PRECISION CONSERVATION: USING PRECISION AGRICULTURE TECHNOLOGY TO OPTIMIZE CONSERVATION AND PROFITABILITY IN AGRICULTURAL LANDSCAPES

M. D. McConnell, and L. W. Burger, Jr.

Department of Wildlife, Fisheries, and Aquaculture
Mississippi State University
Mississippi State, Mississippi

W. Givens

Geosystems Research Institute
Mississippi State University
Mississippi State, Mississippi

ABSTRACT

USDA Farm Bill conservation programs provide landowner incentives to remove less productive lands from agricultural production and reestablish them in natural vegetation (e.g., native grasses, trees, etc.) to achieve conservation objectives. However, removal of arable land from production imposes an opportunity cost associated with loss in revenue from commodities that otherwise would have been produced. Recent Farm Bills have increasingly emphasized targeted practices to achieve specific environmental outcomes that maximize environmental benefits relative to cost. The Habitat Buffers for Upland Birds practice (CP33) under the continuous Conservation Reserve Program (CRP) is an example of a targeted conservation practice which has produced measureable outcomes (increased bobwhite and grassland bird populations) with relatively minor changes in primary land use. However, establishing conservation buffers on profitable farmland may be incompatible with the economic objectives of landowners/producers. Precision implementation of conservation practices such as CP-33, is the foundation of strategic conservation planning and essential to optimize environmental and economic benefits. Toward this end, we developed a geospatial decision support tool (ARCGIS extension) to inform this decision making process. This tool identifies conservation enrollment opportunities based on geospatial information (soil type, hydrology, etc.) and conservation program eligibility requirements; calculates buffer-specific CRP rental rates; incorporates spatially explicit yield information with crop production budgets and commodity prices to produce spatially explicit profit surfaces, simulates whole field profitability of agricultural production vs. alternative conservation buffer enrollment scenarios. We illustrate the geoprocessing workflow of the tool and demonstrate the conditions under which precision implementation of conservation practices can concomitantly increase whole field profitability and environmental services. Precision agriculture technologies provide a powerful conservation planning tool for identifying environmental and economic opportunities in agricultural systems.

Keywords: conservation buffers, profitability, geospatial, spatially explicit.

INTRODUCTION

Agriculture dominates human land use (Robertson and Swinton, 2005) and influences the environmental goods and services produced by agroecosystems. In the United States 50% (382.8 million hectares) of the contiguous 48 states is devoted to cropping or grazing land uses (USDA, 2003). With exponential human population growth (Lutz et al., 2001, UNPD, 2002) and associated increases in food demand (Bongaarts, 1996), production agriculture continues to intensify, favoring mass production of food and fiber resources (Tilman et al., 2002). To meet global demands and remain competitive in global markets, modern agriculture emphasizes maximizing productivity (e.g., increased yield) and minimizing costs. With the human population expected to reach 9.4 billion and per capita arable land expected to be reduced by nearly forty percent by 2050 (Lal, 2000) further intensification of agricultural production is almost certain. Increased agricultural production will involve either allocation of additional land to production or maximization of the potential (e.g., increase yield) of land already in use. Given that the majority of the world's arable land is already in agricultural production (Baligar et al., 2001) future production demands will likely be met through increased production on land currently in use. Precision agriculture (PA) provides a suite of technologies that can potentially increase yield while reducing costs and environmental impacts in a spatially explicit manner (Stull et al., 2004).

One goal of PA is to efficiently allocate inputs so as to maximize yield (Tons/hectare) and/or profitability ($/ha). When yield is maximized, the amount of land needed to meet food demands is reduced. If production and revenue targets can be met with less cropped acreage, the opportunity for land reallocation is created. Less productive agricultural lands (i.e., those with reduced yields or lower profitability) are logical candidates for conservation implementation or alternative land use (i.e. biofuels production; Tilman et al. 2002). Conservation and food production goals can be linked through increasing yield on cultivated land, thereby freeing up land for conservation use (Green et al., 2005). Precision Agriculture can increase profitability for producers while potentially enhancing environmental services of agricultural systems and societal benefits (Zhang et al., 2000). Although, adoption of PA technologies have been increasing since the early 1990s (Daberkow and McBride, 2003), its applications for conservation planning have, until recently, been widely overlooked (Lowenberg-DeBoer, 1996, Stafford, 2000).

