INTEGRATING PRECISION AGRICULTURE AND REMOTE SENSING TECHNOLOGY TO DELIVER TARGETED CONSERVATION ENROLLMENT

by

NICK MENG

(Under the Direction of Mark D. McConnell)

ABSTRACT

Many facets of the environment have suffered as a result of the expansion and intensification of agriculture. The United States Department of Agriculture (USDA) facilitates the Conservation Reserve Program (CRP) which seeks to reduce the environmental impact of agriculture by paying rental payments for agricultural producers to take environmentally sensitive land out of production and reestablish them in a vegetation that helps conserve various natural resources. However, many producers are unaware of the spatial eligibility of CRP practices and of the economic outcome of removing land from production. We utilized precision agriculture technology to create a geospatial Decision Support Tool (DST) that addresses these concerns. We demonstrate the functionality of the DST and its application on a study farm. We also show how remote sensing technology can be integrated into this framework. Results demonstrate that targeted conservation enrollment can be profitable for producers.

INDEX WORDS: Precision Agriculture, Conservation Reserve Program, Precision Conservation, Decision Support Tool, Remote Sensing

INTEGRATING PRECISION AGRICULTURE AND REMOTE SENSING TECHNOLOGY

TO DELIVER TARGETED CONSERVATION ENROLLMENT

by

NICK MENG

B.S., Kansas State University, 2017

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2019

INTEGRATING PRECISION AGRICULTURE AND REMOTE SENSING TECHNOLOGY

TO DELIVER TARGETED CONSERVATION ENROLLMENT

by

NICK MENG

Major Professor:	Nathan P. Nibbelink
Committee:	Mark D. McConnell
	Marguerite Madden

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
August 2019

DEDICATION

I dedicate this thesis to my father, John Meng. Working on the farm with him at a young age helped instill values of hard work and dedication in me. Even though early on in my life I wasn't interested in agriculture, moving away to college made me realize the beauty and value of living off of and being a steward of the land. His insistence on using farming practices that help conserve our natural resources is what inspired me to take on this project and is the reason why I quickly developed a passion for it. I appreciate his constant support of my academic endeavors even in times when I lacked direction. I would not have found a field that I am passionate about and survived a masters program without his support.

ACKNOWLEDGEMENTS

I first would like to thank my advisor Dr. Mark McConnell for giving me the opportunity to attend the University of Georgia on an assistantship and work on such an exciting and applicable project. This experience has allowed me to grow as a student and a person and has put me on the path to accomplish my career goals. I want to thank him for always going above and beyond to mentor me during my time at UGA. I want to thank my parents, John and Mary Meng for supporting me through this whole process. I'm sure it was difficult for them to see me go to school so far away from home, but their unwavering support is the main reason I made it to this point. I want to thank my girlfriend Lauren McCullough for always providing support and encouragement when I've become discouraged and giving me an escape from the stress of graduate school. I also want to thank all the friends I made during my time at UGA. Your willingness to assist me whenever I needed help was vital to my success and I will cherish all the memories we made together.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Food production has expanded and intensified due to steady human population rise and the continued increase in demand for commodities (Robertson et al. 2005; Johnson et al. 2016). Meeting this global demand has expanded agricultural production to environmentally vulnerable areas, creating concern for water quality, soil quality, and wildlife, among other issues. Globally these environmental concerns are only increasing as 13 million hectares of land are converted to agriculture annually (Robertson & Swinton, 2005). Negative environmental outcomes of intensive agriculture include, but are not limited to, loss of topsoil (Johnson et al. 2016), reduced water and air quality (Tomer et al. 2015; Johnson et al. 2016), greenhouse gas production (Palm et al. 2014), and loss of wildlife habitat (Altieri 1991). Protected areas have been suggested as a strategy to combat these issues, though working alone they are insufficient to meet national conservation needs (Knight 1999; Knight et al. 2010). Converting large amounts of agricultural land to protected status is not practical to meet future global food demands (Robertson et al. 2005; Johnson et al. 2016); therefore an approach is needed that integrates conservation into production agriculture to optimize competing objectives.

Through funding from Congress' Farm Bill, The United States Department of Agriculture (USDA) administers the Conservation Reserve Program (CRP) (USDA NRCS 2015) to address the aforementioned issues. CRP is a land retirement program that provides producers with financial incentives to remove environmentally sensitive agricultural land from production and convert it to a more environmentally friendly land cover (e.g., native grass, forest, or wetland)

(Glaser 1985; Morefield et al. 2016; Li et al. 2017). The purpose of CRP is to reduce the negative impact agriculture has on water quality, erosion, and wildlife habitat, as well as provide commodity price control (Johnson et al. 2016). There are currently 35 CRP practices, each addressing one or more environmental concerns (USDA NRCS 2015). Contracts are 10 or 15 years and include payments based off soil type as well as additional incentives depending on the practice (USDA NRCS 2015). A plethora of research illustrates the positive environmental impact of CRP on water quality, carbon emissions, and wildlife habitat (Burger 2000; Miltner 2015; Li et al. 2017).

There are several hindrances to the widespread adoption of CRP practices. Producers are generally unfamiliar with the CRP practices and other conservation practices that are available (Miller 2017). Unfortunately, farmers are unlikely to enroll in a program they have little knowledge about. (Reimer & Prokopy 2014). Other hindrances to CRP participation include a perceived pest problem from conservation areas, lack of technical knowledge to implement a practice, the view that a practice requires too much time, space, or money, and concerns about government intrusion (Arbuckle 2013, Gaines-day & Gratton 2017). The complexity of CRP has also been shown to be a significant hindrance to practice adoption (Reimer & Prokopy 2014). Eligibility and other rules change sometimes yearly making it hard for producers to keep up with changing regulations (USDA NRCS 2015). However, the most significant hindrance to CRP enrollment is producer's assumption that taking land out of production will result in a loss in profit (McConnell and Burger 2011, Muth 2014, McConnell et al. 2016, Lute et al. 2018). Research however has shown that conservation practices can actually be profitable if marginal land is targeted (McConnell and Burger 2011; Lyle et al. 2015; McConnell et al. 2016). With profitable row crop agriculture becoming more challenging, the guaranteed income of a CRP contract will become more appealing to producers (Kitchen et al. 2005) especially on marginally profitable or unprofitable land. Producers however lack the tools to identify low profit areas and analyze the tradeoff of converting those areas to a CRP practice.

Precision agriculture (PA) is defined as a series of spatial information technologies that have the potential to improve farm profitability by increasing yields and lowering input costs (Zhou et al. 2017). One of the most common PA applications is the use of spatially explicit yield data to identify low profiting or unprofitable areas in a field (Zhou et al. 2017). This will be the focus of this study. Using this technology in a conservation framework allows conservation to take place strategically and efficiently (Berry et al. 2003). Previous research has used PA technology to identify unprofitable areas of a field to convert to biofuel production (Bonner et al. 2014), quantify the watershed level effects on soil and water quality of CRP practices (Rao et al. 2007), and target low profiting field areas to establish a conservation practice (Stull et al. 2004; McConnell & Burger 2011; McConnell et al. 2016; Capmourteres et al. 2018). Collectively, this body of research is limited due either to its inability to consider the financial tradeoff of establishing a CRP practice or inability to deliver a comprehensive user friendly Decision Support Tool (DST) to implement these frameworks on all CRP practices. We have created a geospatial DST to address this issue that will help agricultural producers visualize the spatially eligible areas of their field for a given practice and allow them to identify, from spatially explicit yield data, areas in their field that are unprofitable. The user will then be able to determine if an opportunity to increase profit exists through CRP enrollment. Identifying fields where CRP is an economically viable option could increase enrollment and generate landscape-level conservation impacts. The DST will be available as a user-friendly ArcMap (ESRI 2018) script tool. We demonstrate the application of this DST and illustrate the ability for CRP practices to be implemented profitability results from on a farm in Lowndes County, Mississippi.

The ability of conservation agencies to effectively utilize this DST could be hindered by limited availability of spatially explicit yield data (Zhou et al. 2017). Conservation agencies looking to promote conservation practices have varying conservation goals and finite resources to accomplish these goals. Large scale targeting of their efforts is needed for their efficient operation. Landscape-scale identification of subfield areas that are predicted to profit from targeted CRP establishment would address both of these challenges. One study attempted to solve this problem by predicting low profitability areas in Iowa using yield prediction based on soil type standardized by county yield reports (Brandes et al. 2016). Another study identified fields with highly variable yield by creating a soil vulnerability and variability index where fields were ranked based off their potential to benefit from implementing precision agriculture practices (Bobryk et al. 2017). This model uses variables such as soil type and climate variability during the growing season. Similar research uses yield data to create an opportunity index that ranks fields based upon their potential to benefit financially from precision agriculture technology and the practicality of adopting this technology. (Sun et al. 2013; Leroux & Tisseyre 2018). Shortcomings of these models include the need for yield data, inaccuracies associated with their approach, and the complexity of their models. To address these issues, we have developed a simplistic model using National Agriculture Imagery Program (NAIP) imagery that will identify financially vulnerable areas of a field to facilitate targeted conservation enrollment to increase environmental and economic outcomes.

Literature Cited

Arbuckle, J. G. J. 2013. Farmer attitudes toward proactive targeting of agricultural conservation programs. Society & Natural Resources 26(6):625–641.

Berry, J. K., Detgado, J. A., Khosla, R., & Pierce, F. J. (2003). Precision conservation for environmental sustainability. *Journal of Soil and Water Conservation*, *58*(6), 332–339. Retrieved from http://www.jswconline.org/content/58/6/332

Bobryk, C. W., M. A. Yost, and N. R. Kitchen. 2017. Field variability and vulnerability index to identify regional precision agriculture opportunity. Precision Agriculture (2017):1–17.

Bonner, I. J., K. G. Cafferty, D. J. Muth, M. D. Tomer, D. E. James, S. A. Porter, and D. L. Karlen. 2014. Opportunities for energy crop production based on subfield scale distribution of profitability. Energies 7(10):6509–6526.

Brandes, E., G. S. McNunn, L. A. Schulte, I. J. Bonner, D. J. Muth, B. A. Babcock, B. Sharma, and E. A. Heaton. 2016. Subfield profitability analysis reveals an economic case for cropland diversification. Environmental Research Letters 11(1):014009.

Burger, L. W. 2000. Wildlife responses to the Conservation Reserve Program in the Southeast. Pages 55-74 in W. L. Hohman, ed. A comprehensive review of farm bill contributions to wildlife conservation 1985-2000. Technical Report, USDA/NRCS/WHMI-2000.

Capmourteres, V., J. Adams, A. Berg, E. Fraser, C. Swanton, and M. Anand. 2018. Precision conservation meets precision agriculture: A case study from southern Ontario. Agricultural Systems 167(May):176–185.

ESRI 2018. ArcGIS Desktop: Release 10.6 Redlands, CA: Environmental Systems Research Institute.

Farrand, D. T., and M. R. Ryan. 2005. Impactof the Conservation Reserve Program on Wildlife

Conservation in the Midwest. Fish and Wildlife Benefi ts of Farm Bill Programs: 2000–2005 Update 43(Usda 2003):41–62.

Gaines-day, H. R., and C. Gratton. 2017. Understanding Barriers to Participation in Cost-Share Programs For Pollinator Conservation by Wisconsin (USA) Cranberry Growers. Insects 8(3):79.

Glaser, L. K. 1985. Provisions of the Food Security Act of 1985. United States Department of Agriculture.

Homberger, B., J. Duplain, M. Jenny, and L. Jenni. 2017. Agri-evironmental schemes and active nest protection can increase hatching success of a reintroduced farmland bird species. Landscape and Urban Planning 161 (2017):44–51.

Johnson, K. A., B. J. Dalzell, M. Donahue, J. Gourevitch, D. L. Johnson, G. S. Karlovits, B. Keeler, and J. T. Smith. 2016. Conservation Reserve Program (CRP) lands provide ecosystem service benefits that exceed land rental payment costs. Ecosystem Services 18 (2016):175–185.

Knight, A. T., R. M. Cowling, M. Difford, and B. M. Campbell. 2010. Mapping Human and Social Dimensions of Conservation Opportunity for the Scheduling of Conservation Action on Private Land\nMapeo de Dimensiones Humanas y Sociales de la Oportunidad de Conservación para la Programación de Acciones de Conservación en Tierra. Conservation Biology (2010):no-no.

Knight, R. L. 1999. Private lands: The neglected geography. Conservation Biology 13(2):223–224.

Leroux, C., and B. Tisseyre. 2018. How to measure and report within-field variability: a review of common indicators and their sensitivity. Precision Agriculture(0123456789):1–29.

Li, C., L. M. Fultz, J. Moore-Kucera, V. Acosta-Martínez, J. Horita, R. Strauss, J. Zak, F. Calderón, and D. Weindorf. 2017. Soil carbon sequestration potential in semi-arid grasslands in the Conservation Reserve Program. Geoderma 294 (2017):80–90.

Lute, M. L., C. R. Gillespie, D. R. Martin, and J. J. Fontaine. 2018. Landowner and Practitioner Perspectives on Private Land Conservation Programs. Society and Natural Resources 31(2):218–231.

Lyle, G., B. A. Bryan, and B. Ostendorf. 2015. Identifying the spatial and temporal variability of economic opportunity costs to promote the adoption of alternative land uses in grain growing agricultural areas: An Australian example. Journal of Environmental Management 155(March):123–135.

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.

McConnell, M. D., L. W. Burger, J. Delgado, G. Sassenrath, and T. Mueller. 2016. Precision Conservation to Enhance Wildlife Benefits in Agricultural Landscapes 9740 (2016):1–28.

Miller, C. 2017. Conservation Reserve Program in Illinois : Investigation of Participants ' Motives , Expectations , and Desired Outcomes 2017(17).

Morefield, P. E., S. D. LeDuc, C. M. Clark, and R. Iovanna. 2016. Grasslands, wetlands, and agriculture: the fate of land expiring from the Conservation Reserve Program in the Midwestern United States. Environmental Research Letters 11(9):94005.

Muth, D. 2014. Profitability versus environmental performance: Are they competing? Journal of Soil and Water Conservation 69(6):203–206.

Palm, C., H. Blanco-canqui, F. Declerck, L. Gatere, and P. Grace. 2014. Agriculture , Ecosystems and Environment Conservation agriculture and ecosystem services : An overview. “Agriculture, Ecosystems and Environment” 187 (2014):87–105.

Rao, M., G. Fan, J. Thomas, G. Cherian, V. Chudiwale, and M. Awawdeh. 2007. A web-based GIS Decision Support System for managing and planning USDA’s Conservation Reserve Program (CRP). Environmental Modelling and Software 22(9):1270–1280.

Reimer, A. P., and L. S. Prokopy. 2014. Farmer participation in U.S. Farm bill conservation programs. Environmental Management 53(2):318–332.

Robertson, G. P., and S. M. Swinton. 2005. Reconciling agricultural productivity and environmental integrity : a grand challenge for agriculture. Frontiers in Ecology and the Environment 3(1):38–46.

Stull, J., C. Dillion, S. Shearer, and S. Isaacs. 2004. Using Precision Agriculture Technology for Economically Optimal Strategic Decisions: The Case of CRP Filter Strip Enrollment. Journal of Sustainable Agriculture 24(4):39–56.

Sun, W., B. Whelan, A. B. McBratney, and B. Minasny. 2013. An integrated framework for software to provide yield data cleaning and estimation of an opportunity index for site-specific crop management. Precision Agriculture 14(4):376–391.

Tomer, M. D., K. M. B. Boomer, S. A. Porter, B. K. Gelder, D. E. James, and E. McLellan. 2015. Agricultural conservation planning framework: 2. Classification of riparian buffer design types with application to assess and map stream corridors. Journal of Environmental Quality 44(3):768–79.

Wiens, J. 1995. Habitat fragmentation: island v landscape perspectives on bird conservation (1995).

Zhou, X. V., B. C. English, J. A. Larson, D. M. Lambert, R. K. Roberts, C. N. Boyer, M.

Velandia, L. L. Falconer, and S. W. Martin. 2017. Precision farming adoption trends in the Southern U.S. Journal of Cotton Science 21(2):143–155.

CHAPTER 2

A GEOSPATIAL DECISION SUPPORT TOOL TO EVALUATE THE ECONOMIC OUTCOMES OF TARGETED CONSERVATION DELIVERY

---

[1]Meng, N. J., N. Nibbelink, M. Madden, and M. D. McConnell. To be submitted to *Computers and Electronics in Agriculture*

Abstract

A need for conservation has existed since the mechanization of agriculture. Advances in agricultural technology coupled with rising human populations have resulted in the expansion and intensification of agriculture. The environment has suffered as a result of this expansion and intensification including a reduction in wildlife habitat, decrease in water quality, and loss of vital top soil from erosion. Reducing the environmental impact of agriculture means implementing environmentally friendly practices alongside agricultural production. The United States Department of Agriculture (USDA) facilitates the Conservation Reserve Program (CRP) which seeks to accomplish this goal. CRP pays agricultural producers a rental rate to take unproductive and environmentally sensitive land out of production and reestablish them in a native vegetation that helps conserve various natural resources. However, a concern with this program is that producers are unaware of the spatial eligibility requirements of each CRP practice and assume taking land out of production will result in a reduction in profit. Precision agriculture technology used for conservation purposes provides the necessary tools to address these concerns. Producers can identify inherently low yielding and low profit subfield areas using spatially explicit yield data. The producer can determine if these areas overlap with the spatial eligibility of a given CRP practice. We created a decision support tool (DST) that integrates these components and provides a user-friendly approach for agricultural producers to simultaneously optimize their conservation and economic objectives. We demonstrate how to conduct an eligibility and profitability analysis and how to run the tool on various CRP practices and scenarios. We will also discuss the implications of this research and the future direction.

Introduction

The combination of the mechanization of agriculture and increasing human populations has led to the expansion and intensification of agricultural production (Johnson et al. 2016), resulting in the degradation of many facets of the environment (Robertson & Swinton 2005). Negative environmental outcomes of intensive agriculture include, but are not limited to, loss of topsoil (Johnson et al. 2016), reduced water and air quality (Tomer et al. 2015; Johnson et al. 2016), greenhouse gas production (Palm et al. 2014), and loss of wildlife habitat (Farrand 2005; McConnell & Burger 2011). There are 40+ million acres of protected conservation areas in the United States (Bigelow & Botchers 2017), however protected areas are unlikely to address national conservation needs (Knight 1999; Knight et al. 2010) due to the fact that 1/5 of the contiguous land area in the United States is in production agriculture and converting large amounts of agricultural land to protected status will hinder future food production goals. This illustrates a need for conservation and production agriculture to work in harmony (Robertson & Swinton 2005; Johnson et al. 2016; Bigelow & Botchers 2017).

Agricultural conservation policy in the United States, via the Farm Bill, utilizes a variety of programs with different strategies to accomplish conservation goals. The most popular and recognizable program is the Conservation Reserve Program (CRP). CRP seeks to retire land from production for a 10 or 15-year period and convert it to an environmentally friendly land cover (e.g., native grass, forest, or wetland) (Glaser 1985; Morefield et al. 2016; Li et al. 2017). CRP's purpose is to reduce the negative impact agriculture has on water quality, erosion, and wildlife habitat, as well as provide commodity price control (Johnson et al. 2016). There are currently 35 CRP practices, each addressing one or more environmental concerns (USDA NRCS 2015). The financial incentives are annual payments based off the soil type of the land taken out of production, which is called the soil rental rate (SRR) (USDA NRCS 2015). Some practices provide additional financial incentives beyond the SRR (e.g., sign-up incentives). Most practices provide incentives to offset the cost of establishing and maintaining a practice (USDA NRCS 2015). The positive environmental impacts of CRP are seen for many different aspects of the environment. These include the reduction of agriculture's carbon footprint (Li et al. 2017), improvement of water quality (Miltner 2015), and increase in wildlife habitat (Farrand & Ryan 2005; Riffell et al. 2010; Fahrig et al. 2015). Research has also determined the rental rates paid are much less than the value of the ecosystem services CRP provides (Johnson et al. 2016).

There are several hindrances to the widespread adoption of CRP practices. Producers are generally unfamiliar with the CRP practices and other conservation practices that are available (Miller 2017). Other hindrances to CRP participation include a perceived pest problem from conservation areas, lack of technical knowledge to implement a practice, the view that a practice requires too much time, space, or money, and concerns about government intrusion (Arbuckle 2013, Gaines-day & Gratton 2017). The complexity of CRP has also been shown to be a significant hindrance to practice adoption (Reimer & Prokopy 2014). Eligibility and other rules change sometimes yearly making it hard for producers to keep up with changing regulations (USDA NRCS 2015). Unfortunately, farmers are unlikely to enroll in a program they have little knowledge about. (Reimer & Prokopy 2014). The most significant hindrance to CRP enrollment is producer's assumption that taking land out of production will result in a loss in profit (McConnell and Burger 2011, Muth 2014, McConnell et al. 2016, Lute et al. 2018). Research however has shown that a conservation practice can actually be profitable if marginal land is targeted (McConnell and Burger 2011, Lyle et al. 2015, McConnell et al. 2016). The NRCS National Planning Procedures Handbook (NPPH; NRCS 2014) states that conservation should be driven by landowner's objectives further validating this approach. With profitable row crop agriculture becoming more challenging, the guaranteed income of a CRP contract will become more appealing to producers (Kitchen et al. 2005). Producers however lack the tools to identify low profit areas and analyze the tradeoff of converting those areas to a CRP practice.

A comprehensive definition of precision agriculture (PA) is a series of spatial information technologies that have the potential to improve farm profitability by increasing yields and lowering input costs (Zhou et al. 2017). Examples of this technology include variable rate application, global positioning system (GPS)-guidance, and automated section control (Zhou et al. 2017). This research will focus on yield mapping via GPS. Spatially explicit yield data is acquired when a harvester records a GPS location and the grain flow using sensors, which is then converted to dry yield volume (Hopkins 2009). This spatially explicit yield data has many PA applications, though the most common is using it to generate a continuous raster surface of yield and calculate profitability to identify low yielding areas in a field where opportunities to increase profitably through an alternative practice exist (Vellidis et al. 2011, Sun et al. 2013, Maestrini & Basso 2018). Subfield areas where the opportunity to benefit financially from an alternative practice are common as most farmers suffer from variable yield on anywhere from 12% to 20% of the areas in their fields (Lyle et al. 2015; McConnell et al. 2016). A regional study has shown a 71.2% adoption rate of yield monitors, though nationwide there is still a lack of producers with multiple years of accurate yield data (Castle 2016). Previous research has used PA technology to identify unprofitable areas of a field to convert to biofuel production (Bonner et al. 2014), quantify the watershed level effects on soil and water quality of CRP practices (Rao et al. 2007), and target low profiting field areas to establish a conservation practice (Stull et al. 2004; McConnell & Burger 2011; McConnell et al. 2016; Capmourteres et al. 2018). Collectively, this body of research is limited due either to its inability to consider the financial tradeoff of establishing a CRP practice or inability to deliver a comprehensive user friendly DST to implement these frameworks on all CRP practices.

Methods

DST Development Overview

We developed the DST as an ArcMap 10.x (ESRI 2018) script tool using ArcGIS's geospatial library arcpy and other built in python libraries. A DST was developed in previous research, though it only modeled three CRP practices and was not publicly available (McConnell & Burger 2011; McConnell et al. 2016). We expanded this DST's functionality to model the spatial eligibility and economic outcomes of 35 CRP practices and operate in a user friendly manner. The DST has two primary functions: 1) illustrate spatial eligibility of Farm Bill conservation practices, and 2) calculate and compare profitability of row crop agriculture to a given CRP practice.

Required Data Inputs

The user must provide several geospatial layers to run this tool. They must have an accurate layer representing field boundaries (Figure 2.1). Field boundaries should be digitized if their accuracy is insufficient. The user must also provide a state and county specific SSURGO (Soil Survey Geographic Database) layer to calculate the SRR (Figure 2.1). The SSURGO layer can be downloaded for free using the Natural Resource Conservation Service's (NRCS) Geospatial Data Gateway (https://datagateway.nrcs.usda.gov/). Riparian buffer practices (CP-21, CP-22, CP-29, and CP-30) require the user to input National Hydrological Dataset (NHD) layers representing streams, rivers, and wetlands (Figure 2.2). These can also be downloaded via the

NRCS’s Geospatial Data Gateway. Lastly, the user must provide spatially explicit yield data to conduct a profitability analysis (Figure 2.3).

Illustrating Conservation Eligibility

The spatial eligibility for each practice varies (USDA NRCS 2015). Some practices, like CP-3 Tree Plantings, only allow for a whole field to be enrolled. User defined extent practices, like CP-42 Pollinator Habitat Establishment, allow for any area within a field to be enrolled. Wetland practices, like CP-23 Wetland Restoration, require the restoration of or creation of new wetlands with associated grassland buffers (USDA NRCS 2015). The wetland area within the field and buffer distances is defined by the user. The eligibility of riparian buffer and field edge buffer practices are generated by the DST based off the user’s field boundary and NHD layers. The user would first want to conduct an eligibility analysis when analyzing these practices to determine the eligible areas throughout an entire farm (Figure 2.4). This eligibility analysis will output a layer of all eligible areas throughout the farm with the associated SRR. This is useful for the user to identify which fields have eligible areas and then decide which field(s) to conduct a profitability analysis.

