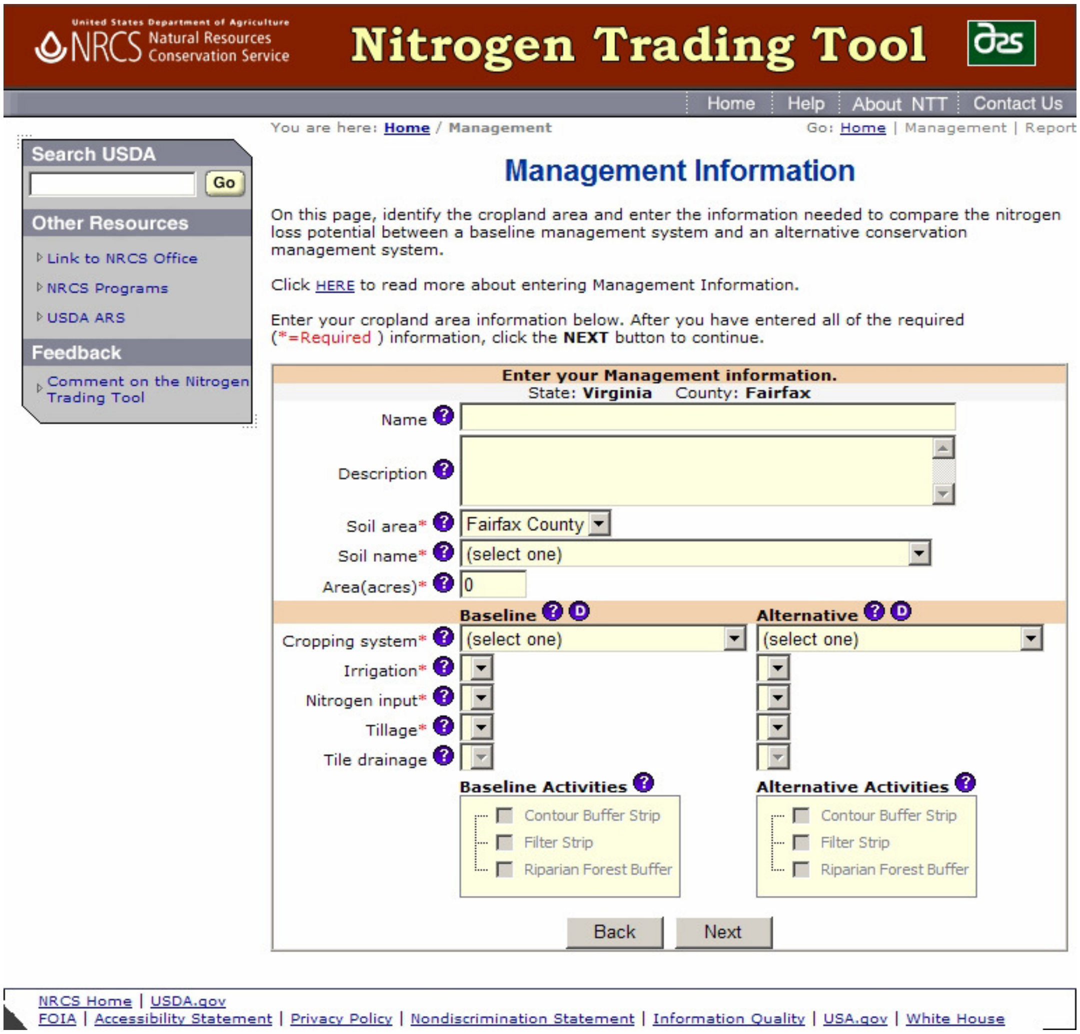

Figure 3. *Web-based Nitrogen Trading Tool user interface prototype (from Gross et al., 2008).*

Delgado et al. (2008) were able to evaluate best management practices to assess reactive and total N losses to the environment in traditional irrigated systems of the arid western USA, manure no till systems from Midwestern USA and no till system from the North Atlantic USA. Figure 4 shows how the aggregate potential savings in reactive nitrogen could be aggregated across a region by, for example, implementing best management practices across these 94 irrigated center pivots across south central Colorado (hypothetical example). If farmers were to implement a cover crop program and other best management practices, the potential savings in reactive N to the environment across this sub region could be 782,000 kg N ha^{-1} $year^{-1}$ (about 64 kg N ha^{-1} $year^{-1}$). A single farmer, for this example, could trade 33,000 kg N ha^{-1} $year^{-1}$ if he implements these best management practices (about 55 kg N ha^{-1} $year^{-1}$; Figure 4).