The emerging field of precision conservation uses PA tools to achieve conservation objectives. Precision conservation [PC] is defined as "a set of spatial technologies and procedures linked to mapped variables directed to implement conservation management practices that take into account spatial and temporal variability across natural and agricultural systems" (Berry et al., 2003). PC, much like PA, is dependent on geospatial tools such as global positioning systems (GPS), geographic information systems (GIS), digital landscape information, spatially explicit mathematical models, and intensive computer analysis (Dosskey et al., 2005). A number research projects on PC's application in conservation planning have been conducted (Berry et al., 2003, Dosskey et al., 2005, Kitchen et al., 2005), but generally focus on nutrient loading and/or erosion control. PC has also been used in strategic establishment of conservation buffers to reduce nutrient runoff and topsoil erosion (Stull et al., 2004, Dosskey et al., 2005), and has been shown to increase buffer effectiveness; however, few examples of the use of PA's or PC's for wildlife conservation planning exist.

Agricultural landowners operate on "boom and bust" patterns of financial ambiguity, and financial concerns have the most influence on producer decisions (Kitchen et al., 2005). Variations in global economies, federal policies (e.g., Farm Bill), commodity prices, subsidy payments, weather/climatic events, input costs, and equipment expenses together provide numerous financial obstacles for landowners. Removing land from production for conservation imposes an opportunity cost associated with loss in revenue from commodities that otherwise would have been produced (USDA, 2003). "Conservation must be compatible with profitability" (Kitchen et al., 2005), and to make conservation implementation economically attractive to agricultural landowners, conservation programs must address economic concerns of producers (USDA, 2003). Conservation and profitability can coexist if both ecological and economic demands are taken into account (Holzkamper and Seppelt, 2006).

Farm policy in the United States, as codified in the Farm Bill and implemented through conservation programs, has evolved to recognize the importance of financial concerns and profitability in the adoption of conservation practices. Consequently, conservation programs provide financial incentives to offset both the direct and opportunity costs of conservation practices adoption. . Conservation buffers represent a suite of BMPs designed to take the most environmentally sensitive lands out of production and address specific resource concerns (e.g. soil erosion, water quality, wildlife conservation) in a manner that is compatible with row crop production systems while removing the least amount of ground from production. These targeted conservation practices often carry extra economic incentives (i.e. signup incentive payments, increased cost-share, elevated rental rates) to induce adoption. To increase the degree of targeting, eligibility of cropland for conservation buffer practices is constrained based on spatial relationships such as hill slope position, proximity to water bodies and wetlands, proximity to field margins, or other ecologically sensitive features. Buffer width, configuration, and plant materials are constrained so as to achieve desired resource outcomes. However, enrollment of all eligible land might not necessarily maximize financial returns, and thus might not be the best land use from a profitability standpoint. A strategic enrollment that maximizes conservation benefits, subject to the constraint that economic benefits equal or exceed that under agricultural production might be considered optimal from a producer standpoint and might increase adoption.

Effective implementation of PC will require computation and analysis of spatially explicit field-level information to identify both enrollment opportunities (eligibility criteria) and spatial variation in profit under production vs. alternative enrollment strategies. However, few agricultural producers possess the geospatial processing skill required to conduct even rudimentary analyses. Decision support tools (DST) can assist producers in making informed decision regarding tradeoffs between production and conservation enrollments. However, to date, no DST exists to assist producers in comparing profitability of crop production with conservation program enrollment in a spatially explicit context. Therefore, the objectives of this paper are to:

1. Describe a geospatial decision support tool designed to identify spatially explicit conservation program opportunities, and
2. Demonstrate its utility in characterizing economic tradeoffs of program participation vs. production.