Calculating Profitability of Row Crop Production

The user needs spatially explicit yield data to conduct a profitability analysis. All errors and outliers should be removed from the yield data before it is input into the DST (Sun et al 2013). The user should remove values outside of a reasonable range of dry yield volume values per crop type. For example, a common range for corn would be 20.18 – .67 tonnes/hectare dry yield volume and a common range for soybeans would be 5.38 – .34 tonnes/hectare. The outliers of the remaining data beyond ± 3 standard deviations of the mean should be removed as well (Sun et al 2013). The user must provide various economic inputs to calculate profitability. These include the commodity price per bushel, government payments received per acre, and production costs per acre. A continuous yield surface is needed to accurately calculate subfield scale profitability; therefore, we interpolate the dry yield volume of the yield points using Inverse Distance Weighted (IDW) to create a raster yield surface. The cell size of the output raster can either be automatically calculated by the DST or input by the user. IDW has been shown to be an accurate interpolation method for yield data (Souza et al 2016). The row crop profitability of the field is calculated by multiplying commodity prices by the dry yield volume and adding government payments. Production costs are then subtracted from this value. The entire equation is as follows:

Row Crop Profitability = (Commodity Price * Dry Yield Volume) + Government Payments – Production Costs.

This value is recorded in the attribute table of the output profitability layer as the Original Profit.

Calculating Profitability of Conservation Enrollment

Profitability calculation for conservation practices with spatial eligibility requirements and limitations (e.g., CP-21, CP-22, CP-29, CP-30, CP-33) requires the user to enter the various buffer distances to be considered within the allowed distances for the given practice. This eligible conservation area is removed from the original profit surface raster and this new raster's average value is calculated to determine the profitability per acre had the CRP area not been farmed at all. This value is recorded in the profitability layer as No Farm Profit. The Soil Rental Rate (SRR) must be determined to calculate the profitability of a CRP practice. The SRR is the dollar amount paid in the CRP contract based off the soil types where the practice will be established. The soil types within each state and county have an established rental rate. A table with these values is included with the DST and is automatically joined to the SSURGO layer.

Within each field's eligible areas, we calculate the SRR by taking the three most prevalent soil types and weighting their SRR values by the percentage of their area. Other required parameters for the CRP profitability calculation include CRP establishment cost per acre, CRP maintenance costs per acre, and CRP contract length (10 or 15 years). Additional incentives can be added to the SRR including a Sign-up Incentive and Rental Rate Incentive. Other incentives include the Cost Share Program and the Practice Incentive Payment which can cover up to 90% of the cost of establishing a practice. The Maintenance Rate Incentive can help cover the cost of maintaining a practice. These incentives are only available for certain practices. CRP profitability is calculated by the following equation:

CRP Profit = (SRR + Incentives) – (Establishment Costs – Establishment Incentives + Maintenance Costs – Maintenance Incentives)

The CRP profit layer is converted to raster format and overlain with the original profit surface. The raster's average value is calculated to determine the Overall Profit and is recorded in the attribute table. The DST has help documentation in the Graphical User Interface (GUI) to allow for smooth operation. A user guide is also included to navigate new users through the capabilities and proper use of the DST (Appendix A). Considerations were made to make the DST as functional and user friendly as possible including disabling parameters in the GUI that are not needed for a given practice, error trapping for common issues, and providing the user with understandable error messages. Progress messages are also included to update the user on the DST's progress. Multiple rounds of testing from authors and a beta test administered to the conservation organizations that will be using this DST ensure that it meets user expectations.

Results

Running the DST results in several output layers. An eligibility analysis outputs a layer of all eligible areas for a given practice with the associated SRR (Figure 2.4). A profitability analysis outputs a layer of the extent of the practice including multiple polygons for practices where multiple buffer distances were considered. Various values are calculated and written to the attribute table including the Field Area (acres), Weighted SRR, Original Profit, CRP Profit, CRP Area (acres), No Farm Profit, Overall Profit, and the Percent Profit Change (difference in Original Profit and Overall Profit). An original profit raster is output as well using predefined symbology and the user defined or default cell size (Figure 2.5). One or more profit surfaces of the original profit surface overlain with the CRP practice are generated as well. A bar graph in PDF format is created that compares whole field original profit to whole field profit with a CRP practice (Figure 2.6).

Field Buffer Practice Example

CP-33 Upland Bird Habitat is the one field edge buffer practice in the CRP program. This practice allows native warm season grasses, forbs, legumes and shrubs to be established in buffer widths ranging from 9.1 to 36.6 meters from the edge of the field. The purpose of this practice is to increase northern bobwhite (*Colinus virginianus*) habitat in agricultural landscapes, though other wildlife benefit as well (USDA NRCS 2015). The user can run an eligibility analysis across their entire farm before deciding which field(s) to conduct a profitability analysis. An eligibility analysis buffers a farm wide layer of field boundaries inward the maximum distance allowed (36.6 meters) and calculates the SRR of all the eligible areas. Once the user decides which field to run the profitability analysis on they must determine which buffer distances to consider and the raster cell size. (Figure 2.7). Another feature for this practice generates a layer of profitable areas within the buffers (Figure 2.5). This is accomplished by comparing, on a cell level, the profitability of the original profit surface raster to the profitability of the CRP practice raster. A cell is extracted if the CRP practice is more profitable. These cells are then converted to polygons, aggregated together considering an aggregation distance of 5 meters, and polygons smaller than 1000 square meters are removed. Using this profitable buffer layer as a guide, the user is able to run the DST another time with this iteration allowing the user to draw their own CP-33 extent within the spatial eligibility of the given practice, enabling them to more precisely target unprofitable areas and draw buffers that would allow the field to be easily farmed (Figure 2.8).

Riparian Buffer Practices Example

CP-21 Filter Strip, CP-22 Riparian Buffers, CP-29 Wildlife Habitat Buffer, and CP-30 Wetland Buffer are all riparian buffer practices. Their specific conservation goals vary slightly with their main goal of establishing riparian buffers to improve water quality (USDA NRCS 2015). These practices require spatially explicit National Hydrological Dataset (NHD) layers, including a wetland, river, and stream layer. The accuracy and completeness of this dataset is variable and should be inspected by the user before using. The stream layer comes as a line type that is the centroid of a stream and thus the user must input a buffer distance of half the width of the stream to accurately model the stream edge. The user should conduct an eligibility analysis with these practices as well (Figure 2.2). The eligibility analysis will buffer from each NHD layer the maximum distance allowed for the given practices (varies from 30.5 to 36.6 meters). Areas in the field boundaries that are within the eligible distance from the NHD layers' edge are considered eligible for a riparian buffer practice. An eligibility layer with the SRR of all eligible areas is generated (Figure 2.4). Next the user may choose a field to run a profitability analysis, which is conducted similarly to CP-33. The DST also generates a profitable buffer layer for these practices and allows the user to draw their own buffers.

User Defined Extent Practices

User defined extent practices include CP-4B Wildlife Habitat Corridors, CP-5A Field Windbreak Establishment, CP-8A Grass Waterway, CP-12 Wildlife Food Plot, CP-15A Grass Contour Strip, CP-16A Shelterbelt Establishment, CP-17A Living Snow Fences, CP-18B Salinity Reducing Vegetation Establishment, CP-24 Cross Wind Trap Strips, CP-38 State Acres for Wildlife Enhancement, and CP-42 Pollinator Habitat Establishment. The conservation goal varies by practice. The extent of the practice is defined by the user within the field. Each practice has different spatial restrictions. CP-42 for example, requires the total area of the practice to be larger than .2 hectares, and strips to be a least 6.1 meters wide. If the user draws an extent that violates these rules an error message will be displayed when the DST is ran. The profitability analysis is conducted in a similar manner as the previously mentioned practices. This workflow is seen in Figure 2.9.

Wetland with Grassland Buffer Practice

Wetland with Grassland Buffer Practices include CP-9 Shallow Water Areas for Wildlife, CP-23 Wetland Restoration (Floodplain), CP-23A Non-Floodplain Wetland Restoration, CP-27 Farmable Wetland (Wetland), CP-28 Farmable Wetland (Buffers), CP-37 Duck Nesting Habitat, CP-39 Farmable Wetland Program (Constructed Wetland), CP-40 Farmable Wetland Program (Aquaculture Wetland), and CP-41 Farmable Wetland Program (Flooded Prairie Wetland). The purpose of these practices is to establish native wetlands for the improvement of water quality, flood control, and to create wildlife habitat (USDA NRCS 2015). All wetland practices are required to have a grassland buffer around the wetland. Each practice has different requirements for wetland area, grassland area, and buffer widths. The DST returns an error if any of these requirements are violated. For example, the buffer size of CP-23 cannot exceed three times the size of the wetland. The DST will calculate the area of the buffer and the wetland, if the buffer is three times larger than the wetland an error will appear instructing the user to consider either a larger wetland or smaller buffers. The user must define the extent of the wetland and the buffer distances to be considered. The profitability analysis is conducted in a similar manner as the previously mentioned practices. This workflow is seen in Figure 2.10.

Whole Field Practices

Whole field practices include CP-1 Introduced Grass or Legume Establishment, CP-2 Native Grass, Forb, and Legume Establishment, CP-3 Tree Plantings, CP-3A Hardwood Tree Plantings, CP-4D Permanent Wildlife Habitat, CP-25 Rare and Declining Habitat, CP-31 Bottomland Hardwood Tree Establishment, and CP-36 Longleaf Pine Establishment. The conservation goal varies by practice. Only a whole field may be enrolled in these practices. The spatial eligibility of whole field practices is any field polygon on the farm, thus an eligibility analysis is not needed. However, fields must meet CP-specific general or continuous CRP eligibility criteria such as Highly Erodible Land, conservation priority area (e.g. Longleaf pine CPA), or state-specific SAFE (CP-38) regional priority areas. The determination of these is beyond the scope of the DST. The profitability analysis is conducted in a similar manner as the previously mentioned practices. The workflow is seen in Figure 2.11.

Alternative Practice

The DST also allows for the user to consider a non-CRP related alternative practice. Examples of alternative practices include converting land to biofuel production or to pasture to graze cattle. Environmental Quality Incentives Program (EQIP) and Wetland Reserve Program

(WRP) practices could also be modeled and analyzed as an alternative practice. The user can manually draw the extent of this alternative practice in their field (Figure 2.12). The user is required to enter basic economic values for their alternative practice (Figure 2.12). These include Total Establishment Costs, Total Maintenance Cost, and Total Profit. The user must also input the number of years considered for all the costs and total profit. The profitability of the alternative practice in $ per acre is calculated from the equation below:

Alternative Practice Profitability = Gross Profit Per Year – (Establishment Cost Per Year + Maintenance Cost Per Year)

As with the CRP practices, the user is able to analyze the financial tradeoff of the alternative practice vs. regular row crop agriculture.

Conclusion

A historical lack of targeted CRP enrollment addressing financial concerns has hindered conservation enrollment (McConnell & Burger 2011;McConnell et al 2016). Arming producers with economic information regarding the enrollment of a CRP practice will result in new acreage being enrolled, which in many cases will be the most environmentally vulnerable land (Muth 2014; Hamada et al. 2015; Muth 2015). The recent expansion of CRP acreage and reduction in SRRs highlights the necessity for efficient and strategic CRP enrollment that targets low profiting areas to take advantage of the increased CRP acreage (USDA NRCS 2019). We have developed a user friendly DST that allows producers to determine the economic tradeoff of converting land to any of 35 CRP practices. It also allows them to consider a non-CRP alternative practice. This DST will be widely distributed to conservation professional for implementation of this approach. Additional research has demonstrated the DST’s application on a study farm (Meng 2019). Other DST's have looked to quantify the reduction in soil erosion (Rao et al. 2007) and the increase in water quality (Dosskey & Eisenhauer 2005; Rao et al. 2007)) of establishing a practice, while other research has quantified the impact of a practice on wildlife populations and called for the creation of a DST to make their framework applicable (Yeiser et al. 2018). Future research should focus on combining these DSTs and frameworks to produce a more comprehensive DST that allows a user to analyze and quantify a CRP practice from a financial and conservation perspective. Future research should also develop a DST to model land retirement programs in other countries (European Union (EU) or Australia) and see if a targeted conservation approach is effective in their production systems and land retirement programs as well. Conservation agencies utilizing this DST have varying conservation goals and finite resources to accomplish these goals. There is a need for large scale targeting of the DST's use for conservation agencies to efficiently use it. We could accomplish this by identifying fields on a landscape scale that are predicted to profit from CRP establishment and have a high likelihood of accomplishing a specific conservation goal (habitat potential, erosion or water quality vulnerability). Current research has used remote sensing technology to accomplish these goals and should be continued into the future (Meng 2019). Many producers do not have the technology to collect spatially explicit yield data, do not know how to use the technology, or are unwilling to release their yield data (Zhou et al. 2017). It would also be beneficial to use remote sensing models to predict yield and use as a replacement for actual yield data. A plethora of research has been devoted to this subject and could be integrated into our DST (Panda et al. 2010; Basso et al. 2013; Lobell et al. 2015.

Literature Cited

Arbuckle, J. G. J. 2013. Farmer attitudes toward proactive targeting of agricultural conservation programs. Society & Natural Resources 26(6):625–641.

Basso, B., D. Cammarano, and E. Carfagna. 2013. Review of Crop Yield Forecasting Methods and Early Warning Systems. The First Meeting of the Scientific Advisory Committee of the Global Strategy to Improve Agricultural and Rural Statistics (2013):1–56.

Bigelow, P. D., and A. Borchers. 2017. Major Uses of Land in the United States, 2012. EIB-178. USDA, Economic Research Service. August.

Bonner, I. J., K. G. Cafferty, D. J. Muth, M. D. Tomer, D. E. James, S. A. Porter, and D. L. Karlen. 2014. Opportunities for energy crop production based on subfield scale distribution of profitability. Energies 7(10):6509–6526.

Capmourteres, V., J. Adams, A. Berg, E. Fraser, C. Swanton, and M. Anand. 2018. Precision conservation meets precision agriculture: A case study from southern Ontario. Agricultural Systems 167(May):176–185.

Castle, M. H. 2016. Has the Usage of Precision Agriculture Technologies Actually Led to Increased Profits for Nebraska Producers? Master thesis in Agricultural Economics. Master thesis (2016).

Dosskey, M. G., and D. E. Eisenhauer. 2005. Establishing conservation buffers using precision information. Journal of Soil and Water Conservation 60(6):349–354.

ESRI 2018. ArcGIS Desktop: Release 10.6 Redlands, CA: Environmental Systems Research Institute.

Fahrig, L., J. Girard, D. Duro, J. Pasher, A. Smith, S. Javorek, D. King, K. F. Lindsay, S. Mitchell, and L. Tischendorf. 2015. Farmlands with smaller crop fields have higher within-field biodiversity. Agriculture, Ecosystems and Environment 200(February):219–234.

Farrand, D. T., and M. R. Ryan. 2005. Impactof the Conservation Reserve Program on Wildlife Conservation in the Midwest. Fish and Wildlife Benefi ts of Farm Bill Programs: 2000–2005 Update 43(Usda 2003):41–62.

Gaines-day, H. R., and C. Gratton. 2017. Understanding Barriers to Participation in Cost-Share Programs For Pollinator Conservation by Wisconsin (USA) Cranberry Growers. Insects 8(3):79.

Glaser, L. K. 1985. Provisions of the Food Security Act of 1985. United States Department of Agriculture.

Hamada, Y., H. Ssegane, and M. C. Negri. 2015. Mapping intra-field yield variation using high resolution satellite imagery to integrate bioenergy and environmental stewardship in an agricultural watershed. Remote Sensing 7(8):9753–9768.

Johnson, K. A., B. J. Dalzell, M. Donahue, J. Gourevitch, D. L. Johnson, G. S. Karlovits, B. Keeler, and J. T. Smith. 2016. Conservation Reserve Program (CRP) lands provide ecosystem service benefits that exceed land rental payment costs. Ecosystem Services 18 (2016):175–185.

Knight, A. T., R. M. Cowling, M. Difford, and B. M. Campbell. 2010. Mapping Human and Social Dimensions of Conservation Opportunity for the Scheduling of Conservation Action on Private Land\nMapeo de Dimensiones Humanas y Sociales de la Oportunidad de Conservación para la Programación de Acciones de Conservación en Tierra. Conservation Biology (2010):no-no.

Knight, R. L. 1999. Private lands: The neglected geography. Conservation Biology 13(2):223–224.

Li, C., L. M. Fultz, J. Moore-Kucera, V. Acosta-Martínez, J. Horita, R. Strauss, J. Zak, F. Calderón, and D. Weindorf. 2017. Soil carbon sequestration potential in semi-arid grasslands in the Conservation Reserve Program. Geoderma 294 (2017):80–90.

Lobell, D. B., D. Thau, C. Seifert, E. Engle, and B. Little. 2015. A scalable satellite-based crop yield mapper. Remote Sensing of Environment 164 (2015):324–333.

Lute, M. L., C. R. Gillespie, D. R. Martin, and J. J. Fontaine. 2018. Landowner and Practitioner Perspectives on Private Land Conservation Programs. Society and Natural Resources 31(2):218–231.

Lyle, G., B. A. Bryan, and B. Ostendorf. 2015. Identifying the spatial and temporal variability of economic opportunity costs to promote the adoption of alternative land uses in grain growing agricultural areas: An Australian example. Journal of Environmental Management 155(March):123–135.

Maestrini, B., and B. Basso. 2018. Predicting spatial patterns of within-field crop yield variability. Field Crops Research 219(January):106–112.

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.

McConnell, M. D., L. W. Burger, J. Delgado, G. Sassenrath, and T. Mueller. 2016. Precision Conservation to Enhance Wildlife Benefits in Agricultural Landscapes 9740 (2016):1–28.

Miller, C. 2017. Conservation Reserve Program in Illinois : Investigation of Participants ' Motives , Expectations , and Desired Outcomes 2017(17).

Miltner, R. J. 2015. Measuring the Contribution of Agricultural Conservation Practices to Observed Trends and Recent Condition in Water Quality Indicators in Ohio, USA. Journal of environmental quality 44(6):1821–31.

Morefield, P. E., S. D. LeDuc, C. M. Clark, and R. Iovanna. 2016. Grasslands, wetlands, and agriculture: the fate of land expiring from the Conservation Reserve Program in the Midwestern United States. Environmental Research Letters 11(9):94005.

Muth, D. 2014. Profitability versus environmental performance: Are they competing? Journal of Soil and Water Conservation 69(6):203–206.

Muth, D. J. 2015. Improving Economic and Environmental Performance through a Precision Business Plan (2015).

Natural Resources Conservation Service. 2014. National planning procedures handbook (NPPH) amendment 4. U.S. Department of Agriculture, Natural Resources Conservation Service, 180-600-H. Policy date: November 2014. Retrieved from https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=36483.wba.

Palm, C., H. Blanco-canqui, F. Declerck, L. Gatere, and P. Grace. 2014. Agriculture , Ecosystems and Environment Conservation agriculture and ecosystem services : An overview. “Agriculture, Ecosystems and Environment” 187 (2014):87–105.

Panda, S. S., D. P. Ames, and S. Panigrahi. 2010. Application of vegetation indices for agricultural crop yield prediction using neural network techniques. Remote Sensing 2(3):673–696.

Rao, M., G. Fan, J. Thomas, G. Cherian, V. Chudiwale, and M. Awawdeh. 2007. A web-based GIS Decision Support System for managing and planning USDA’s Conservation Reserve Program (CRP). Environmental Modelling and Software 22(9):1270–1280.

Reimer, A. P., and L. S. Prokopy. 2014. Farmer participation in U.S. Farm bill conservation programs. Environmental Management 53(2):318–332.

Riffell, S., D. Scognamillo, L. W. Burger, and S. Bucholtz. 2010. Broad-Scale Relations between Conservation Reserve Program and Grassland Birds: Do Cover Type, Configuration and Contract Age Matter. The Open Ornithology Journal 3 (2010):112–123.

Robertson, G. P., and S. M. Swinton. 2005. Reconciling agricultural productivity and environmental integrity : a grand challenge for agriculture. Frontiers in Ecology and the Environment 3(1):38–46.

Souza, E. G., C. L. Bazzi, R. Khosla, M. A. Uribe-Opazo, and R. M. Reich. 2016. Interpolation type and data computation of crop yield maps is important for precision crop production. Journal of Plant Nutrition 39(4):531–538.

Stull, J., C. Dillion, S. Shearer, and S. Isaacs. 2004. Using Precision Agriculture Technology for Economically Optimal Strategic Decisions: The Case of CRP Filter Strip Enrollment. Journal of Sustainable Agriculture 24(4):39–56.

Sun, W., B. Whelan, A. B. McBratney, and B. Minasny. 2013. An integrated framework for software to provide yield data cleaning and estimation of an opportunity index for site-specific crop management. Precision Agriculture 14(4):376–391.

Tomer, M. D., K. M. B. Boomer, S. A. Porter, B. K. Gelder, D. E. James, and E. McLellan. 2015. Agricultural conservation planning framework: 2. Classification of riparian buffer design types with application to assess and map stream corridors. Journal of Environmental Quality 44(3):768–79.

USDA NRCS. (2015). Conservation Reserve Program, (Revision 1). Retrieved from http://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/index

USDA NRCS. (2019). Conservation Reserve Program, (Revision 1). Retrieved from http://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/index

Vellidis, G., B. Ed, and H. S. Brannen. 2011. Tool for for increasing Increasing efficiency maps : Cotton Yield Yield Maps : Cotton Incorporated (2011).

Yeiser, J. M., J. J. Morgan, D. L. Baxley, R. B. Chandler, and J. A. Martin. 2018. Private land conservation has landscape-scale benefits for wildlife in agroecosystems. Journal of Applied Ecology 55(4):1930–1939.

Zhou, X. V., B. C. English, J. A. Larson, D. M. Lambert, R. K. Roberts, C. N. Boyer, M. Velandia, L. L. Falconer, and S. W. Martin. 2017. Precision farming adoption trends in the Southern U.S. Journal of Cotton Science 21(2):143–155.

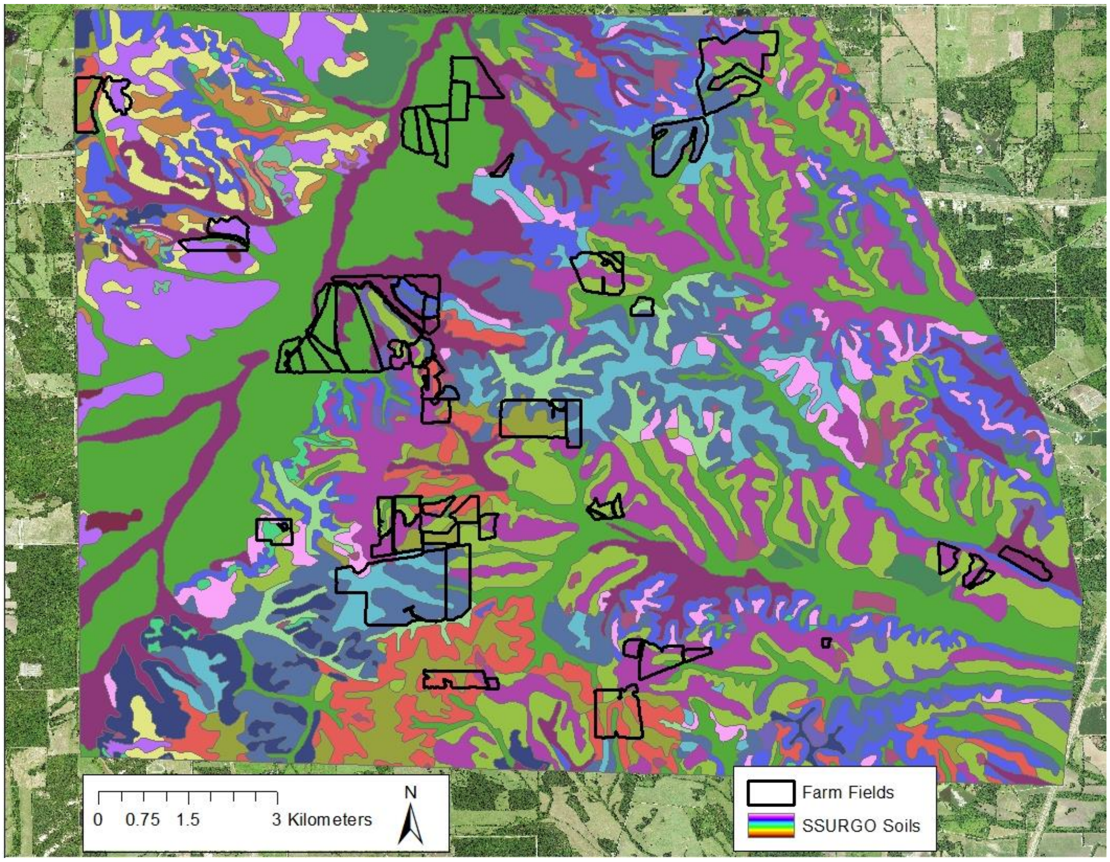


Figure 2.1 SSURGO soils geospatial layer for a farm in Lowndes County, Mississippi, USA.