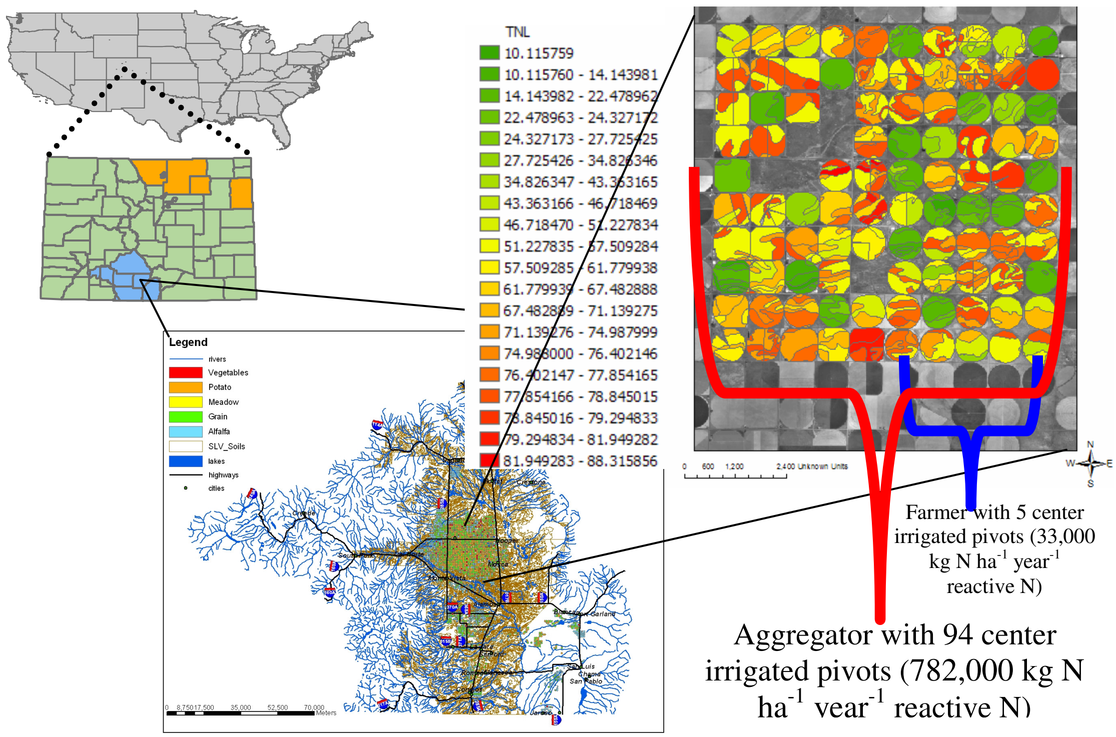

***Figure 4**. A stand alone NTT GIS prototype can be used to quickly evaluate the effects of management practices on total reactive N losses and the resultant potential to trade across regions (Hypothetical example).*

Further analysis that was conducted shows the potential for carbon sequestration equivalent trading resulting from savings in N_2O emissions. Delgado et al. (2008) reported that there was potential to save 900 to 1800 kg CO2 ha^{-1} $year^{-1}$ in carbon equivalents through a reduction of N_2O emissions if farmers were to implement best manure practices in Ohio (about 246 to 491 kg C ha^{-1} $year^{-1}$ equivalents in carbon sequestration do to a better manure management that reduces N_2O emissions, Delgado et al. 2008) For additional information about the potential to trade carbon sequestration equivalents as a result of using best nitrogen management practices and using a NTT prototype, see Gross et al. (2008) and Delgado et al. (2008). Using an NTT with GIS capabilities can help farmers and conservationists to identify potential N loss mitigation zones across regions that could provide opportunities to earn nitrogen credits through improved management. Establishing a standard tool like NTT as a basis for assessing tradeability of nitrogen credits can help connect farmers, aggregators and buyers.