METHODS

Our geospatial decision support tool is designed to operate as a script or an extension in ArcGIS (ArcInfo version 9.3.1) software. It was coded in Python to ensure forward compatibility with ARCGIS version 10.x. The tool consists of 2 distinct modules: 1) to define practice-specific eligibility for 3 conservation buffer practices and 2) to construct profit surfaces from spatially explicit yield data and compare profitability under production vs. alternative buffer enrollments. To illustrate conservation opportunities and economic tradeoffs we chose a candidate set of conservation buffer practices and ran simulation models to identify their eligibility on production agriculture farms in Mississippi, USA.

Eligibility Tool

The vehicle for implementing conservation buffers has been the Continuous Conservation Reserve Program (CCRP), implemented through the Farm Bill. Under CCRP a variety of conservation buffer practices (i.e. filter strips, riparian forest buffers, field borders, and upland habitat buffers) are available to accomplish specific resource conservation objectives associated with national conservation initiatives. Each conservation practice has a unique set of eligibility criteria and financial incentives associated with its adoption. Therefore, our tool first identifies those regions of an agricultural field where a particular practice is eligible, based on spatial relationships.

Multiple inputs are required to quantify eligibility for each practice contingent on its specific resource objective. We used Conservation Practice 21 (CP21): Filter Strips, Conservation Practice 22 (CP22): Riparian Forest Buffers, and Conservation Practice 33 (CP33): Habitat Buffers for Upland Birds to illustrate how this tool identifies conservation opportunities.

All fields must meet a cropping history criterion as defined in the current Farm Bill (4 of the 6 years 1996 – 2001 under the 2002 Farm Bill). Once cropping history is met implementation of a conservation practice on a particular field is a function of the practice-specific eligibility criteria. CP21 and CP22 must both be adjacent and parallel to a wetland or water body (e.g., streams, lakes, wetlands, sinkholes, etc). The portion of the field within 120 feet or 180 feet of the edge of the wetland is eligible for enrollment in CP21 or CP22, respectively (FSA, 2005). Minimum average buffer width is 30 feet and maximum average buffer width is 120 or 180 feet for CP21 and CP22, respectively. Whereas filter strips and riparian forest buffers are typically on the down slope side of a field, Upland Habitat Buffers, CP33 can be established around the entire field boundary. Average buffer width must be between 30-120 feet (FSA, 2005).

Defining spatially-explicit practice eligibility requires a set of user-provided spatial data layers. Required spatial data layer inputs include 1) hydrography, 2) field boundaries, 3) digital soil maps, and 4) county and soil specific CRP rental rates. To maximize the breadth of applicability, we have designed the tool to use NHD hydrography layers, USDA-FSA CLU field boundaries, and SSURGO soil layers. County and soil-specific CRP rental rates are provided in a spreadsheet that is joined to the soils layer. Users may substitute user-developed layers (e.g. field boundaries) for any of these inputs by pointing the tool to the appropriate patch and file name. Once required inputs are obtained the tool performs a series of geoprocessing steps to spatially define the regions of practice-specific eligibility within the planning extent. These practice-specific eligible regions are output as a shapefile and illustrated in the view window on an aerial photograph. We will describe the conceptual framework of this process acknowledging that the process will change for each practice based on eligibility criteria. To model these parameters in spatially explicit context we use ArcGIS (ArcInfo version 9.3.1) software.

The Eligibility Tool will then perform six major functions:

1) Identify and buffer all eligible boundary layers (field boundaries and/or water bodies) within the geographic extent (e.g., farm boundary) by the maximum width for that practice.
2) Combine eligible buffers into one buffer feature layer
3) Intersect buffer feature layer with soils layer
4) Calculate weighted SRR for each buffer based on three most prevalent soils
5) Calculate area for each buffer
6) Output single part, multiple feature buffer layer with buffer specific area and weighted SRR.