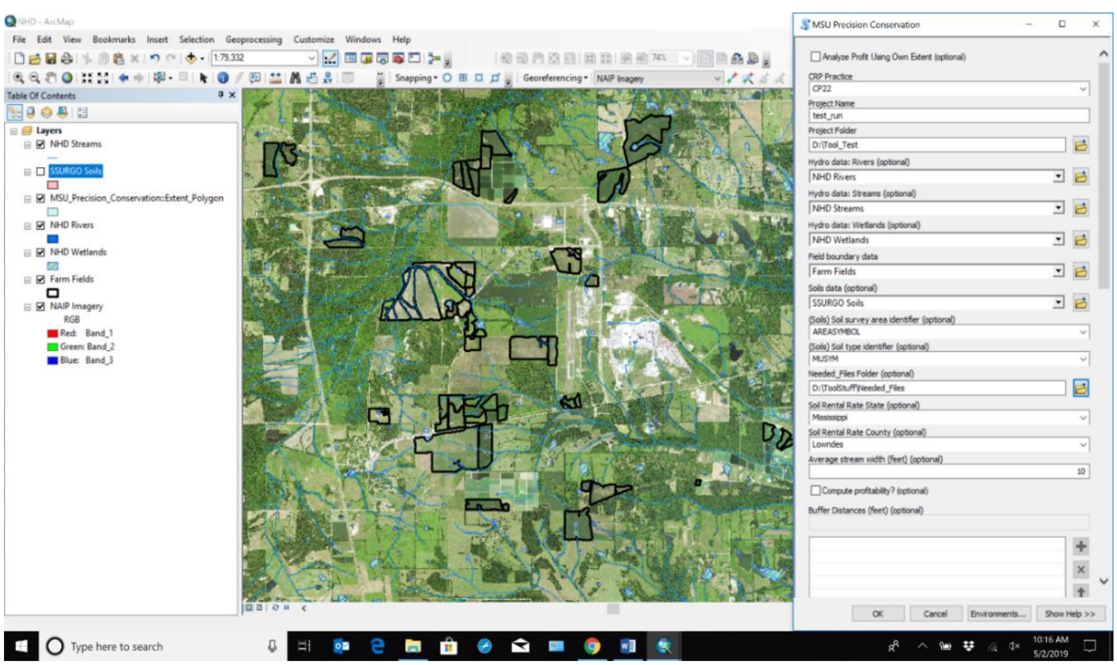


Figure 2.2 DST parameters to run an eligibility analysis.

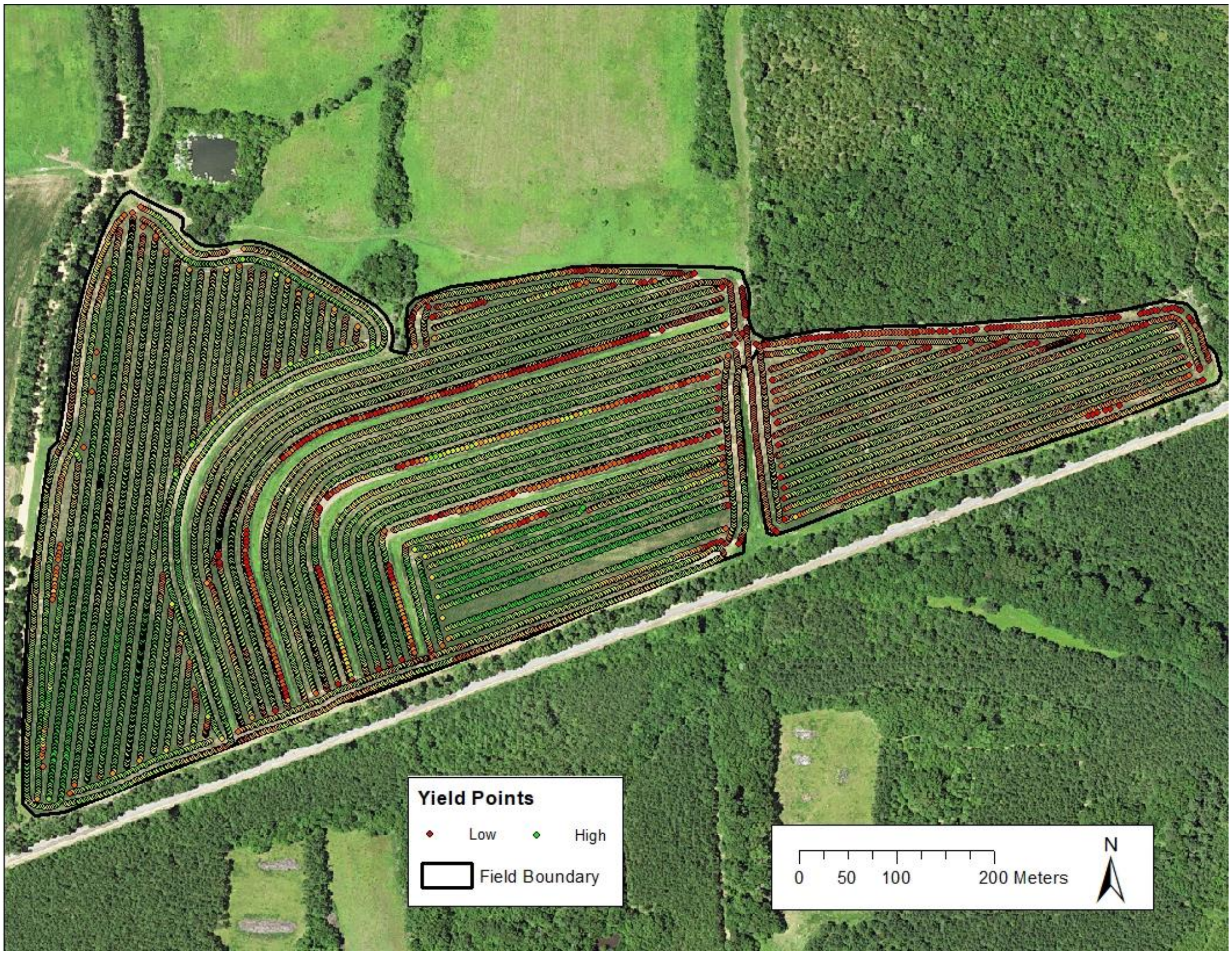


Figure 2.3 Spatially explicit yield data symbolized by dry yield volume.

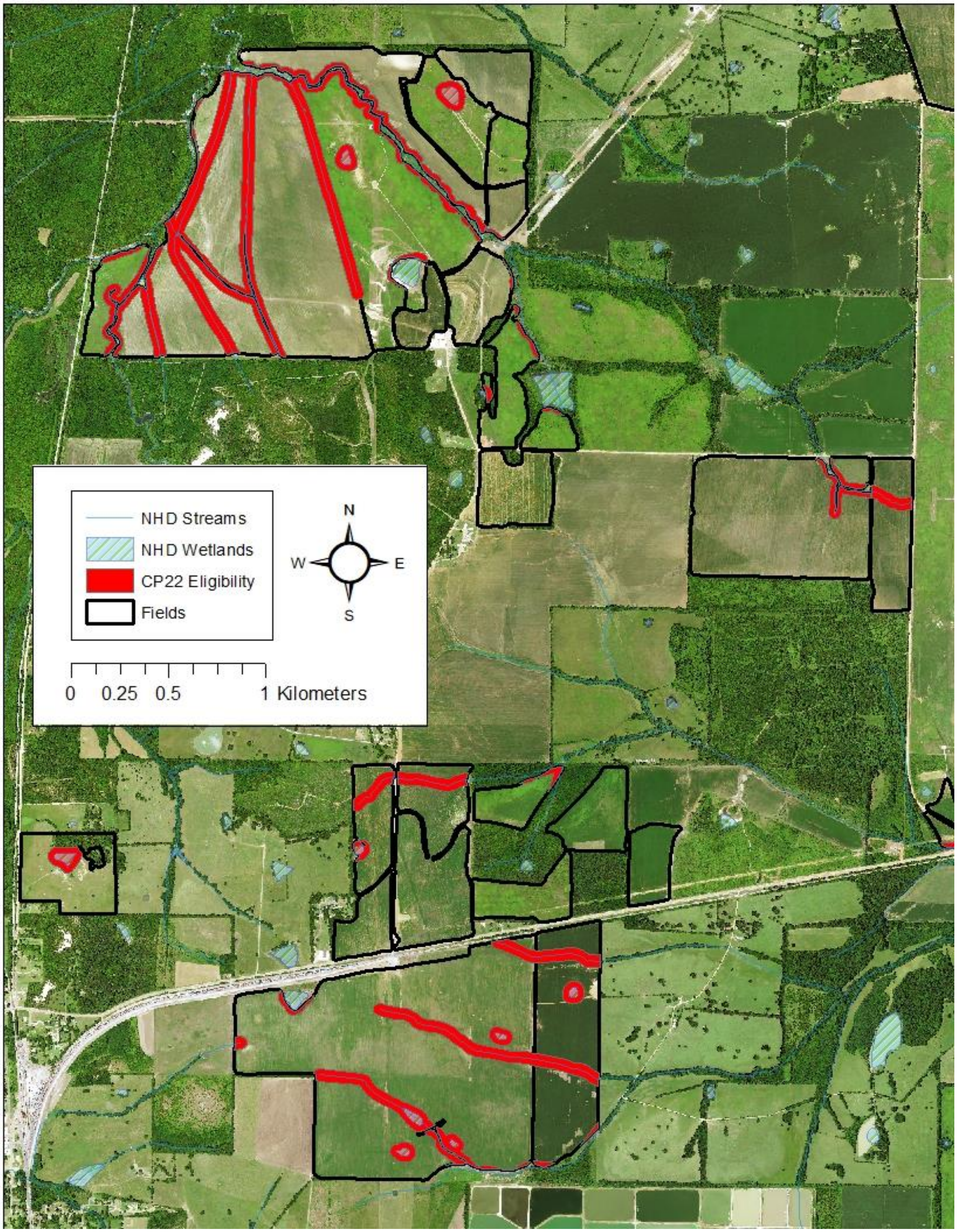


Figure 2.4 An eligibility analysis conducted for CP-22. 89.48 hectares were eligible throughout the farm.

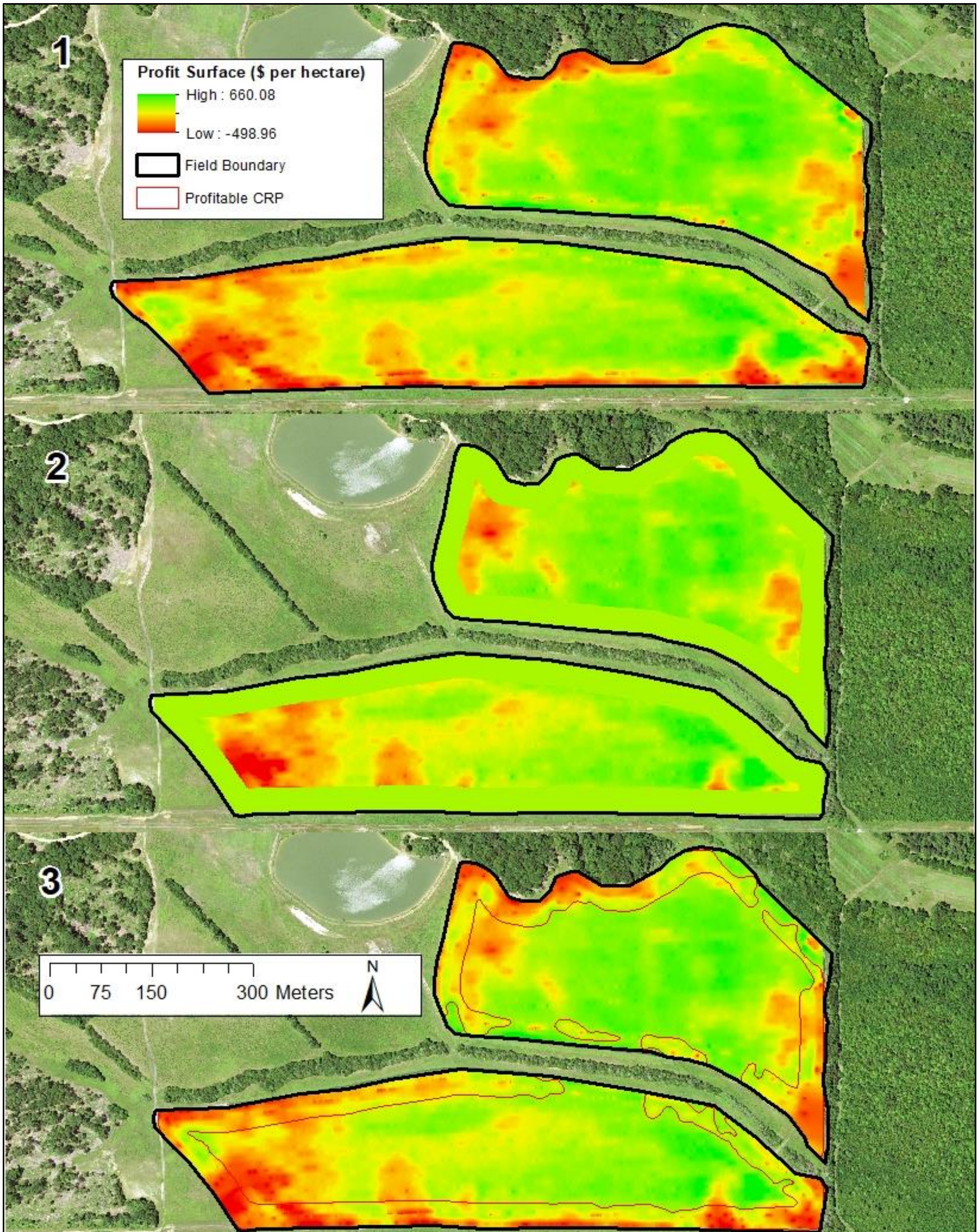


Figure 2.5 Profitability analysis for CP-33. (1) Profit surface for row crop agriculture. (2) Profit surface with a 120 foot CP-33 buffer. (3) Areas within CP-33 elligiblity where CRP is more profitable than row crop agriculture.

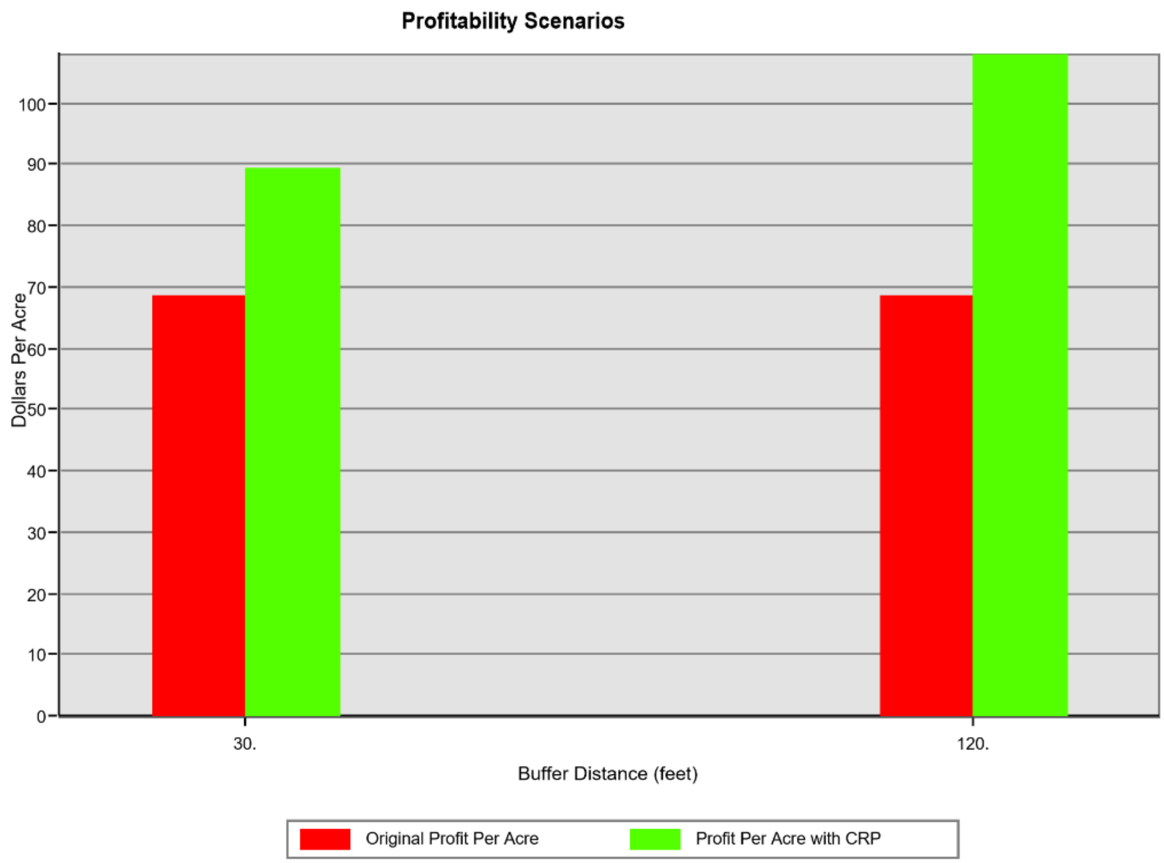


Figure 2.6 Graph in PDF format showing profitability of row crop agriculture vs. establishment of a CRP practice considering various buffer distances.

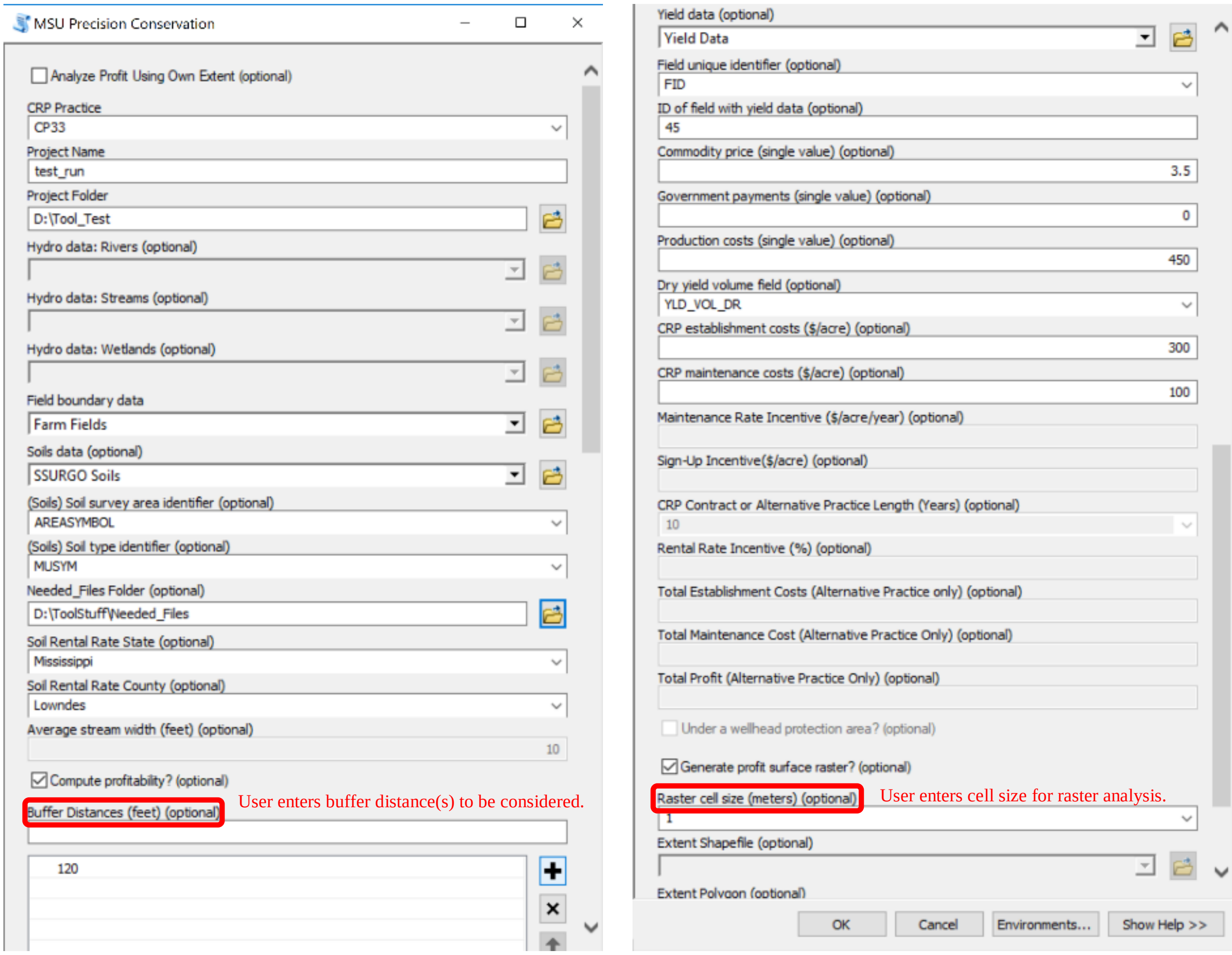


Figure 2.7 DST parameters to conduct a profitability analysis.

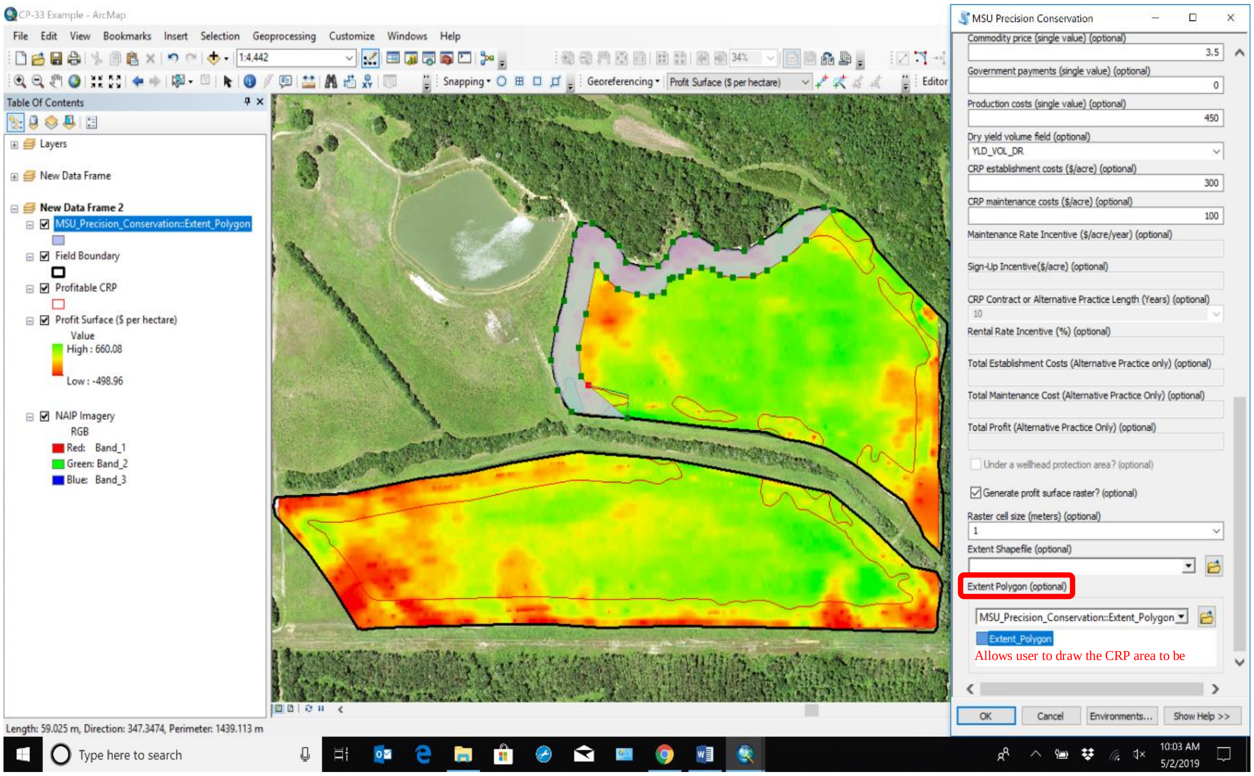


Figure 2.8 Using profitable buffer layer to draw non-uniform CP-33 buffers targeting unprofitable areas.