Precision Conservation and Off-site Transport

The literature is full of papers connecting field erosion with offsite impacts. For example, Feng and Sharratt (2007) used wind erosion prediction systems and GIS to scale flows from field to region. They used this approach across an entire region from Washington State and reported that the areas with summer fallow rotations were more sensitive to erosion. Berry et al. (2003, 2005) used map analysis to assess the potential variable flows from field to surrounding natural areas. They identified that areas with the heaviest contribution to flows can be used to identify the potential hot spots for surface runoff and sediment and agrochemical transport out of the field, as well as where to locate buffers to reduce off site transport. Other recent selected studies were Sechhi et al. (2007) Reschler and Lee (2005) and Bonilla et al. (2007).

For a detailed description of models and tools with potential for Precision Conservation, see Delgado and Berry (2008). They discussed the initial modeling efforts in identifying spatial erosion impacts by accounting for topography and other parameters (Wheeler, 1990; Mitasova et al., 1995; Siegel, 1996; Mitas et al., 1997; Wang et al., 2000; Wischmeier and Smith, 1965). More recent efforts included more advanced models and inclusion of GIS and Digital Elevation Models (DEMs) by other scientists (Desmet and Govers, 1996; Secchi et al., 2007; Reschler and Lee, 2005; Bonilla et al., 2007).

Independent of the approach used to manage conservation across a region, users should consider subsurface flows (Delgado and Berry, 2008; Vadas et al., 2007; Tomer et al., 2007). Precision Conservation Buffers and Riparian Zones also are important tools that can be used to manage variable and temporal flows across regions (Tomer et al., 2007; Dosskey et al., 2002; Lowrance et al., 2000; Hey et al., 2005). There are even opportunities to establish wetlands as nutrient farms if they are established in site specific zones (Hey et al., 2005) and even nutrient traps that can capture phosphorous (Penn et al. 2007) and nitrogen-denitrification traps (Hunter, 2001).

Watershed-scale considerations to management are important as well. Although Hewlett and Hibbert (1967) are credited with the concept of variable source areas (VSAs), Qui et al. (2007) reported on variable hydrology and suggested the need to manage variable source pollution using Precision Conservation. Qui et al. (2007) suggested the need for interconnection between land and water and the different roles varying landscapes play in water resource protection. It is important to consider the temporal and spatial variability in this variable source transport across a watershed (Qui et al., (2007)). The key location of sedimentation ponds also could serve as a conservation practice (Lowrance, 2007). More recently, George et al. (2008) used Precision Conservation techniques to connect animal management with soil and water conservation. They showed the potential to use supplemental feed to manage cattle behavior in a way that considers forest and grassland areas, temporal variability, and water bodies to enhance soil and water conservation across a watershed (George et al., 2008).

Precision Conservation Practices

The USDA NRCS is committed to continued advancement in Precision Conservation as it benefits producers by helping them to efficiently manage their operations (Knight, 2005). Precision Conservation also can benefit taxpayers because it can be used to identify hot spots on the farm and throughout the watershed for a more efficient use of agricultural resources (Knight, 2005).

There are several practices that can be used with Precision Conservation. Delgado and Berry (2008) presented a detailed description of potential practices. A short summary of these practices are described in Table 1. There is potential to apply new technologies to design site specific practices that account for spatial and temporal variability of flows in the environment. Among the potential practices that can be adapted for Precision Conservation are alley cropping, conservation crop rotation, cover crops, field borders, riparian herbaceous cover, riparian forest buffers, filter strips, residue management, supplemental feed, sediment ponds, isolated hay production areas with permanent cover, nutrient traps, and buffers (Table 1; Delgado and Berry, 2008).

Table 1. *Selected conservation practices with potential site specific applications to reduce soil erosion, and contribute to soil and water quality*[†].