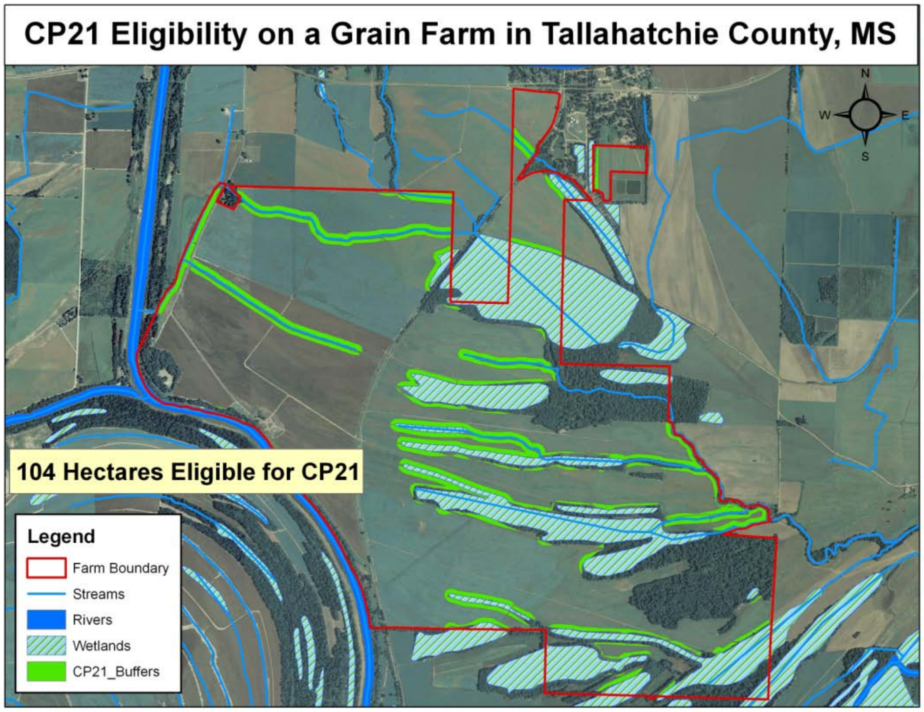

Figure 1. Total area eligible for Conservation Practice 21, Filter Strips on a grain farm in Tallahatchie County, MS.