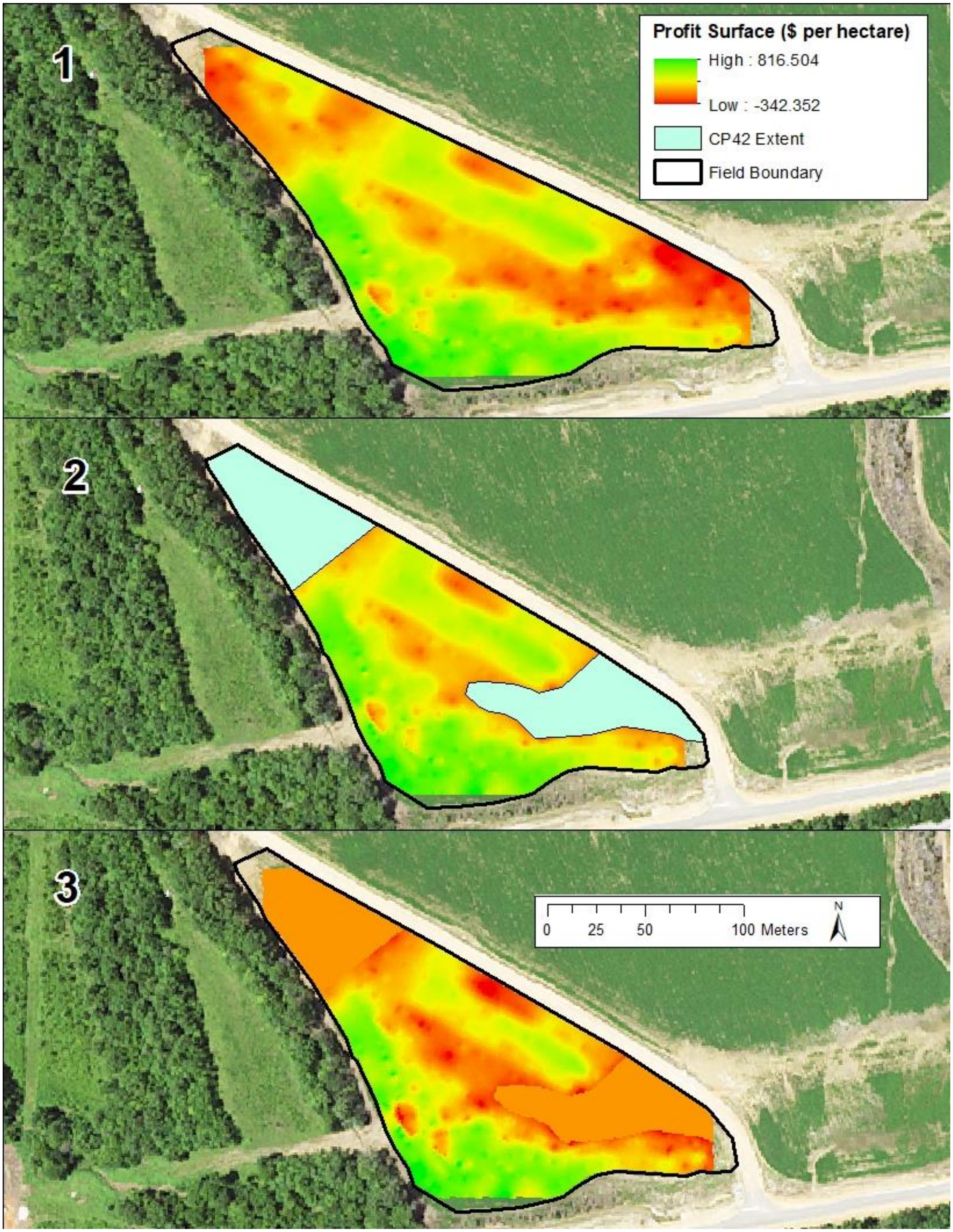


Figure 2.9 Profitabiltiy analysis for CP-42. (1) Row crop agriculture profit surface. (2) Areas considered for CRP. (3) Resulting profit surface after analysis.

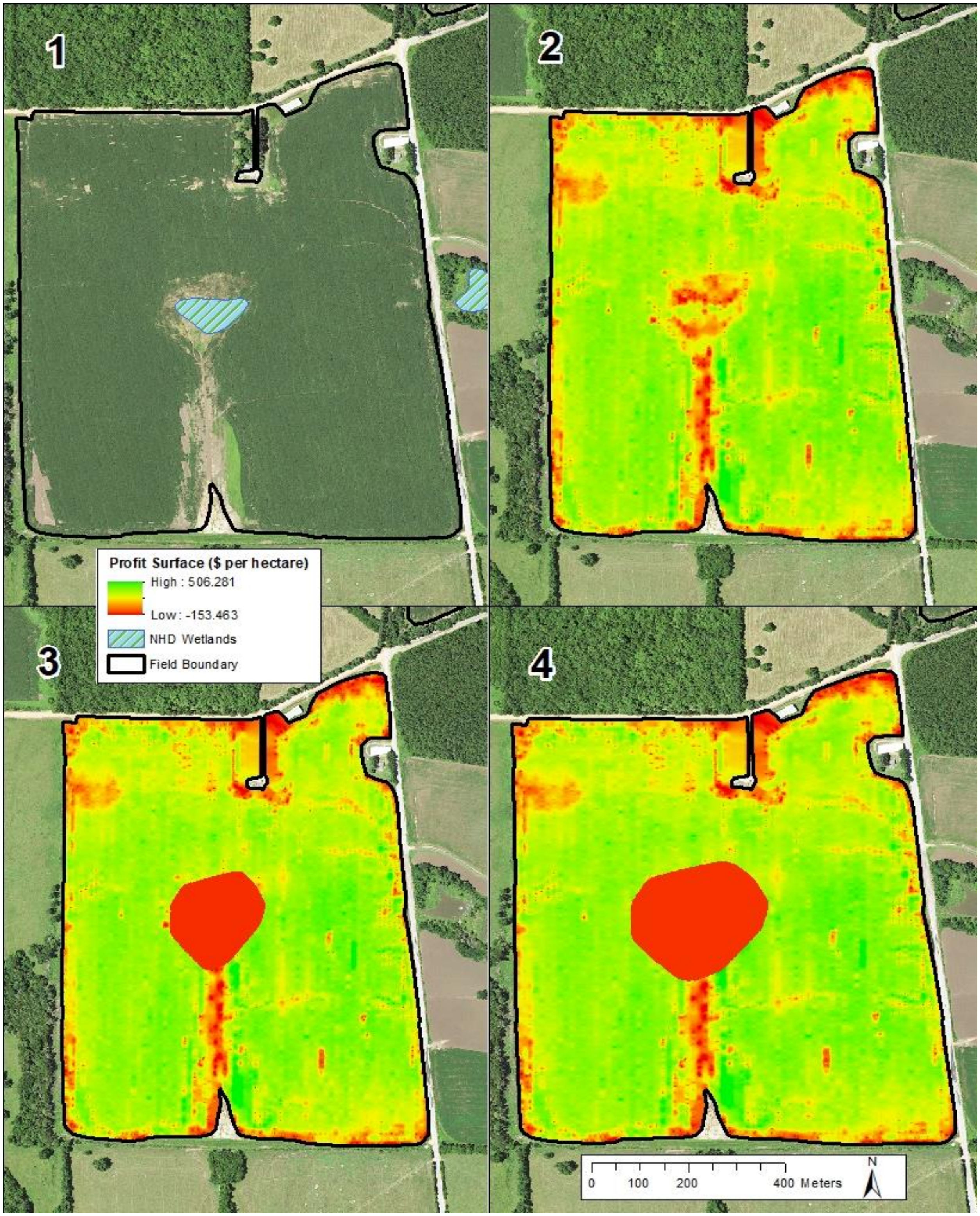


Figure 2.10 Profitability Analysis for CP-23. (1) Field containing NHD wetland. (2) Row crop agriculture profit surface. (3) Profit surface for wetland with 60 foot grassland buffer. (4) Profit surface for wetland with 120 foot grassland buffer.

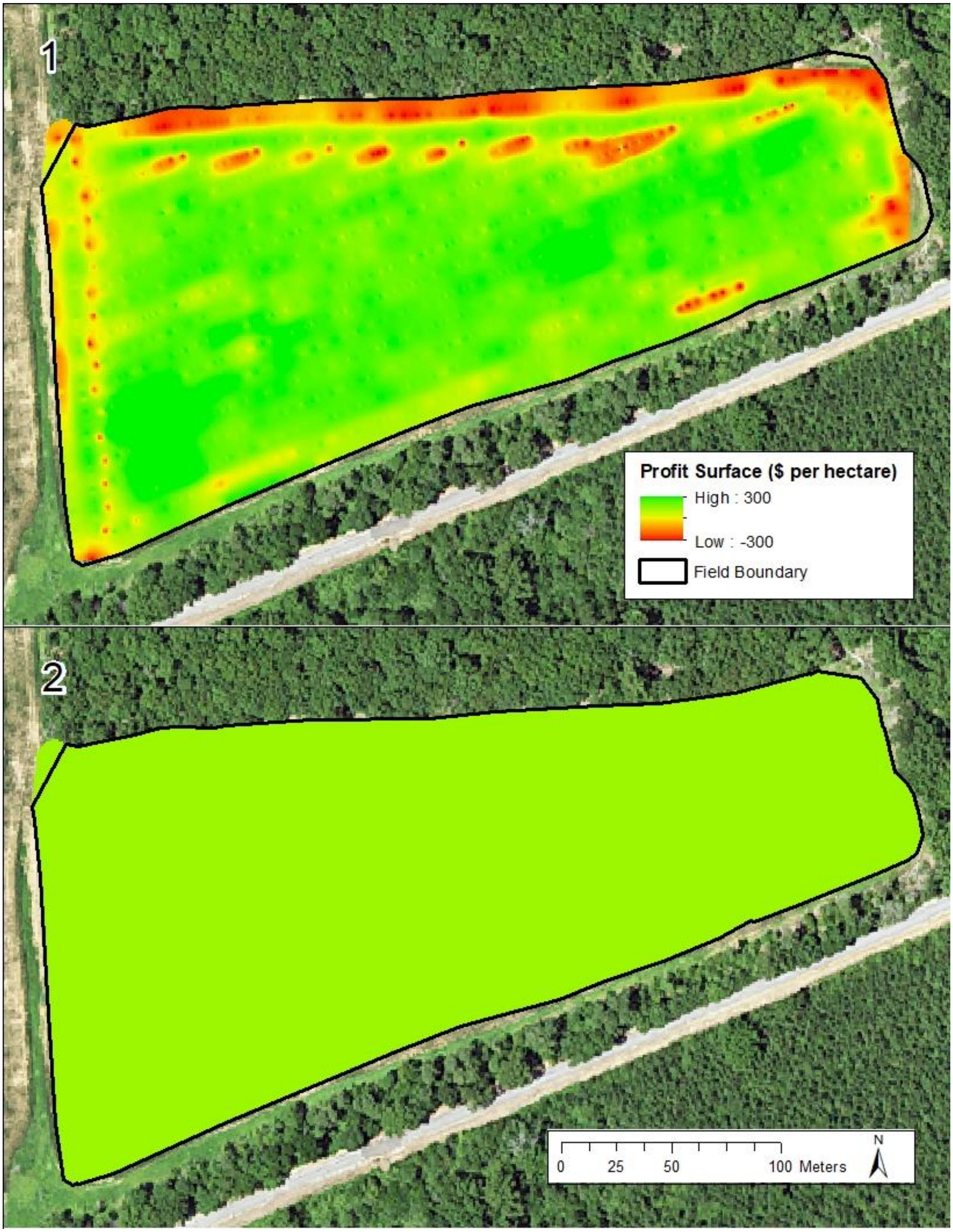
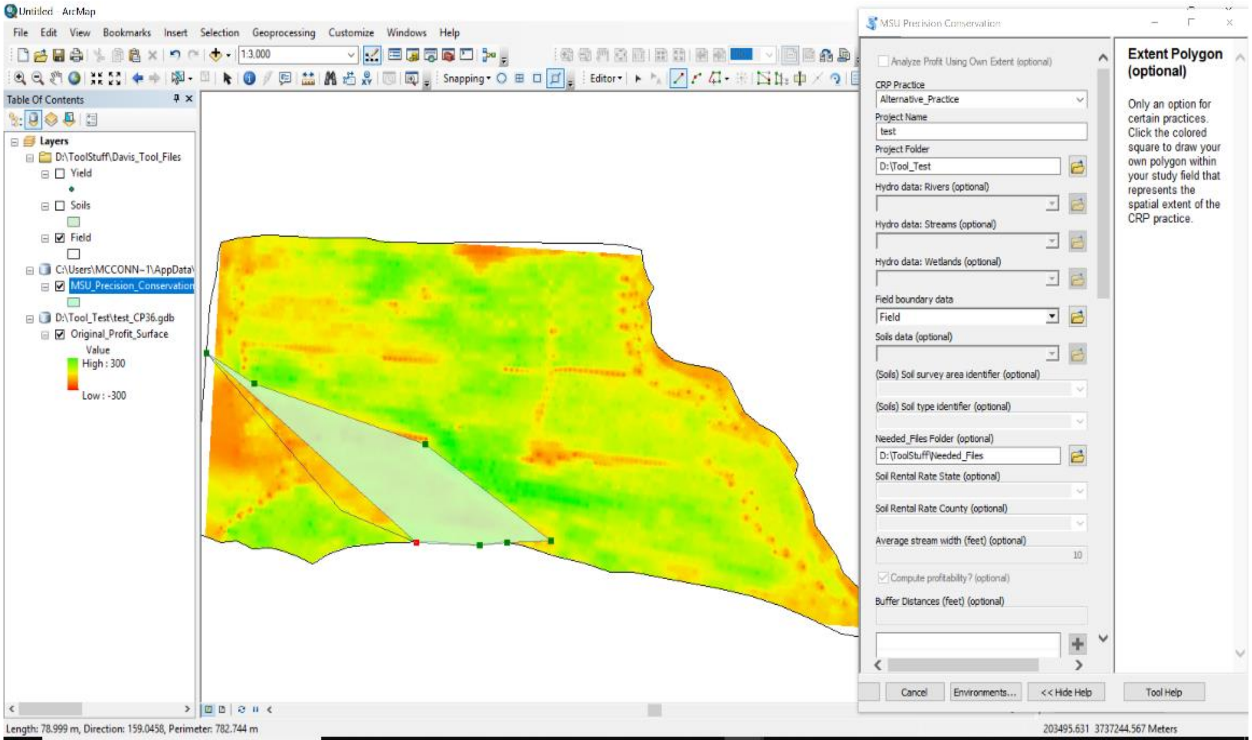


Figure 2.11 Profitability Analysis for CP-31. (1) Row crop agriculture profit surface. (2) Profit for CRP enrollment.



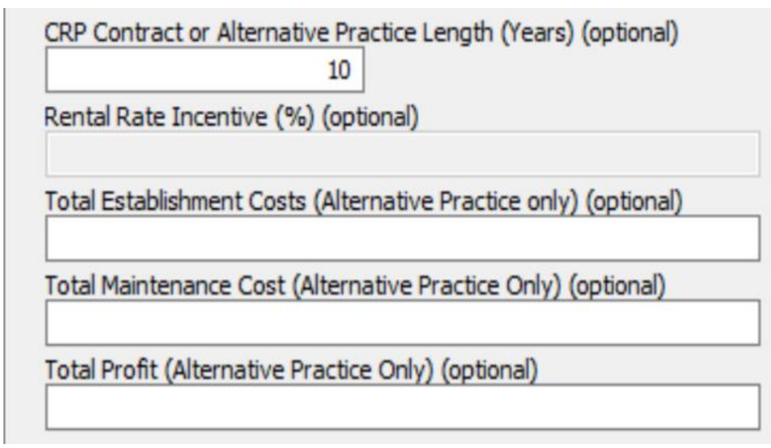


Figure 2.12 Alternative Practice analysis.

CHAPTER 3

USING PRECISION AGRICULTURE TECHNOLOGY FOR TARGETED CONSERVATION DELIVERY

---

[1]Meng, N. J., N. Nibbelink, M. Madden, and M. D. McConnell. To be submitted to *Journal of Soil and Water Conservation*

Abstract

Agriculture is the world's largest industry and will become more intensive to meet global food demands associated with human population growth. Many facets of the environment have been degraded with this increase in agricultural intensity, including loss of natural plant communities as a component of agricultural landscapes supporting wildlife populations that provide essential ecosystem services with broad societal value. Sustainability of global agricultural systems will require strategic integration of conservation practices to protect ecosystems services, health, and productivity. Effective conservation delivery is dependent on being able to quantify and visualize both the expected costs and benefits. Funding from the United States Congress' Farm Bill allows the United States Department of Agriculture (USDA) to administer conservation programs that provide producer incentives to remove environmentally sensitive lands from agricultural production and reestablish them in natural vegetation (e.g., native grasses, trees, etc.). However, removal of arable land from production imposes an opportunity cost associated with loss in revenue from commodities that otherwise would have been produced. Precision agriculture technology provides a unique framework for identifying economic and conservation opportunities in production agriculture. Precision agriculture technology allows producers to identify low yielding areas in their fields and strategize practices to address these low or unprofitable areas. By using precision agriculture in a conservation framework natural resource professionals can demonstrate the overlap between conservation eligibility and economic opportunity. This approach requires spatially explicit information on conservation eligibility and economics in addition to detailed data on farm inputs. We created a decision support tool (DST) that integrates these components and provides a user-friendly approach for agricultural producers to simultaneously optimize their conservation and economic

objectives. We demonstrate these concepts using three scenarios that trade off emphasis on conservation and profitability on a study farm in Lowndes County, Mississippi. The three different scenarios are as follows:

1. Maximum row crop production (no conservation enrollment)
2. Maximum conservation enrollment (maximum acres spatially eligible)
3. Targeted conservation enrollment (conservation only where profitable)

A targeted scenario increased profitability in 37 of our 52 study fields (71%). Of these 37 fields, the mean whole field profitability of row crop agriculture was $316.50 per hectare. Maximum conservation enrollment was $279.59 per hectare and targeted conservation enrollment was $352.12 per hectare. There was an average increase in profitability of 23.77% from row crop agriculture to targeted conservation. These results show that conservation can be profitable to the producer by targeting low yielding areas in a field and establishing long term conservation practices on the landscape.

Introduction

Since the mechanization of agriculture in the early 1900s, food production has expanded and intensified due to steady human population rise and the continued increase in demand for commodities (Robertson et al. 2005; Johnson et al. 2016). Meeting this global demand has expanded agricultural production to environmentally vulnerable areas, creating concern for water quality, soil quality, and wildlife, among other issues. Globally these environmental concerns are only increasing as 13 million hectares of land are converted to agriculture annually (Robertson &

Swinton, 2005). Loss of vital top soil through surface runoff or wind erosion is a major environmental issue facing agricultural producers (Johnson et al. 2016). Runoff can reduce water quality as it carries pesticides, nutrients, and sediment downstream, whereas wind erosion can impair air quality with fine particulate matter (Tomer et al. 2015; Johnson et al. 2016). Agriculture has also been shown to be a significant producer of greenhouse gases (Palm et al. 2014). Wildlife is another natural resource that is negatively impacted by intensive agriculture, and globally millions of hectares of native habitat have been converted into row crops or other forms of agriculture since the mechanization of agriculture (Altieri 1991). Row crops, although used by wildlife, provide lower quality habitat compared to native land cover (Homberger et al. 2017). Agricultural conversion has fragmented once extensive native ecosystems, creating isolated patches of habitat distributed in a hostile matrix that is less effective in supporting wildlife populations (Wiens 1995). Furthermore, agriculture may disrupt essential environmental services such as pollination, as indicated by research showing wild bee populations decreasing with proximity to agricultural production on public lands (Main et al. 2019) There are 158.44 million hectares of cropland in the United States which represents about 1/5 of the entire land area of the contiguous U.S. (Bigelow and Botchers 2017). There are only 40.47 million hectares of protected conservation areas such as national and state parks and wilderness areas (Bigelow and Botchers 2017). This illustrates that protected areas alone are insufficient to meet national conservation needs (Knight 1999; Knight et al. 2010). Converting large amounts of agricultural land to protected status is not practical to meet future global food demands (Robertson et al. 2005; Johnson et al. 2016); therefore an approach is needed that integrates conservation into production agriculture to optimize competing objectives.

Agri-environmental policies (AEP) have aimed at mitigating the negative environmental impacts of agriculture. The AEP model in the Europe Union (EU) focuses on delivery of positive public goods, such as the attractive landscapes produced by agriculture (Baylis et al. 2008). For example, certain beneficial farming practices are subsidized as opposed to focusing on mitigating negative environmental impacts. A producer can receive subsidies for using environmentally friendly farming technology even if that technology is not being used on environmentally sensitive land. In contrast, the United States programs focus primarily on reducing the negative externalities of agriculture (Baylis et al. 2008). These programs use targeted metrics such as the Environmental Benefits Index (EBI) to quantify the conservation value of a practice and its cost. Producers are also allowed to bid on conservation contracts with lower bids increasing probability of acceptance for enrollment (Claassen et al. 2008). These targeted techniques have been shown to increase the cost effectiveness of conservation programs (Claassen et al. 2008). They do however require a certain amount of knowledge to implement (Baylis et al. 2008).

Conservation programs in the United States come in many different varieties. Working lands programs such as the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP) do not seek to retire land, but rather provide financial incentives for producers to practice conservation alongside their agricultural operation (Claassen et al. 2008). In contrast, the Conservation Reserve Program (CRP) is a land retirement program and will be the primary focus of this research. Started in 1985, CRP provides producers with financial incentives to remove environmentally sensitive agricultural land from production and convert it to a more environmentally friendly land cover (e.g., native grass, forest, or wetland) (Glaser 1985; Morefield et al. 2016; Li et al. 2017). CRP’s purpose is to reduce the negative impact agriculture has on water quality, erosion, and wildlife habitat, as well as provide commodity price control (Johnson et al. 2016). There are currently 35 CRP practices, each addressing one or more environmental concerns (USDA NRCS 2015). The financial incentives include a 10 year contract (15 year contract for some practices) with annual payments based on the soil type of the land taken out of production, which is called the soil rental rate (SRR) (USDA NRCS 2015). Some practices provide additional financial incentives beyond the SRR (e.g., sign-up incentives). Establishing and maintaining a practice can be costly, which is why a majority of practices provide financial assistance to offset this cost (USDA NRCS 2015).

CRP enrollment has created numerous positive environmental outcomes across the North American agricultural landscape. For example, CRP lands store carbon in the soil and vegetation thus reducing the carbon footprint of agriculture (Li et al. 2017). Riparian buffers stabilize stream banks and block runoff, thereby improving water quality (Miltner 2015). CRP benefits a variety of wildlife species by establishing native grassland, woodland, or wetland habitat that increase landscape heterogeneity, create wildlife travel corridors, and protect sensitive wildlife habitat (Burger 2000; Burger 2005; Farrand & Ryan 2005; Riffell et al. 2010; Fahrig et al. 2015). CRP has also been shown to have a positive impact on honey bee populations by providing increased floral diversity compared to agriculture (Ricigliano et al. 2019). A case study concluded that the environmental benefit per acre over a ten-year CRP contract was worth between $1,710 and $6,401, while the average rental payment was $1,311, indicating that CRP is a worthwhile investment for taxpayers (Johnson et al. 2016). CRP has the potential to adequately address agriculture’s negative externalities while concomitantly addressing opportunity cost associated with taking land out of production.

Research has shown that a majority of agricultural producers have favorable conservation views. For example, a survey in Illinois showed that 85% of agricultural producers believe it is their responsibility to protect wildlife (Miller 2017). Yet stewardship objectives compete with financial objectives, as illustrated by the fact that Illinois has 127,000 less acres in CRP than it did in 2010 and relatively less acreage than other states of similar size (USDA FSA 2018). One possible explanation for reduced conservation enrollment is that producers are unfamiliar with the CRP practices or other conservation programs that are available. Miller (2017) found that 60-65% of survey respondents were unfamiliar with many conservation programs offered by the NRCS (e.g. State Acres for Wildlife Enhancement (SAFE), Environmental Quality Incentives Program (EQIP)) indicating producers are generally unfamiliar with conservation programs availability (Kurzejeski et al 1992; USDA NRCS 2015; Miller 2017). Other documented hindrances to CRP enrollment include a perceived pest problem from conservation areas, lack of technical knowledge to implement a practice, and the view that a practice requires too much time, space, or money (Gaines-day & Gratton 2017). Most producers favor targeted conservation approaches though they do still have concerns about the intrusion associated with government programs (Arbuckle 2013). This illustrates the need for these practices to be advertised and explained more effectively and the landowner's privacy to be respected. Producers' lack of knowledge regarding each practice's spatial eligibility is a significant hindrance to CRP reaching its full potential (McConnell & Burger 2011; McConnell et al. 2016). CRP's 35 practices all have various economic incentives and spatial eligibility requirements (USDA NRCS 2015), which are subject to change with the passage of a new Farm Bill (~ every 5 years). The perceived need to keep up with all of this information is an unreasonable expectation and may reduce participation (Reimer & Prokopy 2014).

Removing land from production as with CRP is often assumed to reduce profitability, making most producers reluctant to participate in land retirement programs regardless of the environmental benefits (McConnell & Burger 2011; Muth 2014; McConnell et al. 2016; Lute et al. 2018). Reversing this erroneous perception could provide both economic benefits as volatile cash crop prices (corn prices ranged from \$124 to \$300 per Tonne from 2010 to 2019 (USDA NASS 2019)) and increasing production costs (increased 36% from 2007 to 2012 (USDA NASS 2017)) have made profitable farming challenging (Kitchen et al. 2005). Between 2013 and 2016 there was a 45% drop nationwide in net farm income, further illustrating the growing challenge of profitable farming (USDA ERS 2019). Removing land from production to increase farm profitability represents a new form of targeted conservation delivery that could produce economic and environmental benefits (McConnell and Burger 2016). Financial concerns have repeatedly been documented as barriers to conservation adoption (Lynne et al. 1988; Macdonald and Johnson 2000; Sorice et al. 2011; Reimer and Prokopy 2014; Lute et al. 2018). The incentives provided by CRP are vital for conservation adoption as most producers cannot afford to implement a conservation practice without them (Claassen & Duquette 2012; Sweikert & Gigliotti 2019; USDA ERS 2019). Many producers even believe current CRP incentives are not high enough (Sweikert & Gigliotti 2019).

There are limited resources available to producers to determine the economic outcomes of taking an area of land out of production and converting it to CRP. A few case studies done on a small number of fields have shown the workflow and economic outcomes of converting row crop agriculture to a CRP practice (Stull et al. 2004; McConnell & Burger 2011; McConnell et al. 2016). These studies however did not produce a publicly available Decision Support Tool (DST) that can implement this framework across numerous Farm Bill conservation practices. Their case studies also did not consider the economic outcomes of the establishment of multiple CRP practices in a large number of fields with multiple years of yield data.