Alley cropping	There is potential to use spatial and temporal information to plant trees or shrubs in single or multiple rows with agronomic, horticultural crops or forages produced in the alleys and considering the temporal and spatial variability of soils and flows across the landscape. This practice could be used as a way to reduce erosion and/or increase evapotranspiration to reduce the leaching of water and agrochemicals. Site specific flow and temporal variability could be considered to guide the planting of different trees and/or shrubs as needed to account for variability in soil type, salinity, changes in pH, soil depth, wind direction, amount of runoff at specific landscape positions, slope, and other site specific variables. Planting variable trees or shrubs in single or multiple rows as needed (Potential for mining nitrates from goundwater) represents a potential Precision Conservation practice (Tomer et al., 2007; Rowe et al., 1999; Allen et al., 2004; Delgado, 1998, 2001).
Conservation crop rotation	There is potential to use field-scale spatial variability to guide the implementation of crop rotations to maximize reduction of soil erosion. Spatially-variable data from the field can be used to increase carbon sequestration by planting varieties that may contribute higher crop residue in those areas that require more crop residues. Varieties can be planted across a field based on crop residue production, salinity, pH or erosion potential. There is also potential to use cover

	crops in areas of high erosivity and/or set aside field areas that are non productive and have high erosion rates (Schumacher et al., 2005; Delgado, 1998, 2001).
Cover crop	Cover crops are highly beneficial in the majority of the cases. There is potential to use legume cover crops for some areas of the fields if there is a need to add nitrogen, while other areas of the field may require a cover crop scavenger. Cover crops may be planted around those areas that are highly eroded. Cover crops may become a viable and important tool for the sustainability of new biofuel systems (Delgado, 1998; 2001).
Field border	There is potential to use temporal and spatial information to identify the areas of the field with the highest surface flows. Field borders can be plated around the field, and the width of the buffer could be based on distance to water bodies, as well as spatial and temporal flows. Additionally, cool or warm season grasses could be planted, based on the temporal flows to ensure that there is adequate aboveground vegetation growth at the time when the higher flows are occurring. Precision Conservation can be used to determine the best designs for field borders—whether vegetated with grass, legumes or shrubs—by considering the potential of each to reduce off site transport of soil, soil organic matter, and nutrients due to water and wind erosion (Tomer et al. 2007; Dosskey et al. 2005; Berry et al., 2003).
Riparian herbaceous buffer	There is potential to use grasses, grass-like plants, and forbs to develop riparian herbaceous cover that accounts for temporal and seasonal site-specific hydrology. There is the potential to try to synchronize the vegetation growth and water and nutrient use with periods of maximum water flows (Tomer et al., 2007; Dosskey et al., 2002, 2005, 2007; Hey et al., 2005).

Sediment ponds	There is potential to use sediment ponds strategically located across the watershed by taking spatial and temporal flows into consideration (Lowrance et al., 2007).
Nutrient traps	There is potential to use nutrient traps (phosphorous and nitrogen) to reduce the off-site transport of these nutrients. The locations of these traps can be based on the temporal and spatial variability of flows and management (e.g. time of fertilizer applications, etc.) (Penn et al., 2007; Hunter, 2001).
Supplemental animal feeding	There is potential to manage animal behavior and reduction of environmental impacts across a watershed by using supplemental animal feeding based on soil type, leaching dynamics, water bodies and other spatially and temporally variable conditions (George et al., 2008).

[†] *For additional Precision Conservation practices, see Delgado and Berry (2008).*

SUMMARY AND CONCLUSIONS

This paper is a review of papers published during the last few years that describe the various advances in Precision Conservation. These papers show how we can integrate new advances in spatial technologies, such as GPS, GIS, RS, and computer models to help practitioners and conservationists make decisions that contribute to the conservation of soil and water. By integrating spatial and temporal information to guide implementation of best management practices, we can precisely identify appropriate locations for riparian buffers, sediment ponds, and nutrient management farms and can decide how to use ecological engineering practices to identify hot spots and reduce environmental impacts across a watershed. We can use these technologies to assess surface and underground flows, variable hydrology, and variable erosion rates and identify the best locations for the implementation of conservation practices at the watershed and. sub-watershed levels, across a field or at a field border.

The next four decades will see a tremendous increase in worldwide needs to maximize agricultural production. These increases in pressure for higher agricultural production will be driven by continued population growth, biofuel production demands, and global warming. We propose that, to maintain the necessary maximum production, a parallel increase in conservation practices must take place to sustain maximum agricultural production. We also propose that Precision Conservation will be an approach to soil and water conservation that will be necessary to synchronize best management practices that maximize yields while reducing unnecessary inputs and losses of sediment and other chemicals to the environment. As new technological advances continue to emerge, adaptations of Precision Conservation techniques by land owners, managers, farmers, and extension personnel will be widely implemented worldwide across all types of agricultural systems.

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