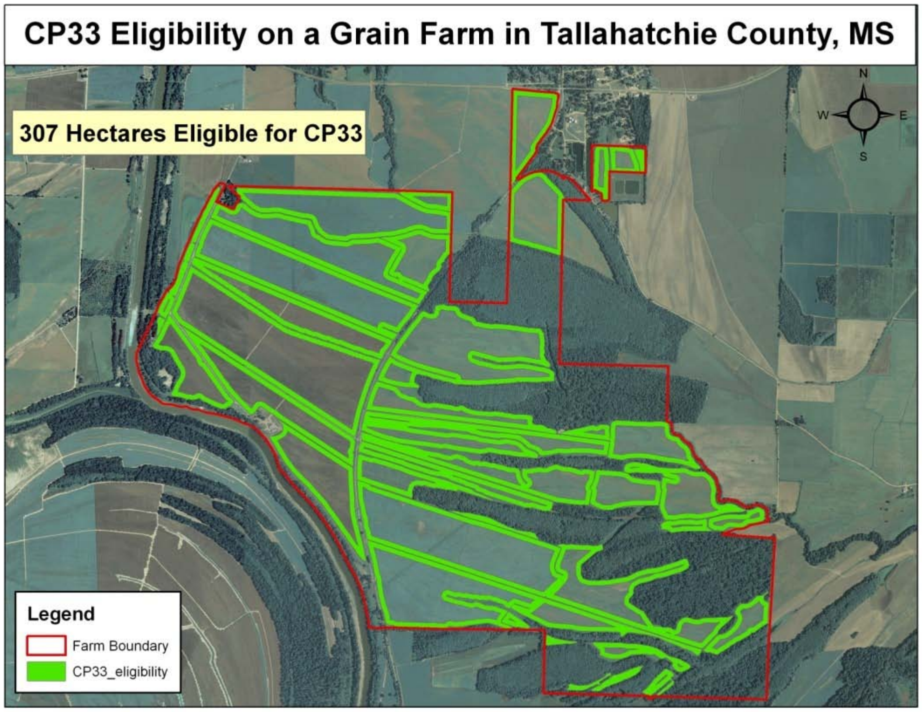

Figure 2. Total area eligible for Conservation Practice 33, Habitat Buffers for Upland Birds on a grain farm in Tallahatchie County, MS.

Profitability Tool

Several inputs and geoprocessing steps are required to calculate profitability of agriculture fields. The most essential element is spatially explicit yield data. Yield data is obtained from GPS yield monitors. Data is typically downloaded from memory cards, calibrated to dry yield, loads are combined into fields, yield data is passed through a series of filtering steps to eliminate erroneous data commonly associated with GPS information (fluctuations in speed, partially full header, non-cutting header position, GPS signal loss, and sensor calibration errors) (Barbour 2006), then exported as a shapefile.

In addition to yield data, economic information about each conservation practice is necessary to calculate profitability under alternative buffer scenarios. Buffer practices under the CCRP typically include a Signup Incentive Payment (SIP), Practice Incentive Payment (PIP), cost share assistance, and county and soil-specific SRR. Together these values less any incurred costs (i.e. maintenance costs), account for total buffer revenue.

Agricultural producers understand that they often experience yield reductions at field margins. These reductions are due to a combination of factors including: production practices (field traffic causing compaction), variable inputs (herbicide, fertilizer, etc), greater weed and insect pressure, and competition with adjacent vegetation for sunlight, water, and nutrients. Yield data is useful for identifying field regions with reduced productivity. Converting yield data into a spatially explicit profitability map is more useful because it illustrates where revenue is gained and/or lost. Once calibrated and cleaned, the yield data can be imported into the tool where the necessary attributes and calculations will be carried out.

The Profitability Tool will perform 5 preliminary functions:

1) Create 6 attribute fields: Commodity Price, Gross Revenue, Government Payments, Total Revenue, Production Costs, Net Revenue
2) Assign and calculate values for each field:
    a. Commodity Price = [User Input]
    b. Gross Revenue = [Commodity Price * Yield]
    c. Government Payments = [User Input]
    d. Total Revenue = [Gross Revenue + Government Payments]
    e. Production Costs = [User Input]
    f. Net Revenue = [Total Revenue – Production Costs]
3) Interpolate yield data by Inverse Distance Weighting using Net Revenue Field to generate profit surface
4) Calculate mean Net Revenue (i.e., profitability) using Zonal Statistics to generate whole field profitability under production alone
5) Export profit map

Figure 3. Profit surface for corn field in Monroe County, MS

Calculating whole field profitability under agricultural production alone identifies field regions where revenue is lost or reduced, whereas, calculating whole field profitability under alternative conservation buffer enrollments identifies field regions where profitability under conservation enrollment is greater than that of production alone. Running this analysis for multiple conservation practices and alternative enrollments within a practice provides a multitude of land use options for agricultural producers.