Precision agriculture (PA) is simply defined as a series of spatial information technologies that have the potential to improve farm profitability by increasing yields and lowering input costs (Zhou et al. 2017). A few examples of this technology include variable rate application, global positioning system (GPS)-guidance, and automated section control (Zhou et al. 2017). The PA technology this research focuses on is yield mapping via GPS. Yield mapping occurs when a harvester records grain flow via sensors and records a GPS location with this information (Hopkins 2009). This grain flow data is converted to dry yield volume, which is a point-specific measurement of yield per unit area. This spatially explicit yield data can be used by producers to identify low yielding areas of a field and recommend alternative management practices to increase their profitability. (Vellidis et al. 2011; Sun et al. 2013; Maestrini & Basso 2018). All producers deal with variable yield, especially around the edges of their fields due to soil compaction, poor seedbed preparation, greater weed abundance, shading by tall field boundary vegetation, and competition from tree roots (Barbour et al. 2007; Blackmore 2014).

Precision agriculture has also been defined as a “philosophical shift in the management of variability within agricultural industries aimed at improving profitability and/or environmental outcomes”. This more inclusive definition acknowledges the increasingly more common practice of using this technology for environmental or conservation purposes. This shift is more specifically called precision conservation, or targeted conservation and is defined by Berry et al. (2003) 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.” Targeted or precision conservation comes in many different forms. One example uses precision information to strategically implement field buffers to maximize their positive effects on water quality (Dosskey & Eisenhauer 2005). Other targeted approaches include planting unprofitable areas to biofuels like switchgrass (*Panicum vigratum*) (Bonner et al. 2014). However, this practice is susceptible to volatile product prices and provides subpar wildlife habitat (Conkling et al. 2017), making CRP the more attractive option (McConnell & Burger 2011; McConnell et al. 2016). Research has shown the benefits of targeting CRP enrollment for wildlife habitat (Yeiser et al. 2018), though currently little research has simultaneously addressed conservation concerns (water, soil, wildlife, etc.) and profitability (McConnell and Burger 2016).

DST's are commonly used for conservation planning purposes (Stull et al. 2004; Dosskey & Eisenhauer 2005; Rao et al. 2007; McConnell & Burger 2011; McConnell et al. 2016). They are vital for linking the knowledge of a specific discipline to the those making decisions or policies (Arciniegas et al. 2013). One existing CRP DST is focused on quantifying the watershed level effects of CRP implementation on soil and water quality (Rao et al. 2007). While this type of DST is useful, it lacks practicality because it does not consider the profitability of implementing a CRP practice. Other research has focused on targeting unprofitable field areas to implement a conservation practice yet are limited due to the small scope of the case study, lack of fields with multiple years of yield data, and failure to produce a deliverable DST to allow producers to make financially sounds conservation decisions (Stull et al. 2004; McConnell & Burger 2011; McConnell et al. 2016; Capmourteres et al. 2018).

A case study in Iowa shows that producers support targeted conservation, though its application is not common (Arbuckle 2013). The potential benefit of targeted conservation is well documented. For example, a 1985 nationwide study showed that 70% of soil erosion in excess of 5 tons per acre was occurring on less than 10% of tilled land, though a small amount of conservation resources were committed to that land (Batie 1985). Furthermore, environmentally vulnerable land is often unprofitable for agriculture (McConnell & Burger 2011; Muth 2014; Hamada 2015; Muth 2015; McConnell et al. 2016). This was quantified in an Australian study that showed around 20% of the area in study fields displayed inconsistent temporal variation and income generation (Lyle et al. 2015). Another study in Mississippi, USA showed 12-15% of eligible area across the study fields to be more profitable under conservation enrollment (McConnell et al. 2016).

There is a lack of DSTs that allow users to identify low yielding areas and simulate the economics of an alternative practice (Bobryk et al. 2017) Furthermore, no DST is available that can spatially model all CRP practices and calculate the economic outcome of each practice. We have created a geospatial DST to address this issue that will help agricultural producers visualize the spatially eligible areas of their field for a given practice and allow them to identify, from spatially explicit yield data, areas in their field that are unprofitable. The user will then be able to determine if an opportunity to increase profit exists through CRP enrollment. Identifying fields where CRP is an economically viable option could increase enrollment and generate landscape-level conservation impacts. The DST will be available as a user-friendly ArcMap (ESRI 2018) script tool. We conducted a case study on a farm in Lowndes County, Mississippi that demonstrates the application of this DST and illustrates the ability for CRP practices to be implemented profitability.

Study Area

Our study farm is located in the Black Prairie region of Mississippi (Figure 3.1). The Black Prairie region is a part of the larger Black Belt Region, which is a crescent shaped region with most of its area in Alabama (Tullos 2004). The name comes from its dark calcareous soils.

The entire region is underlain by Selma Chalk, whose consistency varies throughout the region and has weathered into various soil types that support a wide range of prairie and forest habitats (MacGown et al. 2018). Prairie regions are characterized by well drained, slowly permeable, alkaline soils. This region is also characterized by intensive agriculture. Historically cotton was the main crop grown in this region, as well as some corn, though currently soybeans and beef cattle are more prevalent (Tullos 2004). Our study farm in Lowndes County, Mississippi contains 1,031 hectares of farmland with 52 fields ranging in size from 1.38 to 140.35 hectares. This farm implements a rotation of corn and soybeans. Yield data years range from 2014-2017. There are 14 fields with one year of yield data, 8 fields with two years, 11 fields with three years, and 19 fields with four years.

Methods

DST Development

We used a previously developed DST for this analysis (Meng 2019). This DST was developed to analyze 35 CRP practices and be user friendly enough to be distributed to various conservation agencies. The DST's main function is to calculate the profitability of row crop agriculture and profitability of a given CRP practice. The Soil Rental Rate (SRR) is the dollar amount paid in the CRP contract based off the soil types where the practice will be established. A state and county specific SSURGO (Soil Survey Geographic Database) shapefile is needed for this calculation. The soil types in each state and county have an established rental rate. A table with these values is included with the DST and is joined to the SSURGO layer. Within each field's eligible areas, the SRR is calculated by taking the three most prevalent soil types and weighting their SRR values by the percentage of their area. The first step in this workflow is to determine the eligible areas throughout an entire farm. This eligibility analysis will output a shapefile of all eligible areas throughout the farm with the associated SRR. This would be useful for the user to identify which fields have eligible areas and then conduct a profitability analysis. The user must provide spatially explicit yield data to do this calculation. All errors and outliers should be removed from this data before it is input into the DST (Sun et al 2013). The user should remove values outside of a reasonable range of dry yield volume values per crop type. Our range was 20.18 – .67 tonnes/hectare dry yield volume for corn and 5.38 – .34 tonnes/hectare for soybeans. The outliers of the remaining data beyond ± 3 standard deviations of the mean were removed as well (Sun et al 2013). The user must provide various economic inputs to calculate profitability. These include the commodity price per tonne, government payments received per hectare, and production costs per hectare. A continuous yield surface is needed to accurately calculate field scale profitability; therefore, we interpolated the dry yield volume of the yield points using Inverse Distance Weighted (IDW) to create a raster yield surface. The cell size of the output raster can either be automatically calculated by the DST or input by the user. IDW has been shown to be a highly accurate interpolation method for yield data (Souza et al 2016). The row crop profitability of the field is calculated by multiplying commodity prices by the dry yield volume and adding government payments. Production costs are then subtracted from this value. The entire equation is as follows:

Row Crop Profitability = (Commodity Price * Dry Yield Volume) + Government Payments – Production Costs.

This value is recorded in the output profitability shapefile as the Original Profit Per Acre.

Profitability calculation for conservation practices with spatial eligibility requirements and limitations (e.g., CP-21, CP-22, CP-29, CP-30, CP-33) requires the user to enter the various buffer distances to be considered within the allowed distances for the given practice. This eligible conservation area is erased from the original profit surface raster to come up with the profitability per acre had the buffer area not been farmed at all. This value is also recorded in the profitability shapefile. Another feature of the DST generates a shapefile of profitable areas within the buffers. This is accomplished by comparing, on a cell level, the profitability of the original profit surface raster to the CRP practice raster. A cell is extracted if the CRP practice is more profitable. These cells are then converted to polygons, aggregated together considering an aggregation distance of 5 meters, and polygons smaller than 0.1 hectares were removed. Using this profitable buffer shapefile as a guide, the user is able to run the DST another time with this iteration allowing the user to draw their own conservation scenario within the spatial eligibility of the given practice, allowing them to more precisely target unprofitable areas and draw buffers that would allow the field to be easily farmed. Other required parameters for the CRP profitability calculation include CRP establishment cost per acre, CRP maintenance costs per acre, and CRP contract length (10 or 15 years). A bar graph in PDF format will be created that compares whole field original profit per acre to whole field CRP practice profit per acre. The DST has help documentation in the Graphical User Interface (GUI) to allow for smooth operation.

Conservation Scenarios

We focused on a theoretical three-pronged landowner objective of water quality improvement, pollinator habitat establishment, and upland bird conservation. These conservation priorities represent common interests among landowners in the region. We considered the practices CP-22 Riparian Buffers, CP-33 Upland Bird Habitat Buffer, and CP-42 Pollinator Habitat Establishment to accomplish this objective. CP-22 establishes a strip of trees bordering perennial or seasonal streams, water bodies or wetlands (USDA NRCS 2015). This strip or buffer begins at the top of the stream bank and cannot be less than 10.67 meters and not more than 30.48 meters. The contract length can be either 10 or 15 years. An additional 20% Rental Rate Incentive (RRI) of the SRR is added to the CRP payment. A one-time Sign-Up Incentive (SIP) of $247.10 a hectare is included as well. The Cost-Share Payment and Practice Incentive Payment (PIP) cover 90% of the cost of establishing the practice while the remaining cost is divided by the CRP contract length and amortized with a 6% annual interest rate. CP-33 seeks to establish field edge buffers for upland bird habitat (USDA NRCS 2015). These buffers may be 9.14 to 36.58 meters inward from the field edge. Only a 10-year contract is allowed. A SIP of $370.65 a hectare is included. 90% of the costs of establishing the practice is covered in the form of a Cost-Share Payment and Practice Incentive Payment (PIP) while the remaining cost is divided by the CRP contract length and amortized with a 6% annual interest rate. CP-42 looks to establish plant communities that promote pollinator habitat (USDA NRCS 2015). This practice can be established anywhere in a field as long as each habitat area is larger than 0.2 hectares and strip planting is larger than 6.1 meters wide. Contract length may only be 10 years. A SIP of $370.65 a hectare is included. 50% of the cost of establishing the practice is covered in the form of the Cost-Share Payment while the remaining cost is divided by the CRP contract length and amortized with a 6% annual interest rate. Table 3.1 shows the economics and spatially eligibility of the three practices being considered.

We evaluated farm level profitability ($/hectare) under three farm management scenarios using our DST and strategic conservation enrollment:

1. Maximum row crop production (no conservation enrollment)
2. Maximum conservation enrollment (maximum acres spatially eligible)

3. Targeted conservation enrollment (conservation only where profitable)

The first scenario we considered represented standard row crop production across multiple years and crop types. The second scenario represents maximizing conservation enrollment regardless of financial considerations. We considered the maximum buffer size for CP-22 and CP-33 and the whole field for CP-42. The maximum amount of eligible area was considered and each field's profitability analyzed. The last scenario represented the novel concept formulated by McConnell and Burger (2011) where conservation enrollment only occurs where its profitability exceeds that of agricultural production. Using the profitable buffer layer as a guide, we identified opportunities for increased profitability and simulate enrollment on those areas only to optimize conservation and profitability. Practice extents were only drawn in practical ways that allow the producer to effectively farm the remaining areas (i.e., no increase in field edge complexity). We considered CP-42 on fields with unprofitable areas in the middle of the field that didn't fit into the eligibility of CP-22 or CP-33. We analyzed the whole field profitability of each scenario across the sample fields within the study farm. Multiple profit surfaces were generated for fields that had multiple years of yield data. These profit surfaces were averaged and used to compare the financial tradeoff of implementing one of our three CRP practices. Analyzing multiple years of yield data gave us a more holistic idea of how a field was performing. We considered the average commodity prices of corn and soybeans for the period we have yield data (2014-2017). Commodity prices fluctuated only slightly between these years allowing us to use the four-year average price for each commodity (Figure 3.2). We retrieved production costs to produce each crop from the crop consultant managing the farm production. CRP establishment and maintenance costs were taken from a 2018 Mississippi CRP cost-list sheet. Table 3.1 shows all values used in the profitability analysis. We did not consider a Maintenance Rate Incentive

(MRI) for CP-22 since this incentive is not guaranteed and we wanted to conservatively simulate a CRP contract. All CRP contracts were set to be 10 years. All raster analysis was done considering a 1-meter cell size.

Results

Our DST's eligibility analysis identified 89.48 hectares were eligible for CP-22 (Figure 3.3) and 413.94 hectares were eligible for CP-33 (Figure 3.4) across our study farm. Examples of fields with various scenarios for CP-33 (Figure 3.5), CP-22 (Figure 3.6), and CP-42 (Figure 3.7) are seen below. Average profitability for the targeted conservation scenario was more profitable than row crop agriculture in 37 of the 52 fields (71.15%) whereas the average profitability for maximum conservation was more profitable than row crop agriculture in 14 of the 52 fields (26.92%). The average profitability of row crop agriculture was $316.51 per hectare in this subset of fields. The average profitability decreased to $279.59 per hectare when we considered the maximum amount of CRP area. Finally, under the targeted conservation approach the average profitability increased to $352.12 per hectare. The whole field profitability on average increased by 24.46% amongst these 37 fields where we implemented a target conservation strategy (Figure 3.8). It is important to note the variation in profit increase among these fields. Values ranged from .26% to 264.54% (Figure 3.9). Among these fields we compared the frequency distribution of profitability values (cells) of row crop agriculture and targeted conservation (Figure 3.10). Compared to row crop agriculture, the distribution of targeted conservation shows a reduction in pixels in the very low or negative profitability region, a spike in the $200 to $250 per hectare region, which is the range of an average CRP contract, and an overall shift towards higher profitability. The maximum conservation scenario for CP-42, which entailed enrolling the entire field, showed an average field profitability of $158.29 per hectare. This is a 63.12% decrease in profit from row crop agriculture. No CRP was enrolled in the maximum row crop production scenario, whereas 7.01 ha (±6.23)/field were enrolled in the maximum conservation scenario, and 2.06 ha (±1.67)/field were enrolled in the targeted conservation scenario. The maximum conservation scenario would enroll 35.34% of the farmable area, compared to 7.59% for the targeted conservation approach. The average percent profit increase varied across fields depending on how many years of yield data was available (Figure 3.11). Fields with one year of yield data had an average profit increase of 41.02% (±51.40%), two years an increase of 5.93% (±5.93%), three years an increase of 3.26% (±7.88%), and four years an increase of 27.84% (±13.47%). The average profit increase varied by CRP practice as well (Figure 3.12). Fields where CP-33 was considered saw an increase in profitability of 31.98% (±57.00%), CP-22 an increase of 3.64% (±4.52%), and CP-42 an increase of 3.59% (±6.90%). These differences were likely attributable to the spatially more restrictive eligibility requirements of CP22 and the acreage limitations of CP42, compared to CP33.

Discussion

Our results illustrate that conservation can be implemented in an informed and profitable manner when precision agriculture technology is used to target low profiting or unprofitable areas for CRP enrollment. Our results show that a targeted conservation approach generated the most profitable scenario, while maximum conversation and maximum production scenarios were significantly less profitable. We saw a decrease in profitability from the maximum production scenario to the maximum conservation scenario. This confirms producers concerns that taking land out of production and converting it to CRP with an untargeted strategy can result in a reduction of profit. Overall we saw a reduction in profitability for whole field enrollments (CP-42). Whole field enrollments have historically represented the majority of CRP enrollments (80% of CRP payments in 2005) (Claassen et al. 2008), mainly because non-whole field enrollments did not become available until the 1996 Farm Bill as a pilot program (USDA NRCS 2015). Based off our criteria for determining which of the three CRP practices to analyze, we considered six fields for CP-42. The maximum conservation scenario converted a whole field to CP-42 and showed a 63.12% decrease in profit from maximum production. The most financially sound way to enroll CRP, in most cases, was in only a portion of a field that was unprofitable leaving the remaining acreage available for profitable production. This is in contrast to the previous "shotgun" approach where practices were non-strategically scattered across the landscape (Nowak 2009). The fact that the targeted conservation approach resulted in the highest profit further illustrates its importance to landscape-scale conservation efforts and results in a positive financial tradeoff, which is most important to many producers (Sweikert & Gigliotti 2019). Figure 3.9 illustrates the extreme variation in profitability increase of the targeted conservation approach which shows that there is a large variation in the magnitude of how low profiting or unprofitable areas are. We recommend producers target fields with the largest increase in profitability to optimize profitability. This would also result in fewer hectares being taken out of production, if that is a concern for the producer. Research has demonstrated enrolling more area in CRP increases overall conservation benefits (wildlife habitat, increased water quality, decreased soil erosion) (Yeiser et al. 2018). Whereas the maximum conservation scenario would produce the greatest conservation benefit, this scenario is not financially practical for producers. Removing large areas of profitable land from production in a maximum conservation scenario could also be detrimental to global food production goals for 2050 (Hunter et al. 2017). The risk of profitable areas being converted back to row crop production during high commodity prices periods would be substantial, thus creating unintentional negative conservation consequences. Comparing the distribution of profitability value pixels of row crop agriculture to targeted conservation shows a significant reduction in low and negative profitability pixels and a spike in moderately profitable pixels ($200 - $250 per hectare) (Figure 3.10). The noticeable shift towards and greater frequency of profitable cells further illustrates how a targeted conservation strategy can increase overall farm profitability and reduce the amount of unprofitable marginal land farmed.

We recommend producers use our DST to experiment with various commodity prices to mitigate the risk of missing economic opportunities from both crop production and conservation. This would allow the producer to make an informed decision regarding future land use decisions. Focusing only on profitable conservation scenarios could minimize conservation areas being converting back to production due to fluctuating commodity prices and would result in long term and landscape scale conservation benefits (Nowak 2009; Lute et al. 2018; Yeiser et al. 2018). We observed significant variation in the average increase of profitability from row crop agriculture to targeted conservation based off how many years of yield data a field had. We suspect that this variation was due to the different sample sizes of fields with various years of yield data. We saw the highest increase in profitability through targeted conservation in a field that only had one year of yield data, but average increase in profitability was comparable to scenarios with four years of yield data (Figure 3.11). It is not recommended that producers make management decisions based off one year of yield data. A single year can have climatic conditions that are extremely beneficial or detrimental to yields, thus they do not give you an idea on how the field is performing on average. However, the 16 fields we analyzed with 4 years of yield data still showed a significant increase (27.84%) in profitability from row crop agriculture to targeted conservation. We also observed variation in profitability amongst the three CRP practices (CP-42, CP-33, CP-22). The amount of eligible area varied by practice (Figures 3.3 and 3.4) due to varying spatial eligibility requirements. There were limited hectares of CP-22 on our study farm to find many profitable scenarios with this practice, compared to CP-33 which has less restrictive spatial eligibility criterion. CP-33 is also an ideal practice to address the common yield-reducing edge effects that many fields exhibit (Barbour et al. 2007; Blackmore 2014). We found no scenario were CRP was profitable in 15 of our fields. These high yielding fields should continue to be sustainably farmed by the producer using sound practices. High producing fields like these will be vital to meeting the food production goals of 2050 (Hunter et al. 2017). Our results represent a case study across multiple fields on one agricultural farm within the Black Belt Prairie region of Mississippi, therefore we caution recognize and caution readers on interpreting our results beyond our spatial inference. However, our results illustrate the potential and applicability of precision agriculture technology in a targeted conservation scenario. We encourage future research to incorporate multiple farming systems across large agricultural landscapes.

Future Directions

The production system of a corn and soybean rotation in the Black Prairie region of Mississippi where we tested our DST is specific to only certain regions of the United States. The DST should be tested in other systems, for example wheat and corn production systems in the Midwest, to see if similar results are observed. Our DST can quantify the economic tradeoff of establishing a CRP practice. Other DST's have looked to quantify the reduction in soil erosion

(Rao et al. 2007) and the increase in water quality (Dosskey & Eisenhauer 2005; Rao et al. 2007)) of establishing a practice, while other research has quantified the impact of a practice on wildlife populations and called for the creation of a DST to make their framework applicable (Yeiser et al. 2018). Future research should focus on combining these DSTs and frameworks to produce a more comprehensive suite of tools that allows a user to analyze and quantify a CRP practice from a financial and conservation perspective. Research has simulated various environmental outcomes of CRP enrollment (Rao et al. 2007; Tomer et al. 2015; McConnell et al. 2016; Yeiser et al. 2018). Future research should continue to focus on quantifying the economic outcomes and environmental outcomes (e.g. wildlife habitat, water quality, soil erosion, carbon sequestration) of CRP enrollment. Future research could also develop a DST to model land retirement programs in other countries (European Union (EU) or Australia) and see if a targeted conservation approach is effective in their production systems and land retirement programs as well. Conservation agencies utilizing this DST have varying conservation goals and finite resources to accomplish these goals. We need large scale targeting of the DST's use for conservation agencies to efficiently use it. We could accomplish this by identifying fields on a landscape scale that are predicted to profit from CRP establishment and have a high likelihood of accomplishing a specific conservation goal (habitat potential, erosion or water quality vulnerability). Future research should focus on using remote sensing technology to accomplish these goals. Many producers do not have the technology to collect spatially explicit yield data, do not know how to use the technology, or are unwilling to release their yield data (Zhou et al. 2017). It would also be beneficial to use remote sensing models with satellite imagery to predict yield and use as a replacement for actual yield data. A plethora of research has been devoted to this subject and could be integrated into our DST (Panda et al. 2010; Basso et al. 2013; Lobell et al. 2015).

Literature Cited

Altieri, M. A. (1991). How Best Can We Use Biodiversity in Agroecosystems? Outlook on Agriculture, 20(1), 15–23. https://doi.org/10.1177/003072709102000105

Arbuckle, J. G. J. (2013). Farmer attitudes toward proactive targeting of agricultural conservation programs. *Society & Natural Resources*, *26*(6), 625–641. https://doi.org/10.1080/08941920.2012.671450

Arciniegas, G., Janssen, R., & Rietveld, P. (2013). Effectiveness of collaborative map-based decision support tools: Results of an experiment. *Environmental Modelling and Software*, *39*, 159–175. https://doi.org/10.1016/j.envsoft.2012.02.021

Barbour, P. J., Martin, S. W., & Burger, W. (2007). Estimating Economic Impact of Conservation Field Borders on Farm Revenue. *Cm*, *6*(1), 0. https://doi.org/10.1094/cm-2007-0614-01-rs

Basso, B., Cammarano, D., & Carfagna, E. (2013). Review of Crop Yield Forecasting Methods and Early Warning Systems. *The First Meeting of the Scientific Advisory Committee of the Global Strategy to Improve Agricultural and Rural Statistics*, 1–56. https://doi.org/10.1017/CBO9781107415324.004

Baylis, K., Peplow, S., Rausser, G., & Simon, L. (2008). Agri-environmental policies in the EU and United States: A comparison. *Ecological Economics*, *65*(4), 753–764. https://doi.org/10.1016/j.ecolecon.2007.07.034

Berry, J. K., Detgado, J. A., Khosla, R., & Pierce, F. J. (2003). Precision conservation for environmental sustainability. *Journal of Soil and Water Conservation*, *58*(6), 332–339. Retrieved from http://www.jswconline.org/content/58/6/332

Bhandari, S., Raheja, A., Green, R. L., & Do, D. (2017). Towards collaboration between unmanned aerial and ground vehicles for precision agriculture, *10218*, 1021806. https://doi.org/10.1117/12.2262049

Bigelow, P. D., and A. Borchers. 2017. Major Uses of Land in the United States, 2012. EIB-178. USDA, Economic Research Service. August.

Blackmore, B. S. (2014). at Silsoe National Soil Resources Institute This thesis is submitted in fulfilment of the requirements Simon Blackmore The role of yield maps in Precision Farming A PhD thesis by papers Supervisors : R . J . Godwin and P . Bullock, (January 2003).

Bobryk, C. W., Yost, M. A., & Kitchen, N. R. (2017). Field variability and vulnerability index to identify regional precision agriculture opportunity. *Precision Agriculture*, 1–17. https://doi.org/10.1007/s11119-017-9541-6

Bonner, I. J., Cafferty, K. G., Muth, D. J., Tomer, M. D., James, D. E., Porter, S. A., & Karlen, D. L. (2014). Opportunities for energy crop production based on subfield scale distribution of profitability. *Energies*, *7*(10), 6509–6526. https://doi.org/10.3390/en7106509

Burger, L. W. 2005. The Conservation Reserve Program in the Southeast: issues affecting wildlife habitat value. Pages 63 – 92 in J. B. Haufler, ed. Fish and wildlife benefits of Farm Bill conservation programs: 2000-2005 update. The Wildlife Society Technical Review 05-2.

Burger, L. W. 2000. Wildlife responses to the Conservation Reserve Program in the Southeast. Pages 55-74 in W. L. Hohman, ed. A comprehensive review of farm bill contributions to wildlife conservation 1985-2000. Technical Report, USDA/NRCS/WHMI-2000.

Capmourteres, V., Adams, J., Berg, A., Fraser, E., Swanton, C., & Anand, M. (2018). Precision conservation meets precision agriculture: A case study from southern Ontario. *Agricultural Systems*, *167*(May), 176–185. https://doi.org/10.1016/j.agsy.2018.09.011

Claassen, R., Cattaneo, A., & Johansson, R. (2008). Cost-effective design of agri-environmental payment programs: U.S. experience in theory and practice. *Ecological Economics*, *65*(4), 737–752. https://doi.org/10.1016/j.ecolecon.2007.07.032

Claassen, R., & Duquette, E. (2012). Additionality in U . S . Agricultural Conservation Programs: A Preliminary Analysis of New Data, (May), 1–33.

Conkling, T. J., Belant, J. L., DeVault, T. L., & Martin, J. A. (2017). Effects of crop type and harvest on nest survival and productivity of dickcissels in semi-natural grasslands. *Agriculture, Ecosystems and Environment*, *240*, 224–232. https://doi.org/10.1016/j.agee.2017.01.028

Dosskey, M. G., & Eisenhauer, D. E. (2005). Establishing conservation buffers using precision information. *Journal of Soil and Water Conservation*, *60*(6), 349–354. Retrieved from http://www.jswconline.org/content/60/6/349.short

ESRI 2018. ArcGIS Desktop: Release 10.6 Redlands, CA: Environmental Systems Research Institute.

Fahrig, L., Girard, J., Duro, D., Pasher, J., Smith, A., Javorek, S., … Tischendorf, L. (2015). Farmlands with smaller crop fields have higher within-field biodiversity. *Agriculture, Ecosystems and Environment*, *200*(February), 219–234. https://doi.org/10.1016/j.agee.2014.11.018

Farrand, D. T., & Ryan, M. R. (2005). Impact of the Conservation Reserve Program on Wildlife

Conservation in the Midwest. *Fish and Wildlife Benefi Ts of Farm Bill Programs: 2000–2005 Update 43*, (Usda 2003), 41–62.

Gaines-day, H. R., & Gratton, C. (2017). Understanding Barriers to Participation in Cost-Share Programs For Pollinator Conservation by Wisconsin (USA) Cranberry Growers. *Insects*, *8*(3), 79. https://doi.org/10.3390/insects8030079

Glaser, L. K. (1985). Provisions of the Food Security Act of 1985. United States Department of Agriculture.

Hamada, Y., Ssegane, H., & Negri, M. C. (2015). Mapping intra-field yield variation using high resolution satellite imagery to integrate bioenergy and environmental stewardship in an agricultural watershed. *Remote Sensing*, *7*(8), 9753–9768. https://doi.org/10.3390/rs70809753

Homberger, B., Duplain, J., Jenny, M., & Jenni, L. (2017). Agri-evironmental schemes and active nest protection can increase hatching success of a reintroduced farmland bird species. *Landscape and Urban Planning*, *161*, 44–51. https://doi.org/10.1016/j.landurbplan.2017.01.001

Hunter, M. C., Smith, R. G., Schipanski, M. E., Atwood, L. W., & Mortensen, D. A. (2017). Agriculture in 2050: Recalibrating targets for sustainable intensification. *BioScience*, *67*(4), 386–391. https://doi.org/10.1093/biosci/bix010

Johnson, K. A., Dalzell, B. J., Donahue, M., Gourevitch, J., Johnson, D. L., Karlovits, G. S., … Smith, J. T. (2016). Conservation Reserve Program (CRP) lands provide ecosystem service benefits that exceed land rental payment costs. *Ecosystem Services*, *18*, 175–185. https://doi.org/10.1016/j.ecoser.2016.03.004

Kitchen, N. R., Sudduth, K. A., Myers, D. B., Massey, R. E., Sadler, E. J., Lerch, R. N., … Palm,

H. L. (2005). Development of a conservation-oriented precision agriculture system: Crop production assessment and plan implementation. *Journal of Soil and Water Conservation*, *60*(6), 421–430. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-33745875489&partnerID=tZOtx3y1

Knight, A. T., Cowling, R. M., Difford, M., & Campbell, B. M. (2010). Mapping Human and Social Dimensions of Conservation Opportunity for the Scheduling of Conservation Action on Private Land. *Conservation Biology*, no-no. https://doi.org/10.1111/j.1523-1739.2010.01494.x

Knight, R. L. (1999). Private lands: The neglected geography. *Conservation Biology*, *13*(2), 223–224. https://doi.org/10.1046/j.1523-1739.1999.013002223.x

Kurzejeski, E. W., L. W. Burger, Jr., M. J. Monson, and R. L. Lenkner. 1992. Wildlife conservation attitudes and future land-use intentions of Conservation Reserve Program participants in Missouri. The Wildlife Society Bulletin 20:253-259

Li, C., Fultz, L. M., Moore-Kucera, J., Acosta-Martínez, V., Horita, J., Strauss, R., … Weindorf, D. (2017). Soil carbon sequestration potential in semi-arid grasslands in the Conservation Reserve Program. *Geoderma*, *294*, 80–90. https://doi.org/10.1016/j.geoderma.2017.01.032

Lobell, D. B., Thau, D., Seifert, C., Engle, E., & Little, B. (2015). A scalable satellite-based crop yield mapper. *Remote Sensing of Environment*, *164*, 324–333. https://doi.org/10.1016/j.rse.2015.04.021

Lute, M. L., Gillespie, C. R., Martin, D. R., & Fontaine, J. J. (2018). Landowner and Practitioner Perspectives on Private Land Conservation Programs. *Society and Natural Resources*, *31*(2), 218–231. https://doi.org/10.1080/08941920.2017.1376139

Lyle, G., Bryan, B. A., & Ostendorf, B. (2015). Identifying the spatial and temporal variability of economic opportunity costs to promote the adoption of alternative land uses in grain growing agricultural areas: An Australian example. *Journal of Environmental Management*, *155*(April), 123–135. https://doi.org/10.1016/j.jenvman.2015.02.006

Lynne, G. D., J. S. Shonkwiler, and L. R. Rola. 1988. Attitudes and farmer conservation behavior. American Journal of Agriculture Economics 70:12-19.

Macdonald, D. W. and P. J. Johnson. 2000. Farmers and the custody of the countryside: trends in loss and conservation of non-productive habitats 1981-1998. Biological Conservation 94:221-234.

MacGown, Joe, et al. "The Black Belt Prairie in Mississippi and Alabama." *Mississippi Entomological Museum*, Mississippi State University, 6 Sept. 2018, mississippientomologicalmuseum.org.msstate.edu/habitats/black.belt.prairie/BlackBeltPrairie.htm.

Maestrini, B., & Basso, B. (2018). Predicting spatial patterns of within-field crop yield variability. *Field Crops Research*, *219*(January), 106–112. https://doi.org/10.1016/j.fcr.2018.01.028

Main, A. R., Webb, E. B., Goyne, K. W., & Mengel, D. (2019). Field-level characteristics influence wild bee functional guilds on public lands managed for conservation. *Global Ecology and Conservation*, e00598. https://doi.org/10.1016/j.gecco.2019.e00598

McConnell, M., & Burger, L. W. (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. https://doi.org/10.2489/jswc.66.6.347

McConnell, M. D., Burger, L. W., Delgado, J., Sassenrath, G., & Mueller, T. (2016). Precision

Conservation to Enhance Wildlife Benefits in Agricultural Landscapes, *9740*, 1–28. https://doi.org/10.2134/agronmonogr59.2013.0031

Miller, C. (2017). Conservation Reserve Program in Illinois : Investigation of Participants' Motives , Expectations , and Desired Outcomes, Illinois Natural History Survey Technical Report *2017*(17), 36 pp.

Miltner, R. J. (2015). Measuring the Contribution of Agricultural Conservation Practices to Observed Trends and Recent Condition in Water Quality Indicators in Ohio, USA. *Journal of Environmental Quality*, *44*(6), 1821–31. https://doi.org/10.2134/jeq2014.12.0550

Morefield, P. E., LeDuc, S. D., Clark, C. M., & Iovanna, R. (2016). Grasslands, wetlands, and agriculture: the fate of land expiring from the Conservation Reserve Program in the Midwestern United States. *Environmental Research Letters*, *11*(9), 94005. https://doi.org/10.1088/1748-9326/11/9/094005

Muth, D. (2014). Profitability versus environmental performance: Are they competing? *Journal of Soil and Water Conservation*, *69*(6), 203–206. https://doi.org/10.2489/jswc.69.6.203A

Muth, D. J. (2015). Improving Economic and Environmental Performance through a Precision Business Plan.

Nowak, P. (2009). Lessons learned: Conservation, conservationists, and the 2008 flood in the US Midwest, *64*(6), 2008–2010. https://doi.org/10.2489/jswc.64.6.172A

Palm, C., Blanco-canqui, H., Declerck, F., Gatere, L., & Grace, P. (2014). Agriculture , Ecosystems and Environment Conservation agriculture and ecosystem services : An overview. *"Agriculture, Ecosystems and Environment," 187*, 87–105. https://doi.org/10.1016/j.agee.2013.10.010

Panda, S. S., Ames, D. P., & Panigrahi, S. (2010). Application of vegetation indices for agricultural crop yield prediction using neural network techniques. *Remote Sensing*, *2*(3), 673–696. https://doi.org/10.3390/rs2030673

Rao, M., Fan, G., Thomas, J., Cherian, G., Chudiwale, V., & Awawdeh, M. (2007). A web-based GIS Decision Support System for managing and planning USDA's Conservation Reserve Program (CRP). *Environmental Modelling and Software*, *22*(9), 1270–1280. https://doi.org/10.1016/j.envsoft.2006.08.003

Reimer, A. P., & Prokopy, L. S. (2014). Farmer participation in U.S. Farm bill conservation programs. *Environmental Management*, *53*(2), 318–332. https://doi.org/10.1007/s00267-013-0184-8

Ricigliano, V. A., Mott, B. M., Maes, P. W., Floyd, A. S., Fitz, W., Copeland, D. C., … Anderson, K. E. (2019). Honey bee colony performance and health are enhanced by apiary proximity to US Conservation Reserve Program (CRP) lands. *Scientific Reports*, *9*(1), 4894. https://doi.org/10.1038/s41598-019-41281-3

Riffell, S., Scognamillo, D., Burger, L. W., & Bucholtz, S. (2010). Broad-Scale Relations between Conservation Reserve Program and Grassland Birds: Do Cover Type, Configuration and Contract Age Matter. *The Open Ornithology Journal*, *3*, 112–123. https://doi.org/10.2174/1874453201003010112

Robertson, G. P., and S. M. Swinton. 2005. Reconciling agricultural productivity and environmental integrity : a grand challenge for agriculture. Frontiers in Ecology and the Environment 3(1):38–46.

Sorice, M. G., W. Haider, J. R. Conner, and R. B. Ditton. 2011. Incentive structure of and private landowner participation in an endangered species conservation program. Conservation Biology 25:587-596.

Souza, E. G., Bazzi, C. L., Khosla, R., Uribe-Opazo, M. A., & Reich, R. M. (2016). Interpolation type and data computation of crop yield maps is important for precision crop production. *Journal of Plant Nutrition*, *39*(4), 531–538. https://doi.org/10.1080/01904167.2015.1124893

Stull, J., Dillion, C., Shearer, S., & Isaacs, S. (2004). Using Precision Agriculture Technology for Economically Optimal Strategic Decisions: The Case of CRP Filter Strip Enrollment. *Journal of Sustainable Agriculture*, *24*(4), 39–56. https://doi.org/10.1300/J064v24n04

Sun, W., Whelan, B., McBratney, A. B., & Minasny, B. (2013). An integrated framework for software to provide yield data cleaning and estimation of an opportunity index for site-specific crop management. *Precision Agriculture*, *14*(4), 376–391. https://doi.org/10.1007/s11119-012-9300-7

Sweikert, L. A., & Gigliotti, L. M. (2019). Evaluating the role of Farm Bill conservation program participation in conserving America's grasslands. *Land Use Policy*, *81*(May 2017), 392–399. https://doi.org/10.1016/j.landusepol.2018.10.023

Tomer, M. D., Boomer, K. M. B., Porter, S. A., Gelder, B. K., James, D. E., & McLellan, E. (2015). Agricultural conservation planning framework: 2. Classification of riparian buffer design types with application to assess and map stream corridors. *Journal of Environmental Quality*, *44*(3), 768–79. https://doi.org/10.2134/jeq2014.09.0387

Tullos, Allen. "The Black Belt." *Southern Spaces*, Emory University, 19 Apr. 2004, southernspaces.org/2004/black-belt.

USDA ERS (2019) U.S. and State-Level Farm Income and Wealth Statistics. Retrieved from https://www.ers.usda.gov/data-products/farm-income-and-wealth-statistics/data-files-us-and-state-level-farm-income-and-wealth-statistics/

USDA FSA (2018). Conservation Reserve Program Statistics. Retrieved from https://www.fsa.usda.gov/programs-and-services/conservation-programs/reports-and-statistics/conservation-reserve-program-statistics/index

USDA NASS (2017). U.S. Farm Production Expenditures August 2018. Retrived from https://www.nass.usda.gov/Publications/Highlights/2018/2017_Farm_Production_Expenditures.pdf

USDA NASS (2019). Prices Received for Corn by Month - United States. Retrived from https://www.nass.usda.gov/Charts_and_Maps/graphics/data/pricecn.txt

USDA NRCS. (2015). Conservation Reserve Program, (Revision 1). Retrieved from http://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/index

Vellidis, G., Barnes, E., Brannen, H. (2011). Cotton Yield Maps: Tool for Increasing Efficiency & Profitability. *Cotton Incorporated.* Retrieved from https://www.cottoninc.com/wp-content/uploads/2017/03/Cotton-Yield-Maps-PDF.pdf

Wiens, J. (1995). Habitat fragmentation: island v landscape perspectives on bird conservation.

Wunder, S., Engel, S., & Pagiola, S. (n.d.). Taking stock: A comparative analysis of payments for environmental services programs in developed and developing countries. *Ecological Economics*. Retrieved from http://www.sciencedirect.com/science/article/B6VDY-4S8HVVY-2/2/ca90c7c5f5eb853b711131e3a8ca578f

Yeiser, J. M., Morgan, J. J., Baxley, D. L., Chandler, R. B., & Martin, J. A. (2018). Private land conservation has landscape-scale benefits for wildlife in agroecosystems. *Journal of Applied Ecology*, *55*(4), 1930–1939. https://doi.org/10.1111/1365-2664.13136

Zhou, X. V., English, B. C., Larson, J. A., Lambert, D. M., Roberts, R. K., Boyer, C. N., … Martin, S. W. (2017). Precision farming adoption trends in the Southern U.S. *Journal of Cotton Science*, *21*(2), 143–155.

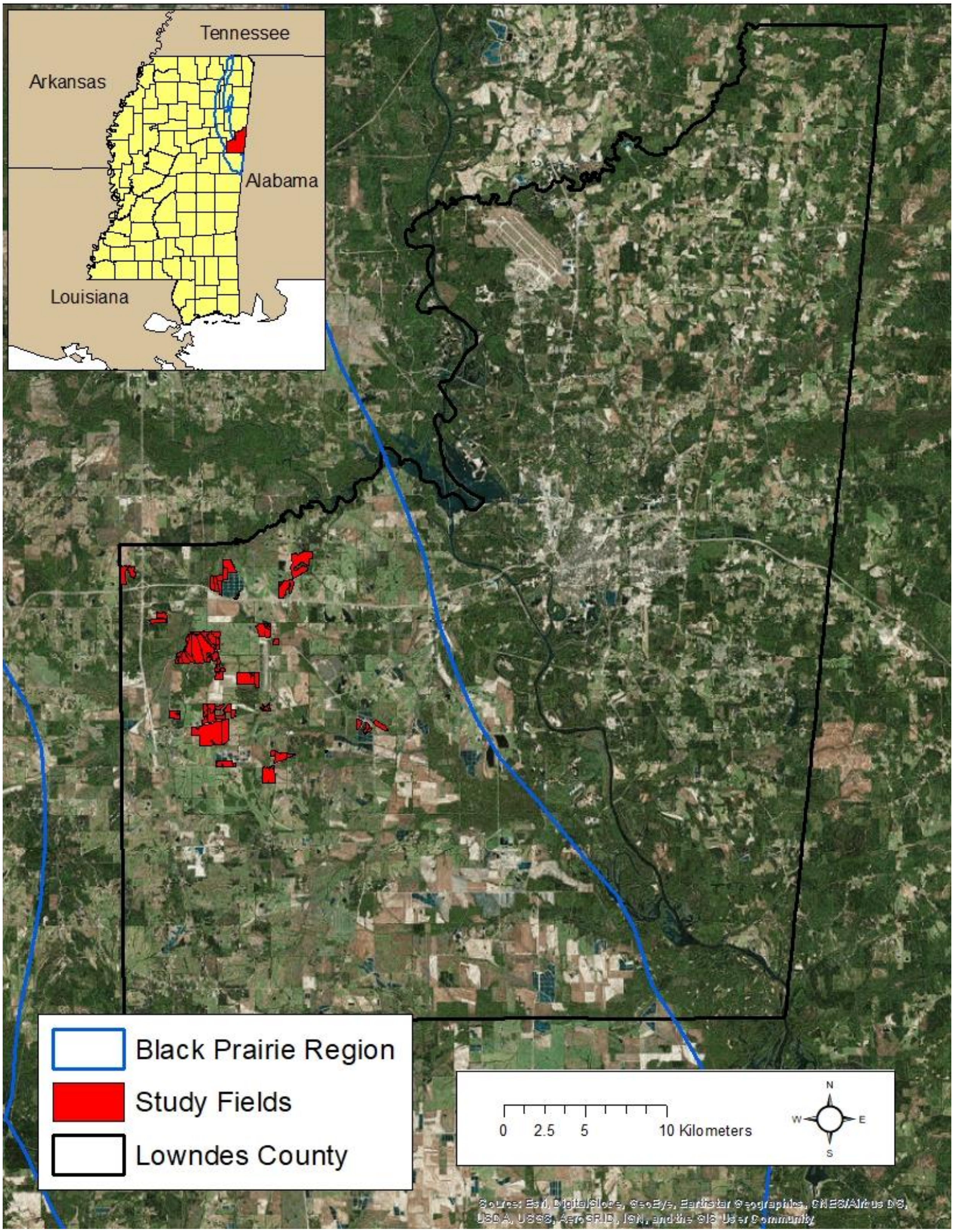


Figure 3.1 Location of Lowndes County, Mississippi, USA.

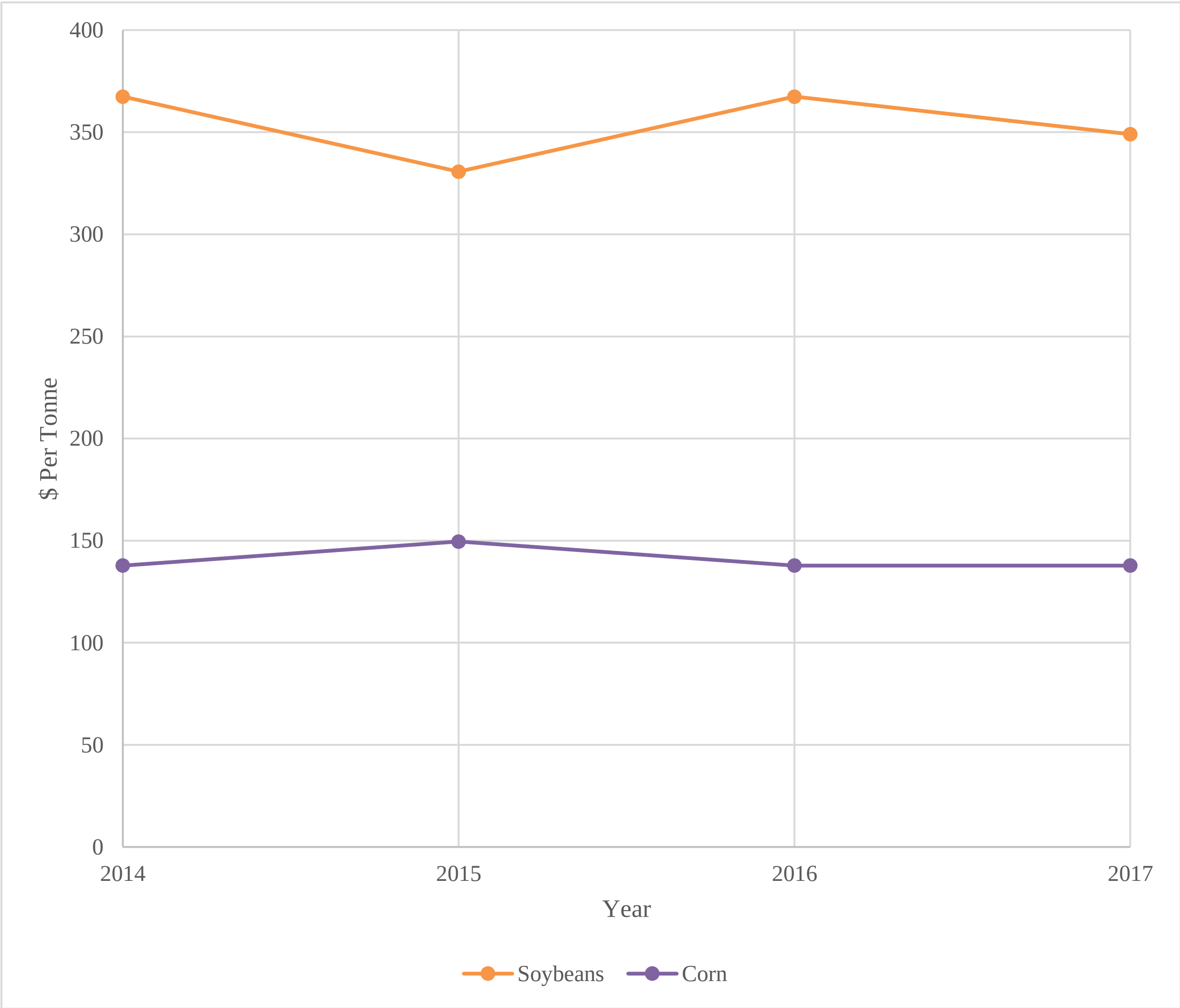


Figure 3.2 Average soybean and corn prices (2014-2017). Data Source: www.macrotrends.net/charts/commodities.

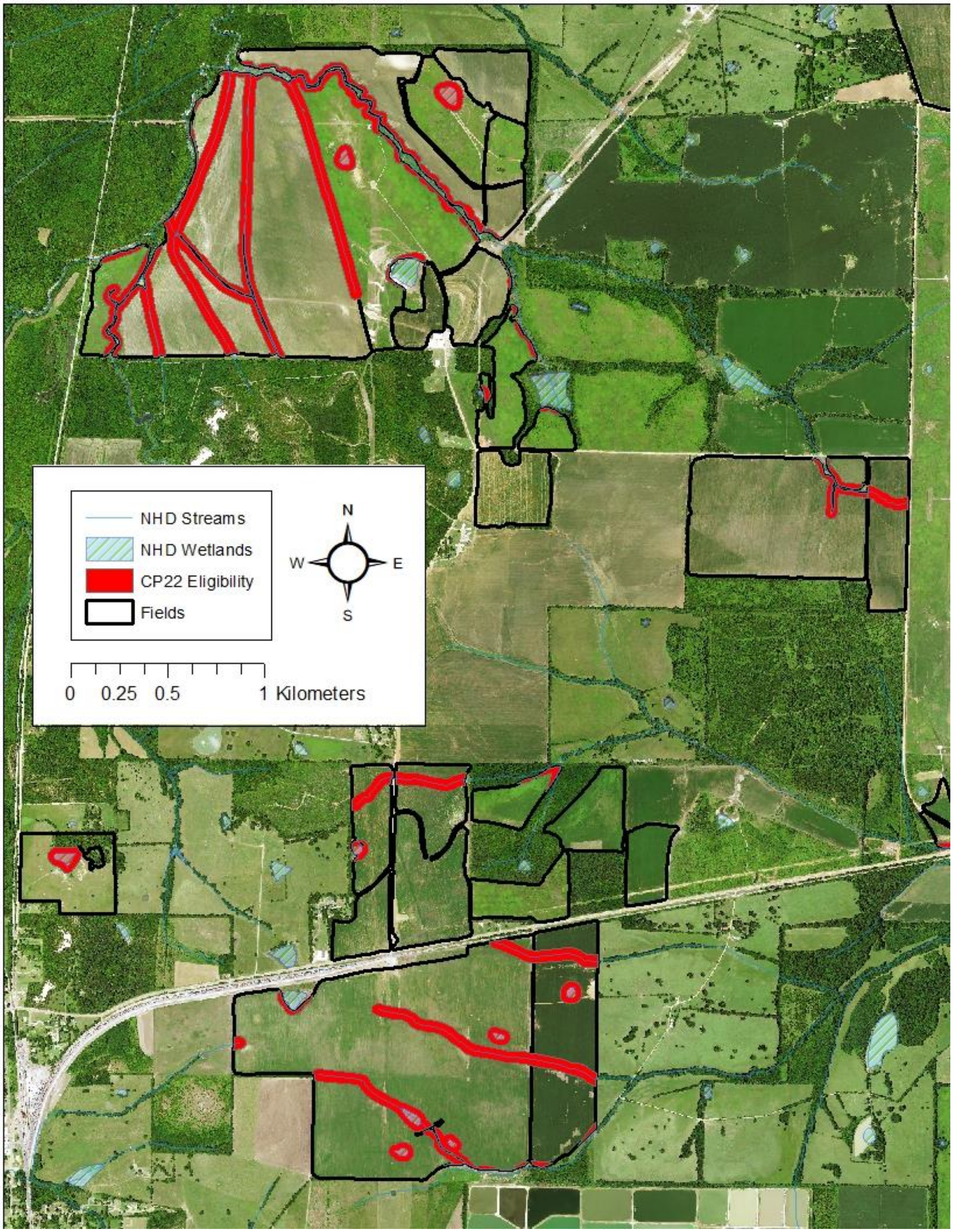


Figure 3.3 CP-22 eligible fields that were analyzed. 89.48 hectares were eligible throughout the farm.