The Profitability Tool will then perform 6 final functions:

1) Create alternative width buffer polygons adjacent to eligible boundary layers (field boundaries and/or water bodies)
2) Add practice specific financial incentives to previously calculated weighted SRR to generate Buffer Revenue Field
3) Convert buffer layer to raster using Buffer Revenue Field
4) Replace buffer region from previously created profit surface with newly created buffer layer using Raster Calculator
5) Calculate mean Net Revenue (i.e., profitability) using Zonal Statistics to generate whole field profitability under each buffer scenario
6) Export profit map
7) Calculate difference in profit for alternative buffer widths relative to full production

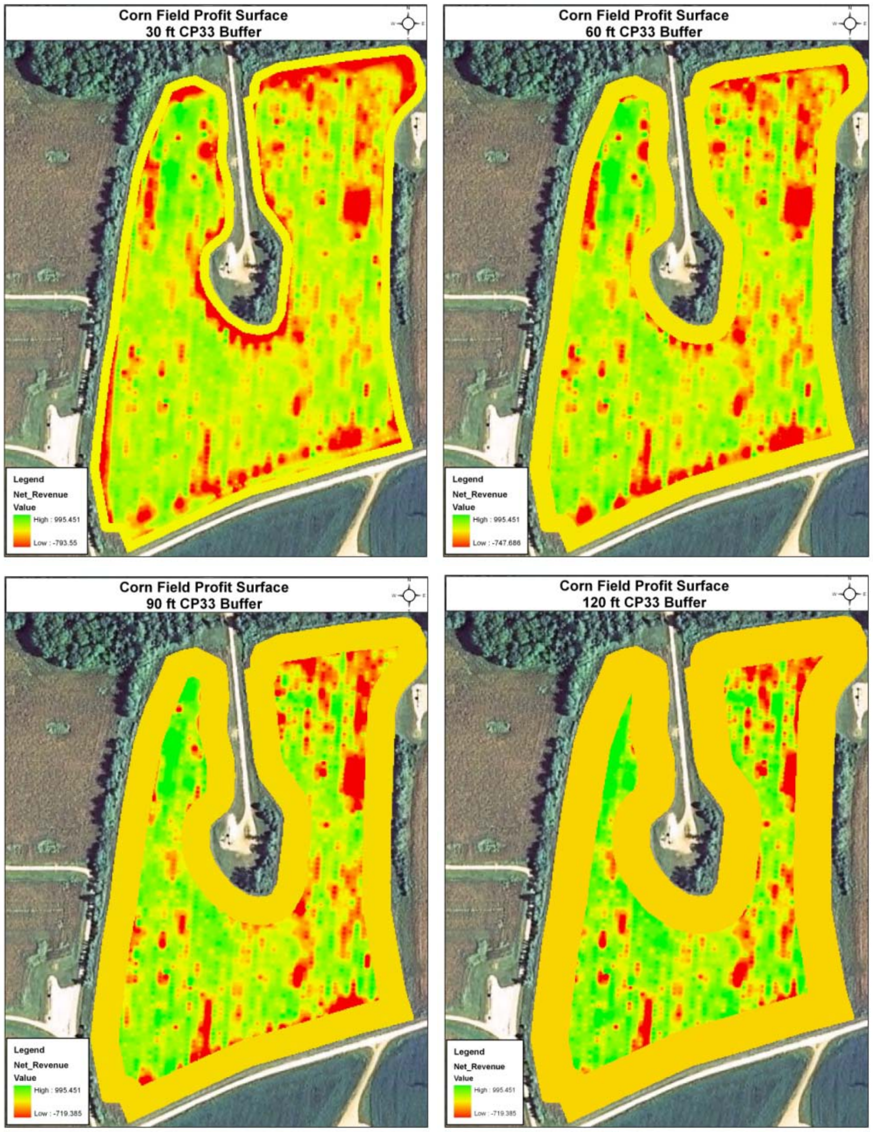

Figure 4. Profit surfaces of alternative CP33 buffer widths on corn field in Monroe County, MS.

RESULTS

Eligibility Tool

Our research demonstrates the utility and effectiveness of PA technologies coupled with a geospatial decision support tool to identify conservation opportunities in agricultural landscapes. Quantifying conservation eligibility is paramount because most producers and natural resource planners cannot visualize where and how conservation programs fit into their production systems. Illustrating eligible land for multiple conservation practices provides options to producers to optimize not only their economic interests but also their specific natural resource concerns (i.e., water quality, soil loss, wildlife habitat). The use of geospatial technology is essential to this process and our decision support tool produces simple, spatially explicit maps that producers can use to inform land use decisions.