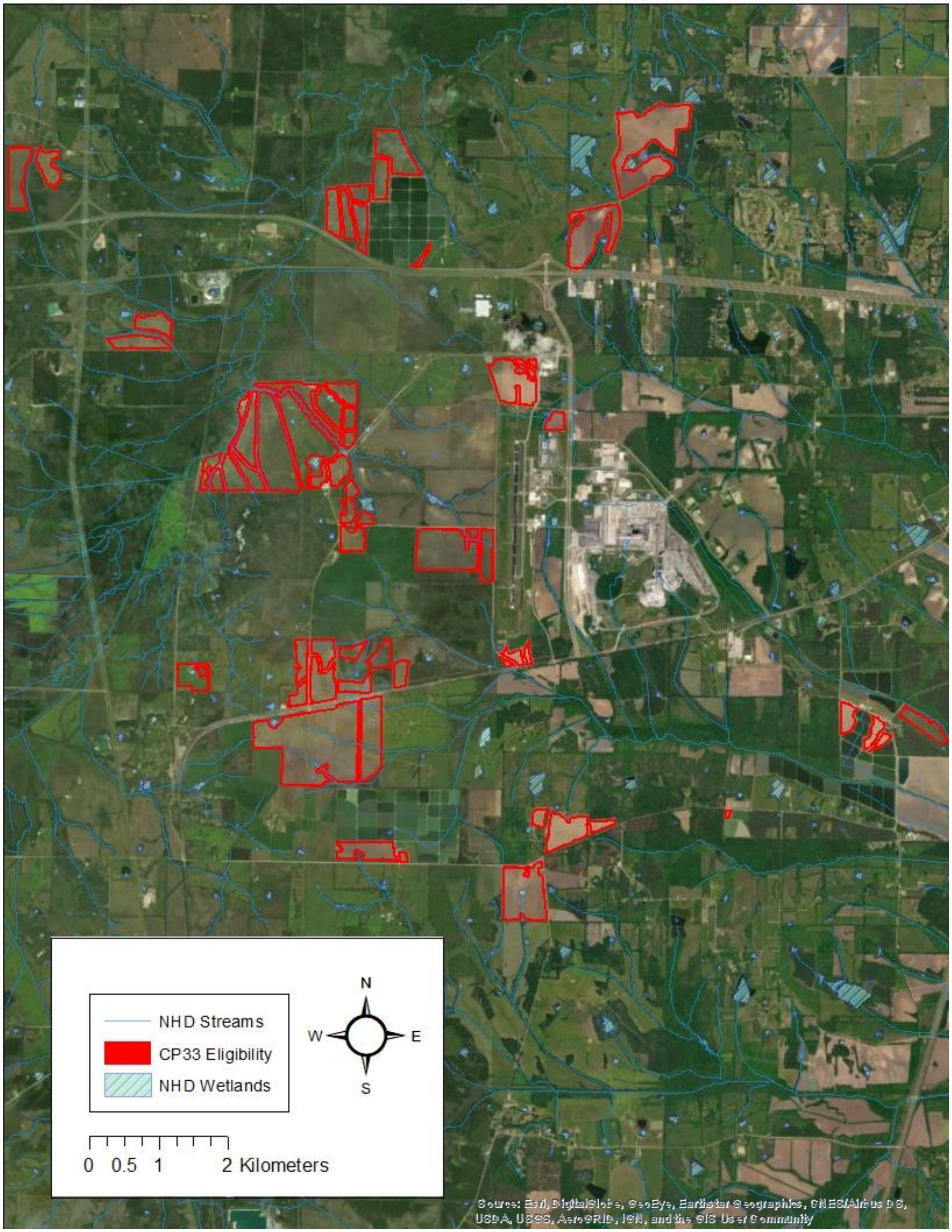


Figure 3.4 CP-33 eligible fields that were analyzed. 413.94 hectares were eligible throughout the farm.

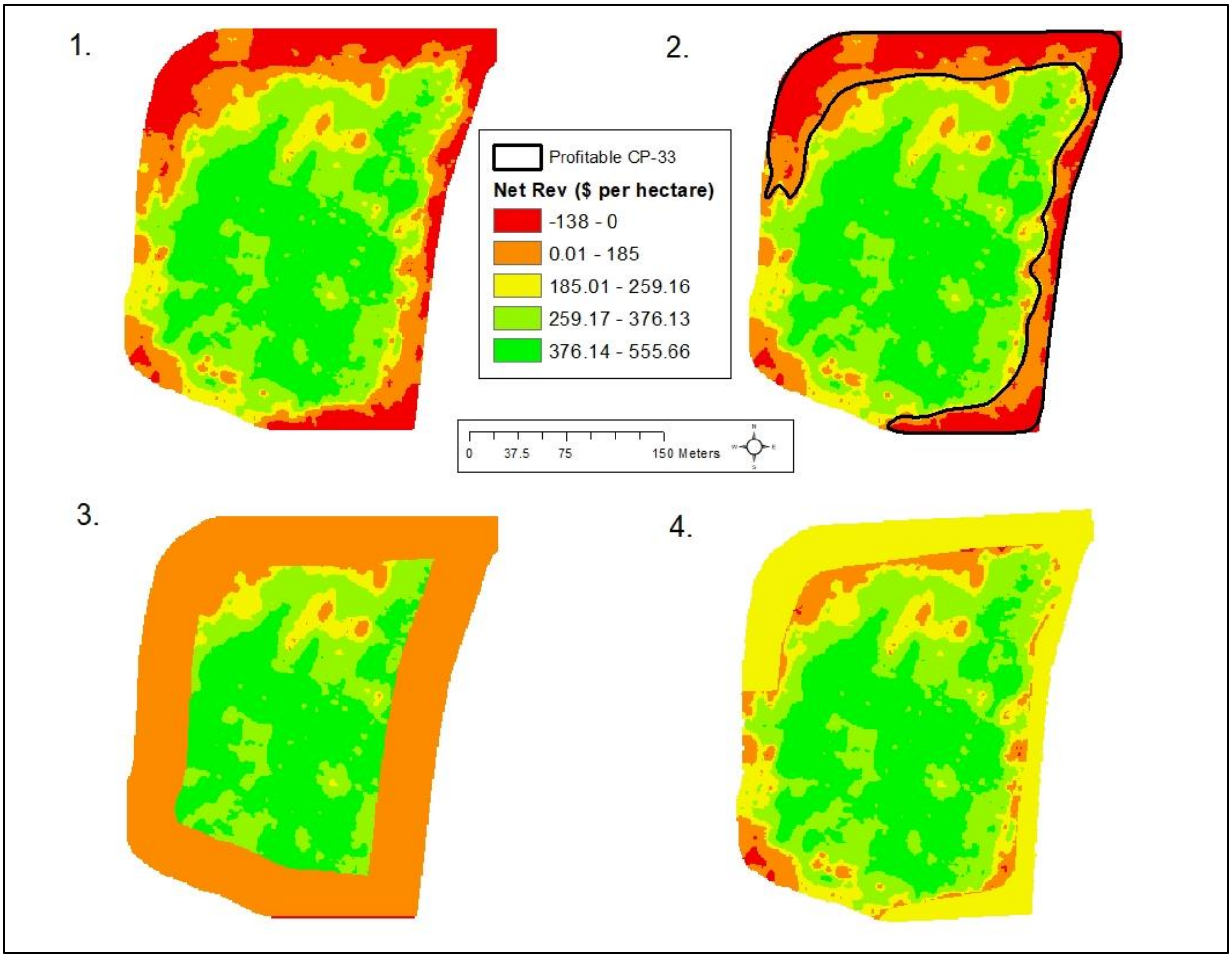


Figure 3.5 CP-33 profit surfaces for various conservation scenarios. (1) Row crop agriculture. Whole field profit: $239.37 per hectare (2) Row crop agriculture with outline of profitable CRP areas (3) Maximum conservation. Whole field profit: $262.34 per hectare (4) Targeted conservation. Whole field profit: $296.17 per hectare.

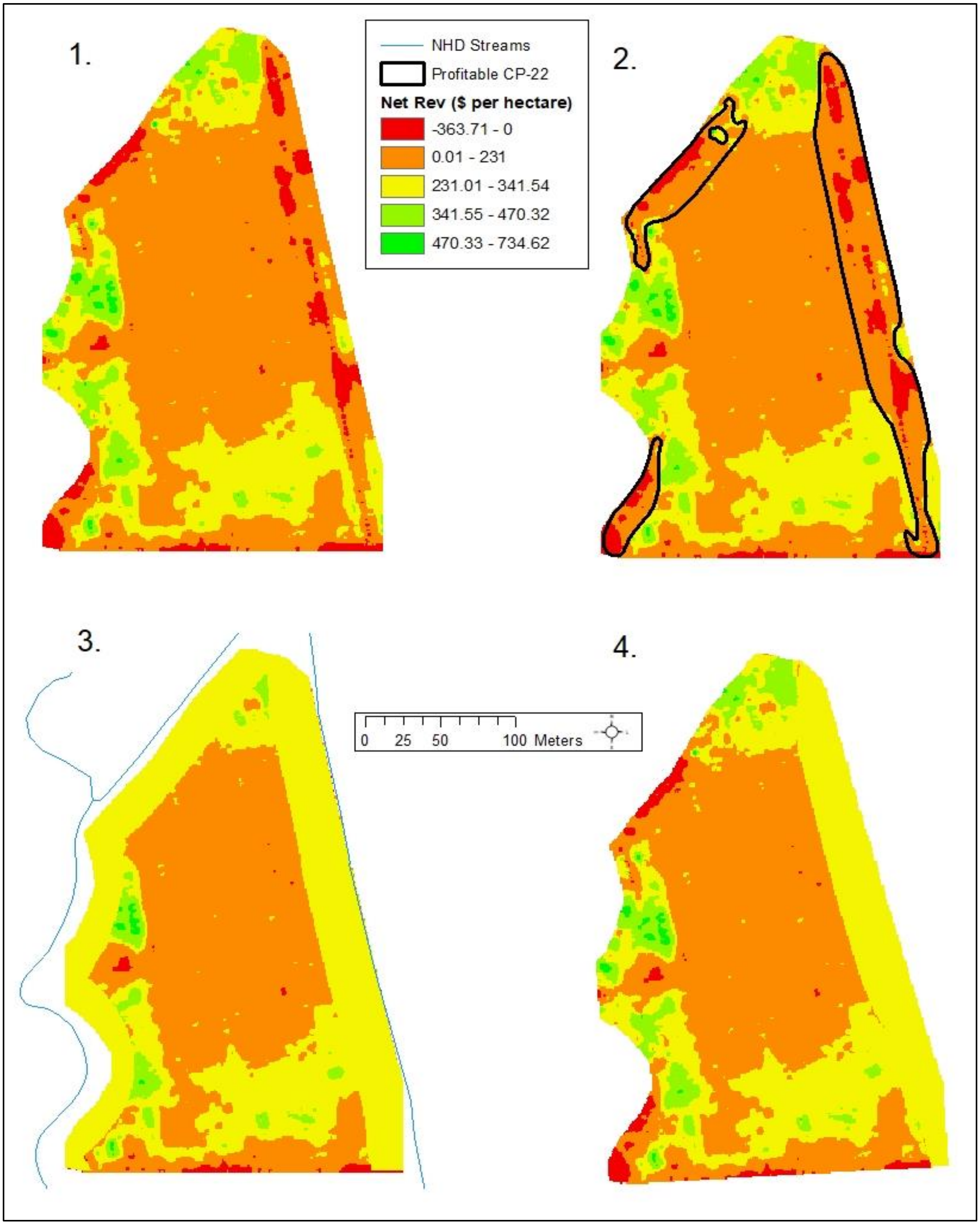


Figure 3.6 CP-22 profit surfaces for various conservation scenarios. (1) Row crop agriculture. Whole field profit: $178.45 per hectare (2) Row crop agriculture with outline of profitable CRP areas (3) Maximum conservation. Whole field profit: $201.71 per hectare (4) Targeted conservation. Whole field profit: $200.97 per hectare.

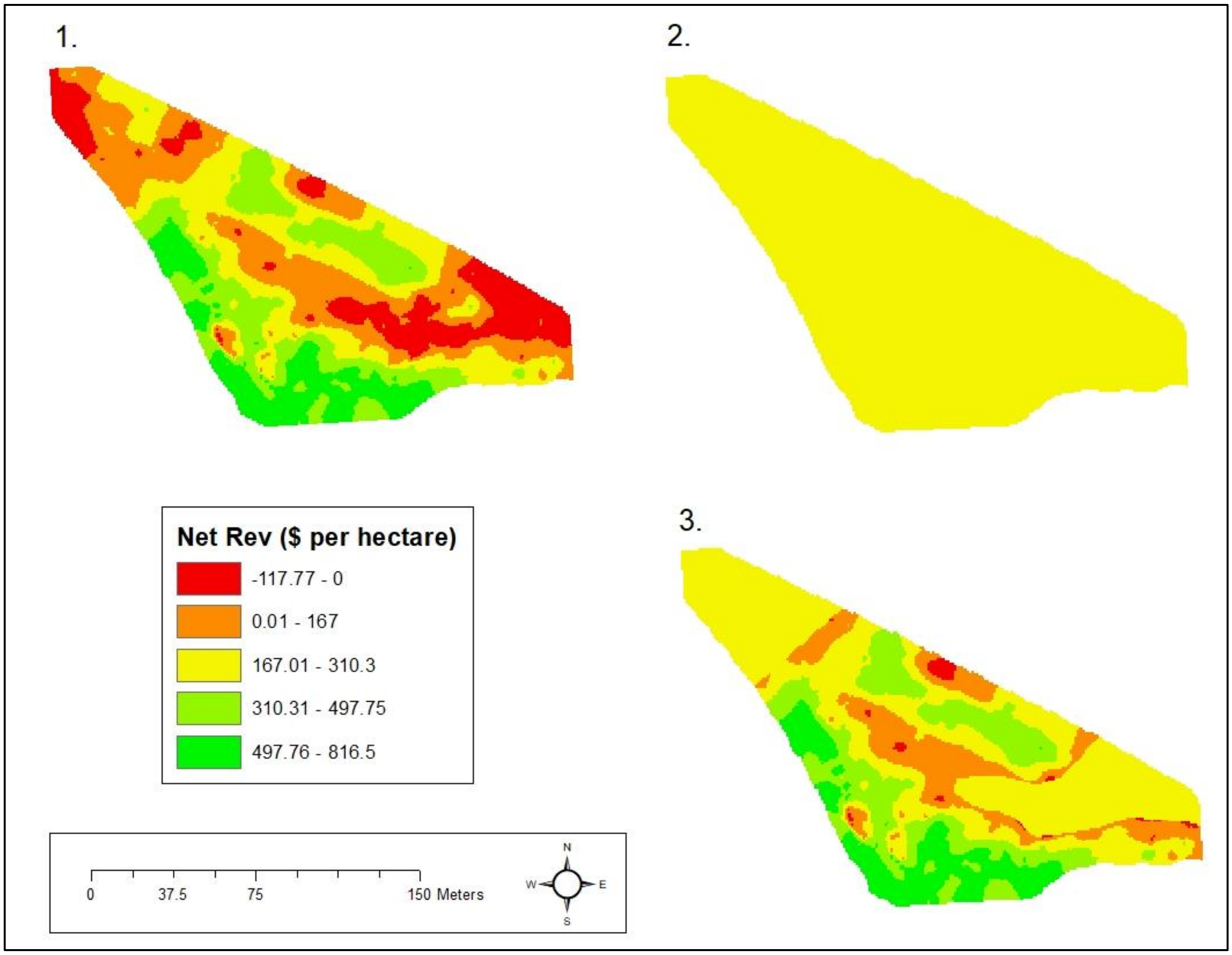


Figure 3.7 CP-42 profit surfaces for various conservation scenarios. (1) Row crop agriculture. Whole field profit: $225.23 per hectare (2) Maximum conservation. Whole field profit: $167.68 per hectare (3) Targeted conservation. Whole field profit: $267.51 per hectare.

Farming Scenario Inputs						
	Conservation Practices				Crop Production	
	CP-22	CP-33	CP-42		Soybean	Corn
Establishment Costs ($/hectare)	$815.43	$489.26	$741.30	Commodity Price ($/tonne)	$349.06	$137.78
Maintenance Costs ($/hectare)	N/A	$247.10	$247.10	Input Cost ($/hectare)	$617.75	$1,111.95
MRI ($/hectare)	N/A	N/A	N/A	Govt. Payment ($/hectare)	N/A	N/A
SIP ($/hectare)	$247.10	$370.65	$370.65			
RRI (%)	20%	N/A	N/A			
Establishment Covered (%)	90%	90%	50%			
Maintenance Covered (%)	0%	0%	0%			
Max Conservation Buffer Distance	30.48M	36.58 M	N/A			
Contract Length	10 yrs.	10 yrs.	10 yrs.			

Table 3.1 CRP and Crop Economics.

Field	Field Hectares	Original Profit ($ per hectare)	Max Enrollment Hectares	Max Enrollment Profit ($ per hectare)	Targeted Hectares	Targeted Enrollment Profit ($ per hectare)	Years of Yield Data	Practice
1	140.36	497.88	16.87	477.89	N/A	N/A	2	CP22
2	34.33	516.78	2.34	499.86	N/A	N/A	3	CP22
3	12.03	561.66	2.31	501.71	N/A	N/A	3	CP22
4	49.74	534.80	3.65	534.53	2.24	540.93	4	CP22
5	62.34	473.34	9.56	455.23	2.14	477.84	4	CP22
6	11.48	406.63	4.78	373.00	0.90	416.56	4	CP22
7	22.54	398.25	6.29	383.33	0.79	402.45	4	CP22
8	6.17	178.46	2.10	201.71	1.00	200.97	4	CP22
9	6.67	357.03	3.61	282.09	N/A	N/A	4	CP22
10	15.07	480.63	4.02	441.00	N/A	N/A	4	CP22
11	91.27	491.68	22.46	466.35	6.48	505.76	1	CP33
12	47.72	415.23	16.18	385.92	3.96	434.25	1	CP33
13	12.62	340.38	6.34	298.03	1.05	356.00	1	CP33
14	29.39	251.45	8.45	314.04	5.83	327.26	1	CP33
15	13.71	261.14	6.49	279.79	3.82	315.52	1	CP33
16	14.56	235.14	6.10	263.71	2.19	286.93	1	CP33
17	2.36	230.84	1.73	214.93	0.52	272.38	1	CP33
18	23.08	165.66	9.47	219.38	5.67	238.85	1	CP33
19	14.94	110.31	5.75	207.86	3.87	221.65	1	CP33
20	8.37	-103.26	3.76	42.87	2.43	64.10	1	CP33
21	3.65	-79.32	3.20	219.47	N/A	N/A	1	CP33
22	4.72	734.31	2.69	466.77	N/A	N/A	1	CP33
23	35.14	662.70	10.75	543.79	N/A	N/A	1	CP33
24	12.42	306.70	7.24	262.79	1.57	327.61	2	CP33
25	7.51	581.43	4.07	394.57	N/A	N/A	2	CP33
26	10.90	628.84	5.48	443.03	N/A	N/A	2	CP33
27	55.67	604.43	13.17	546.76	1.82	609.72	3	CP33
28	12.00	425.38	4.69	358.59	0.40	429.48	3	CP33
29	13.93	377.17	5.39	327.31	0.66	382.14	3	CP33
30	12.22	294.25	14.31	279.72	4.23	327.48	3	CP33
31	6.88	246.41	3.40	219.42	1.16	258.19	3	CP33
32	4.42	474.85	2.66	340.16	N/A	N/A	3	CP33
33	7.87	541.00	3.57	415.47	N/A	N/A	3	CP33
34	8.33	592.64	4.29	404.06	N/A	N/A	3	CP33
35	9.86	506.90	4.55	397.76	0.61	517.85	4	CP33
36	14.73	442.31	6.49	385.03	1.68	454.96	4	CP33
37	8.22	372.03	4.61	275.47	0.55	378.78	4	CP33
38	17.27	272.70	7.31	298.27	3.86	325.83	4	CP33
39	14.74	272.75	6.04	291.11	2.86	318.88	4	CP33
40	5.83	239.37	3.04	262.32	1.49	296.17	4	CP33
41	3.93	231.58	2.92	209.34	0.74	268.65	4	CP33
42	5.62	231.14	7.86	233.09	3.92	256.96	4	CP33
43	6.47	218.31	4.12	209.22	1.96	255.85	4	CP33
44	1.39	159.03	1.23	180.83	0.51	240.63	4	CP33
45	25.83	51.22	3.45	164.10	2.89	186.73	4	CP33
46	26.37	447.03	8.81	385.35	N/A	N/A	4	CP33
47	5.64	506.75	5.64	146.23	0.76	498.47	1	CP42
48	11.93	482.76	11.93	165.83	0.70	484.02	2	CP42
49	9.14	382.16	9.14	167.68	0.58	388.89	2	CP42
50	9.19	515.75	9.19	136.92	0.37	526.25	2	CP42
51	1.96	225.21	1.96	167.68	0.57	267.51	2	CP42
52	39.04	462.94	39.04	165.43	1.54	464.50	3	CP42
Sum	1031.57	19214.77	364.52	16306.80	78.31	13527.00		

Table 3.2 Analysis Results.

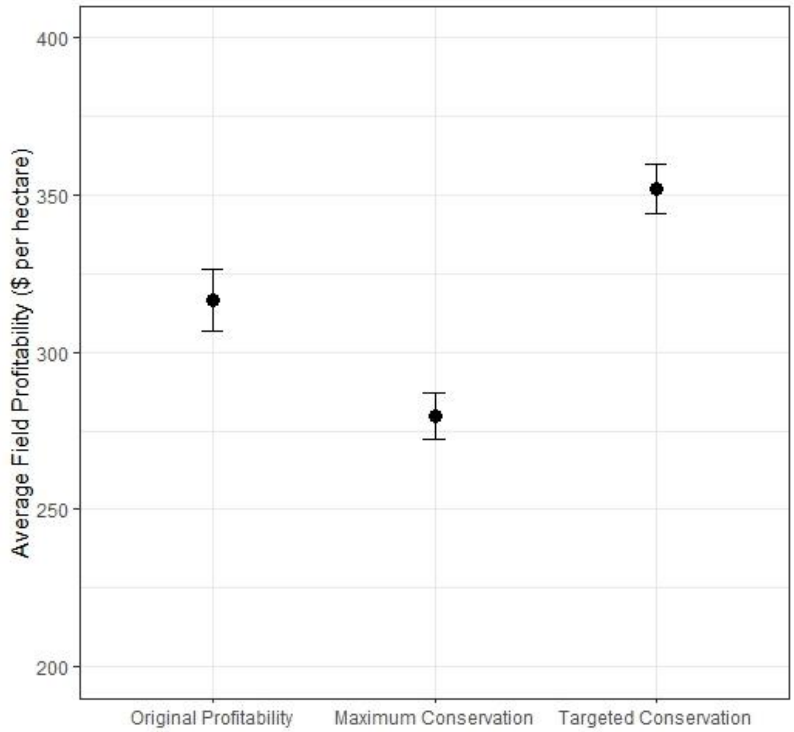


Figure 3.8 Average Profitability of Each Scenario.

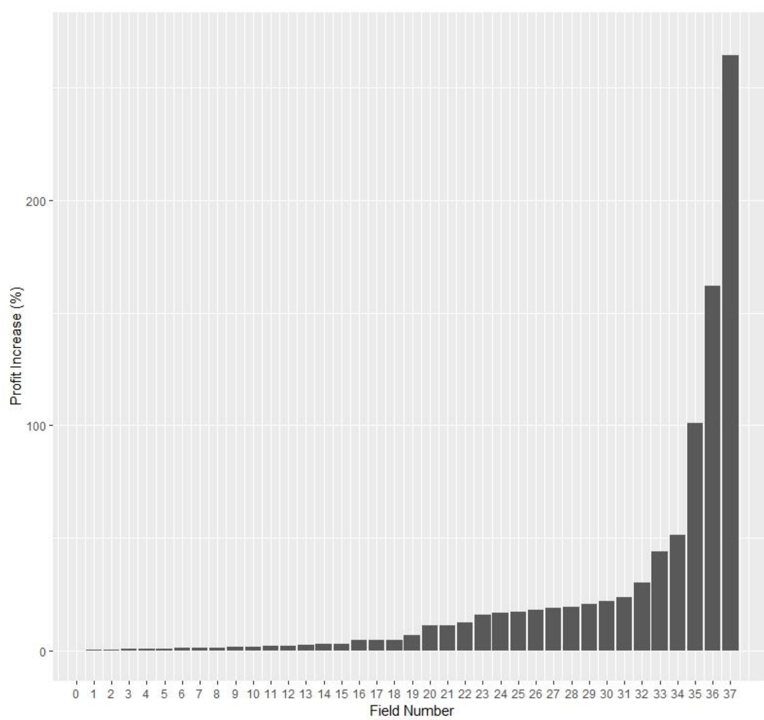


Figure 3.9 Profit Increase of Field with Targeted Conservation Scenario.