Profitability Tool

Our tool uses PA technology to identify economic opportunities in agricultural fields. Spatially explicit profit maps are generated to visualize the monetary distribution of alternative enrollments. Simple calculations are then done to compare profitability of production alone to one of many conservation scenarios. Clearly, year-specific profitability does not capture the full range of spatial and temporal variation associated with stochastic environmental conditions and crop rotations. Spatially-explicit profit surfaces can be averaged over multiple years to better inform decision making.

Figure 5 illustrates how conservation buffers can be used to increase whole field profitability by removing marginal land from production and enrolling it in a conservation practice. It is important to note that not all fields experience yield reductions near field margins at a magnitude that would justify conservation enrollment, however, across an entire farm this process can be instrumental at increasing total revenue if applied strategically (conservation only where profitable).

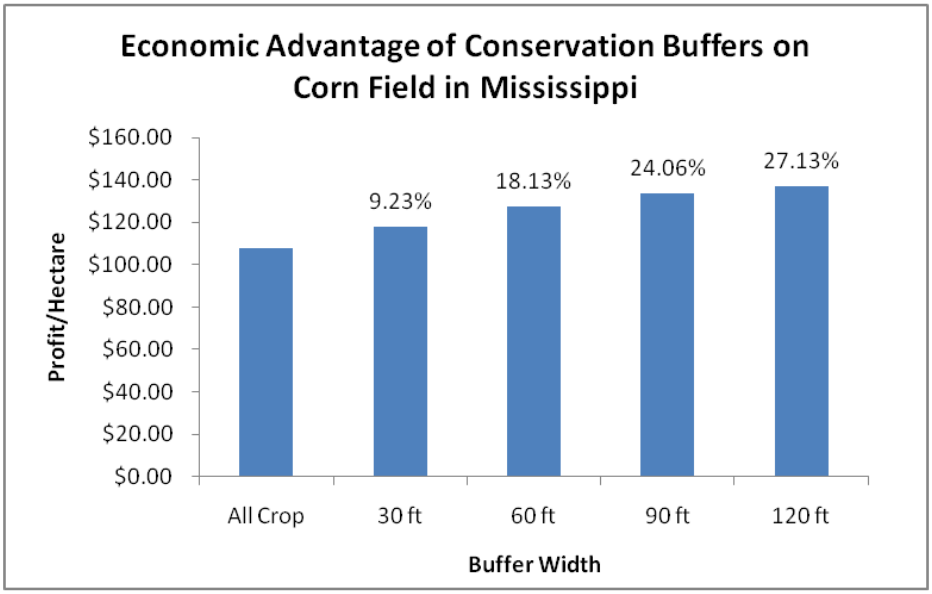

Figure 5 . Change in whole-field profitability under alternative conservation buffer enrollments.

DISCUSSION

Traditionally conservation implementation in agricultural landscapes was thought to hinder or directly reduce profitability. However, as financial incentives increase in scope, quantity, and specificity, strategic enrollment of conservation programs can actually increase profitability. The key to realizing the potential in these programmatic opportunities is helping producers visualize spatially explicit economic and environmental tradeoffs. Precision agriculture technology used in a precision conservation framework can help to optimize both profitability and environmental benefits. Although most producers desire to be good stewards of natural resources and value environmental services that their land produces, economic constraints often hinder adoption. Natural resource professionals must find innovative solutions that balance environmental and economic tradeoffs. Precision conservation provides the necessary tools to implement profitable conservation in a spatially explicit framework that optimizes financial returns to the producer. Our research provides a geospatial decision support tool that identifies conservation and economic opportunities in agricultural landscapes and evaluates the economic tradeoffs of conservation enrollment versus agricultural production. This tool can aid in achieving landscape or watershed level conservation goals by increasing adoption of conservation practices.

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