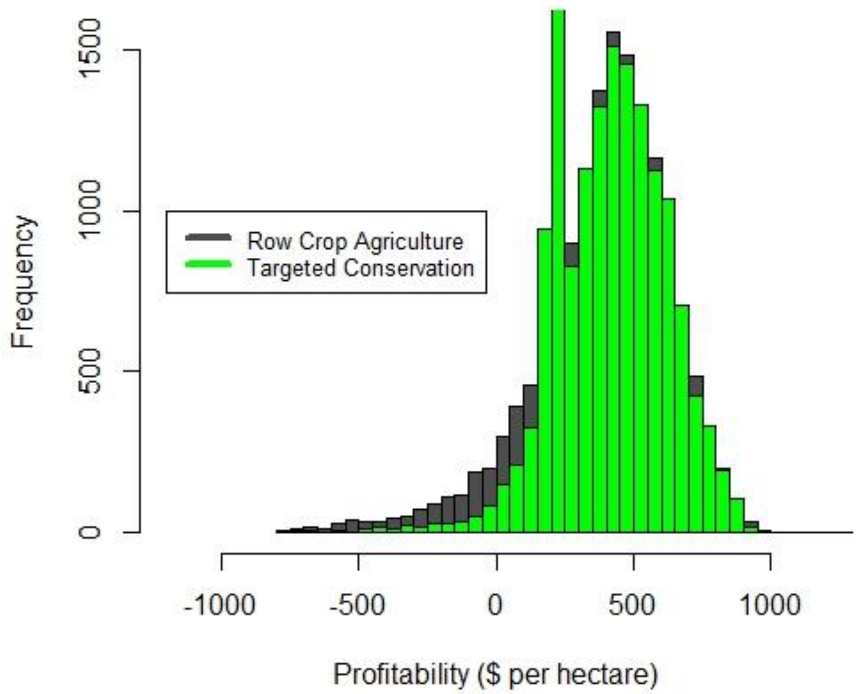


Figure 3.10 Distribution of profit pixel values for row crop agriculture and targeted conservation.

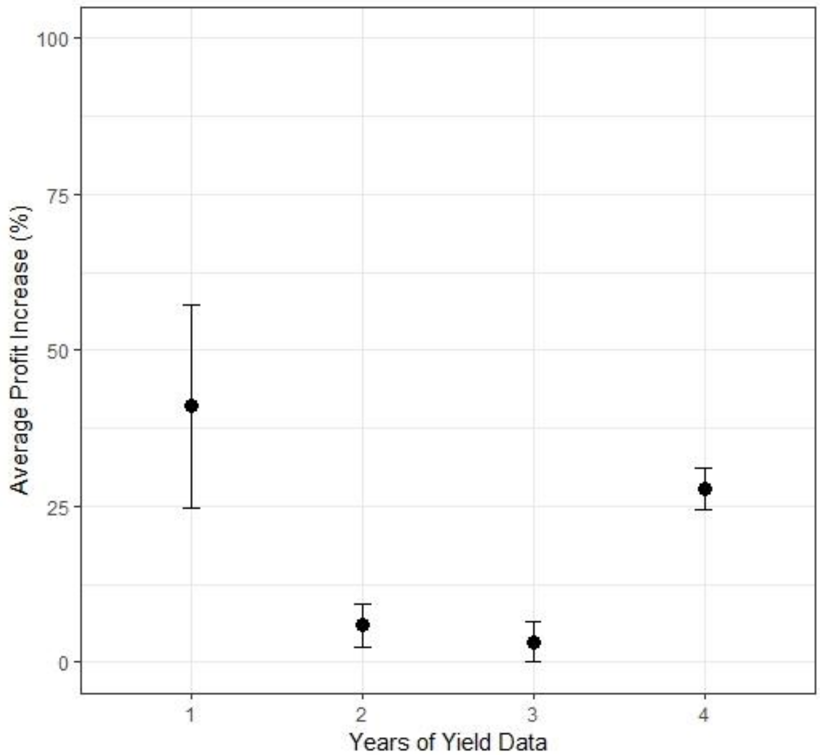


Figure 3.11 Average Increase in Profit by Years of Yield Data.

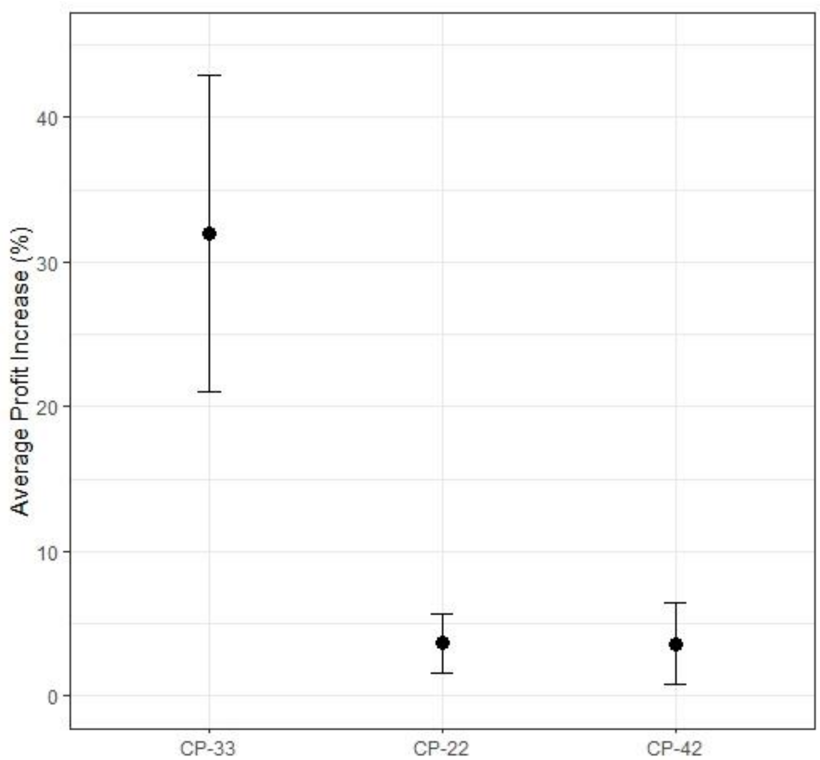


Figure 3.12 Average Increase in Profit by CRP Practice.

CHAPTER 4

USING NAIP IMAGERY TO IDENTIFY UNPROFITABLE AREAS OF A FIELD FOR LANDSCAPE SCALE TARGETED CONSERVATION ENROLLMENT

[1]Meng, N. J., N. Nibbelink, M. Madden, and M. D. McConnell. To be submitted to *Remote Sensing in Ecology and Conservation*

Abstract

Globally human populations continue to rise and to meet this increasing demand for food it is predicted that agricultural production will have to double its current production rate by 2050. Currently we have already seen the negative environmental impacts of high intensity agricultural production, mainly a reduction in native landcover that provides important ecosystem services. Sustainable agriculture will need to provide a balance of agricultural production and conservation practices that provide these ecosystem services. However, conservation practices will not be widely implemented unless producers are able to quantify and visualize their expected costs and benefits. The United States Department of Agriculture's (USDA) Farm Bill conservation program provides producers incentives to remove less productive lands from agricultural production and reestablish them in natural vegetation (e.g., native grasses, trees, etc.). However, many producers are reluctant to participate in these programs due to the perceived loss in revenue from commodities that otherwise would have been produced. Using precision agriculture technology in a conservation framework allows producers and conservation professionals the ability to identify the overlap between conservation eligibility and economic opportunity. This framework requires spatially explicit farm production and conservation practice data to model the profitability of row crop agriculture and a conservation program. We previously created a decision support tool (DST) that allows agricultural producers to simultaneously optimize their conservation and economic objectives. The prevalence of conservation planning frameworks like ours creates the need for landscape scale identification of low productivity areas in a field. We also needed an alternative approach that is not reliant on spatially explicit yield data which is often limited. We used remote sensing technology to identify low productivity areas in fields that would be logical candidates for increasing

profitability via a Farm Bill conservation practice. We used the Modified Soil-Adjusted Vegetation Index (MSAVI) calculated from NAIP (National Agriculture Imagery Program: United States Department of Agriculture – Farm Service Agency) imagery from the 2014 growing season to identify the least productive areas in our study fields. We then compared the average profitability of the areas identified as the least productive to the remaining areas of the field using profit surfaces generated from spatially explicit yield data. Statistical analysis revealed a significant difference between the areas identified as least productive and the rest of the field ($p \leq 0.001$). The absolute difference in profitability ranged from $459.88 to $343.77 per hectare. Further research should apply this concept to identify the overlap between unprofitable field regions and spatially explicit conservation priority maps.

Introduction

Steady increases in human population and the mechanization of agriculture have caused food production to expand and intensify (Robertson and Swinton. 2005; Johnson et al. 2016). This global demand has been met at the expense of the environmental integrity, with negative effects seen in water quality, soil quality, and wildlife, to mention a few (Wilcove et al. 1998; Tilman et al, 2002) Unfortunately, these environmental concerns are only being magnified as globally 13 million hectares of land is converted to agriculture each year (Robertson and Swinton 2005). Agriculture has negatively affected almost every facet of the environment. For example agricultural producers have lost significant amounts of top soil through surface runoff or wind erosion (Johnson et al. 2016). This top soil is vital for profitable production and can also result in water quality issues due to sedimentation (Tomer et al. 2015; Johnson et al. 2016). Pesticide and fertilizer runoff from agriculture can also cause water quality issues (Tomer et al. 2015; Johnson et al. 2016). Agriculture is also a substantial producer of harmful greenhouse gases (Palm et al. 2014). Millions of hectares of wildlife habitat has been lost as land has been converted to agriculture (Farrand 2005). Modern production agriculture is not conducive to sustainable wildlife populations and has created a fragmented landscape among suitable wildlife habitat creating a reduction or even loss of many wildlife species (Wiens 1995; Homberger et al. 2017). Increasing the amount of protected land is not the solution to these conservation issues as significant amounts of land cannot be taken out of production and changed to protected status if we want to meet our future food production goals (Robertson et al. 2005; Johnson et al. 2016). Conservation and production must coexist in these agriculture ecosystems for a sustainable future.

Conservation incentive programs vary worldwide with some countries having no incentives programs (Baylis et al. 2008; Crossman & Bryan 2009; Lyle et al. 2015). The United States was one of the first countries to implement country-wide conservation programs and have conservation programs that come in my different forms (Claassen et al. 2008). An increasingly popular variety is the working lands programs. These seek to provide financial incentives to producers to practice conservation strategies alongside their agricultural operation as opposed to completely removing land from production (Claassen et al. 2008). A couple of examples include the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP) (Claassen et al. 2008). However, the most prevalent program is the Conservation Reserve Program (CRP). CRP provides producers incentives to take environmentally sensitive land out of production and convert it to a native land cover (e.g., native grass, forest, or wetland) that addresses the negative environmental impacts of agriculture including water quality, soil erosion, and wildlife habitat, and to provide commodity price control as well (Glaser 1985;

Johnson et al. 2016; Morefield et al. 2016; Li et al. 2017). Each of the 35 CRP practices looks to target environmentally sensitive land for a specific conservation purpose (USDA NRCS 2015). The rental rate paid is based off the soil quality of the land being converted to a CRP practice with additional incentives included depending on the practice. Other incentives include financial assistance for establishing and maintaining a given practice (USDA NRCS 2015). Contracts are 10 or 15 years depending on the practice (USDA NRCS 2015). CRP has a proven record of positive environmental outcomes including but not limited to carbon sequestration (Li et al. 2017), increased water quality in streams and rivers (Miltner 2015), and increased wildlife habitat (Farrand & Ryan 2005; Riffell et al. 2010; Fahrig et al. 2015). Research has quanitifed the economic value of the ecosystem services provided by CRP and found that they fair exceed the rental rates paid (Johnson et al. 2016). These results show that CRP is in fact addressing the environmental concerns it was created to address.

Precision agriculture (PA) is defined as a series of spatial information technologies that have the potential to improve farm profitability by increasing yields and lowering input costs (Zhou et al. 2017). There is a wide variety of PA technologies with a few common being variable rate application, global positioning system (GPS) guidance and yield monitors, and grid soil sampling (Castle 2016; Zhou et al. 2017). Remote sensing technology is commonly used for PA purposes (Mulla 2013). Common applications include disease and drought stress monitoring, soil organic matter estimation, and yield prediction (Seelan et al. 2003; Atzberger 2013; Sibley et al. 2014). A derivative of PA, precision conservation, applies PA technologies to target the implementation of conservation practices by taking into account spatial and temporal variations across natural and agricultural systems (Berry et al. 2003). Examples of precision conservation applications include targeted implementation of riparian buffers for maximum effect on water quality (Dosskey and Eisenhauer 2005) and identifying environmentally vulnerable subfield areas (Bobryk et al. 2017).

A limiting factor of CRP enrollment is the assumption by producers that taking land out of production will result in reduced profitability, making them ignore the potential environmental benefits of CRP enrollment (McConnell & Burger 2011; Muth 2014; McConnell et al. 2016). Converting land to CRP can in fact be profitable if marginal land is targeted (Stull et al. 2004; McConnell & Burger 2011; McConnell et al. 2016; Capmourteres et al. 2018). Increasing production costs (increased 36% from 2007 to 2012 (USDA NASS 2017)) and volatile crop prices (corn prices ranged from $124 to $300 per Tonne from 2010 to 2019 (USDA NASS 2019)) are making profitable farming more difficult and add to the appeal of the guaranteed revenue of a CRP contract (Kitchen et al. 2005). Research indicates that most farmers will not adopt a conservation practice without financial incentives, illustrating the importance of incentives programs like CRP (Claassen & Duquette 2012; Sweikert & Gigliotti 2019; USDA ERS 2019). Producers and conservation professionals have limited access to the technology needed to quantify the financial tradeoff of establishing a CRP practice. Existing research has illustrated the concepts we discussed, though until recently were not able to produce a user friendly decision support tool for implementation of this framework (Stull et al. 2004; McConnell & Burger 2011; McConnell et al. 2016; Capmourteres et al. 2018).

Recent research has created a geospatial DST to address the previously discussed issues that will help producers visualize the spatially eligible of CRP practices on their farm and allow them to identify, from spatially explicit yield data, areas in their field that are unprofitable (Meng 2019). The user is then able to determine if an opportunity to increase profit exists through CRP enrollment. Identifying fields where CRP is an economically viable option could increase enrollment and generate landscape-level conservation impacts. The DST is available as a user-friendly ArcMap (ESRI 2018) script tool. A case study conducted in Lowndes County, Mississippi, USA analyzed 52 fields, many with multiple years of yield data, and showed increased profitability through targeted CRP enrollment in 37 out of the 52 fields (Meng 2019).

The ability of conservation agencies to effectively utilize this DST could be hindered by limited availability of spatially explicit yield data (Zhou et al. 2017). Even though yield monitors are one of the most widely adopted PA technologies (71.2% adoption rate (Castle 2016)) there are still not enough producers who have multiple years of accurate yield data. An alternative approach is needed to accurately identify potentially unprofitable areas in a field when yield data is not available. Conservation agencies looking to promote conservation practices have varying conservation goals and finite resources to accomplish these goals. Large scale targeting of their efforts is needed for their efficient operation. Landscape-scale identification of subfield areas that are predicted to profit from targeted CRP establishment would address both of these challenges. Previous research has attempted to address these issues by predicting subfield profitability in Iowa using yield prediction based on soil type standardized by county yield reports (Brandes et al. 2016). This model also considered current grain prices to create a fine scale profitability map (Brandes et al. 2016). To date, this is the only research to predict subfield profitability for a large region. A shortcoming of the model includes the error associated with making fine scale yield predictions based on soil type normalized by county yield reports, due to the prevalence of temporally variable factors effecting yield and the fact that soils are amended regularly with inputs to increase yield beyond their natural potential (Farmaha et al. 2016). Another shortcoming is the complexity of the model and its inability to consider crops other than corn and soybeans. Another study identified fields with highly variable yield by creating a soil vulnerability and variability index where fields were ranked based off their potential to benefit from implementing precision agriculture practices (Bobryk et al. 2017). This model used variables such as soil type and climate variability during the growing season. This method could be used to identify profitable areas to implement a CRP practice, however, the complexity of the model makes it impractical for conservation professionals to implement. Similar research uses yield data to create an opportunity index that ranks fields based upon their potential to benefit financially from precision agriculture technology and the practicality of adopting this technology. (Sun et al. 2013; Leroux & Tisseyre 2018). This framework relies on spatially explicit yield data, which is not always readily available (Zhou et al. 2017). This research is also more focused on the potential to adopt precision agriculture technology as opposed to a CRP practice. Yield variability at a subfield level is highly correlated with reduced profitability, illustrating the potential for precision agriculture via targeted conservation enrollment (Brandes et al 2016; Bobryk et al 2017). To address this issue with the previously discussed research we have developed a simple model that will identify financially vulnerable areas of a field to facilitate targeted conservation enrollment to increase environmental and economic outcomes.

Study Area

Our study farm is located in the Black Prairie region of Mississippi (Figure 4.1). The Black Prairie region is a part of the larger Black Belt Region, which is a crescent shaped region with most of its area in Alabama (Tullos 2004). The name comes from its dark calcareous soils. The entire region is underlain by Selma Chalk, whose consistency varies throughout the region and has weathered into various soil types that support a wide range of prairie and forest habitats (MacGown et al. 2018). Prairie regions are characterized by well drained, slowly permeable, alkaline soils. This region is also characterized by intensive agriculture. Historically cotton was the main crop grown in this region, as well as some corn, though currently soybeans and beef cattle are more prevalent (Tullos 2004). Our study farm in Lowndes County, Mississippi contains 1,031 hectares of farmland with 52 fields ranging in size from 1.38 to 140.35 hectares. This farm implements a rotation of corn and soybeans. There are 40 fields that have yield data for 2014.

Methods

We developed a model to analyze NAIP (National Agriculture Imagery Program: United States Department of Agriculture – Farm Service Agency) imagery to approximate crop productivity through the use of a vegetation index, which captures the productivity of crops at a given time. We downloaded four band NAIP imagery for our study area flown during the growing season (July 5, 2014). We used 2014 imagery because it was the only imagery flown during the growing season for which we had multiple years of yield data to validate our model. We calculated the Modified Soil Adjusted Vegetation Index (MSAVI) from this imagery. MSAVI is a variation of the Normalized Difference Vegetation Index (NDVI), but accounts for multiple problems with NDVI, which include saturation of dense vegetation, atmospheric interference, and soil background reflectance (Xue and Su 2017). This vegetation index is commonly used in precision agriculture applications and is proven effective (Mulla 2013, Xue and Su 2017). We calculated the MSAVI vegetation index for all the imagery using the following equation:

$$MSAVI = (2NIR + 1) - \sqrt{(2NIR + 1)^2 - 8(\mathrm{NIR} - \mathrm{R})}$$

NIR is the near infrared band, which measures surface reflectance in the wavelength range from 833 – 920 nm. Red is the visible red band ranging from 604 – 664 nm. We calculated the percent reflectance of the red and NIR band by dividing each band by 255 (radiometric resolution - 1) before calculating MSAVI. This vegetation index resulted in values ranging from (1 to -1). We used a field boundary layer obtained from our study farm's crop consultant. Our initial analysis indicated insufficient accuracy of these field boundaries; therefore, we edited them using heads-up digitizing at a 1:1000 scale in ArcMap (ESRI 2018) to correspond with the 2014 NAIP imagery. One aspect of CRP eligibility requires that fields be used for an agricultural purpose for 4 years out of the 6-year time frame between Farm Bills (USDA NRCS 2015). The USDA provides an annual landuse map in raster format called Cropscape (USDA NASS 2017). We downloaded Cropscape data from 2012 to 2017 for our study area. Each year of data was reclassified as either agriculture (1) or non-agricultural (0). We ran zonal statistics considering the mean for all six years of data using the field boundary layer to generate the percentage of each field that is in agricultural production. We selected fields that were at least 70% in agricultural use for at least 4 out of the 6 years. We used 70% as our cutoff because we assume that there is error in the moderate resolution Cropscape data.

Low MSAVI values are assumed to be the lowest yielding and thus the least profitable (Whiting et al. 2006). We wanted to identify clusters of low MSAVI values throughout each field that would be practical to implement a conservation or alternative practice. We extracted the lower quartile of MSAVI pixels within each field. Having accurate field boundaries was vital for this extraction as to not include MSAVI pixels in the distribution that are not located in the given field. If the average MSAVI value of a field was below 0 it was skipped because this field is bare soil, sparse vegetation, or either recently harvested or planted. We converted these extracted pixels to polygons and aggregated them using an aggregation distance of 3 meters. We removed polygons smaller than 0.1 hectares that could not be practically converted to a conservation practice. Any holes within our aggregated polygon that were smaller than 0.2 hectares were filled. The polygons were then simplified using a tolerance of 5 meters and smoothed using a tolerance of 100 meters. Figure 4.2 shows major steps in the model. Different aggregation and tolerance distances were evaluated to determine a process that balances practicality for land conversion while avoiding high productivity areas.

Profit Surface Calculations

Spatially explicit yield data is required to calculate a spatially explicit profit surface and is acquired via GPS equipped grain harvester. A harvester records grain flow via sensors and records a GPS location with this information (Hopkins 2009). This grain flow data is converted to dry yield volume. All errors and outliers were removed from this data before the profit surface was generated (Sun et al 2013). We removed values outside of a reasonable range of dry yield volume values per crop type. We filtered yield values beyond our predetermined ranges for dry yield volume (corn 20.18 – .67 tonnes/hectare; soybeans 5.38 – .34 tonnes/hectare). Then we removed outliers of the remaining data beyond ± 3 standard deviations of the mean (Sun et al 2013). We needed a continuous yield surface to accurately calculate field scale profitability. We interpolated the dry yield volume of the yield points. We used Inverse Distance Weighted (IDW) to create a raster yield surface. We considered a cell size of 1 meter for the output raster. IDW has been shown to be a highly accurate interpolation method for yield data (Souza et al 2016). Economic inputs that must be determined to calculate profitability include the commodity price per ton and production costs per hectare. The row crop profitability of the field was calculated by multiplying commodity prices by the dry yield volume and then subtracting production costs. The entire equation is as follows:

Row Crop Profitability = (Commodity Price * Dry Yield Volume) - Production Costs.

We considered a commodity price of \$349.06 (\$/tonne) for soybeans and \$137.78 (\$/tonne) for corn. We mosaicked together all profit surface for 2014, which were generated in previous research (Meng 2019). We conducted a paired t-test comparing the average profitability within the low MSAVI value polygons across all fields to the average profitability within the remaining area of the fields.

Results

Based off farming requirements for CRP enrollment, 49 of the 52 fields were CRP eligible. The model generated low MSAVI value polygons in 37 of the 52 fields (Figure 4.3). Our approach generated low MSAVI value polygons on 8.46% of the total farmable area with an average polygon area of 2.47 (± 3.45) hectares and an average MSAVI value of -.06 (± .05). The average profitability across the 40 fields with yield data was \$388.98 (± \$234.5) per hectare. Results from the t-test showed a significant difference in profitability between low MSAVI polygons and the remaining field area ($p<0.001$). Average profitability within the low MSAVI value polygons was -\$36.97 per hectare (95% CI: -\$188.71 - \$114.75), whereas average profitability in the remaining field area was \$364.84 per hectare (95% CI: \$271.17 - \$458.52) (Figure 4.4). The absolute difference in profitability ranged from \$459.88 to \$343.77 per hectare.

Discussion

Previous research has determined that targeted conservation implementation of conservation practices should occur at a landscape scale to achieve natural resource conservation and producer's objectives (Evans et al. 2013; Yeiser et al. 2018). International agriculture environmental schemes have developed targeted conservation frameworks for identifying marginal land for conversion to more environmentally friendly practices as well (Crossman & Bryan 2009; Lyle et al. 2015). However, many of these frameworks require spatially explicit yield data that is not always available, illustrating the need for an alternative to yield data to identify unprofitable field areas to increase targeted conservation implementation. Frameworks that do not require yield data use complex models making them difficult for conservation professionals to implement. We have illustrated an applicable and simplistic framework to address both of these problems. The significant difference between the profitability within the low MSAVI value polygon and the profitability within the rest of the field illustrates that our approach is effective in identifying some unprofitable areas in our fields. The average profitability within these low MSAVI value polygons was -$36.97 meaning not farming these areas would increase profitability by avoiding lost revenue. Environmentally friendly practices that come with incentives, CRP for example, would more drastically increase revenue. However, the model was not perfect in identifying unprofitable areas. Many factors effect yield that are not identifiable even in high resolution aerial imagery flown during the growing season (Farmaha et al. 2016). We identified, through visual observation, several cases were the model did not generate a polygon in fields where there were obvious opportunities to increase profitability. Fields that have low MSAVI values across the entire field were not identified with this model since only the lower quartile of pixels are extracted. The process of converting the lower quartile of pixels to polygons, aggregating, then simplifying and smoothing them introduced plenty of opportunities for profitable areas of the field to be included in the final output. We determined parameters such as aggregation distance and tolerance distance through trial and should be investigated further. Only 3 of our 52 field were identified as not eligible for CRP. In an intensive production system like the soybean and corn rotation in our study farm it is expected that a large majority of fields meet the production requirement of CRP.

We encourage future research to build off of our framework by increasing the accuracy of this model and developing a DST to be used by conservation professionals. Our previous research indicates that natural resource managers should avoid making management decisions from one year of yield data (Meng 2019). We apply the same caution with this approach as yields year to year can vary significantly due to factors beyond the farmer's control (Meng 2019). An area identified as a low productivity area one year may not be consistently low from year to year. We encourage natural resource managers to apply our framework on multiple years of imagery and identify areas in a field where low MSAVI value polygons overlap over multiple years. We believe these areas represent the highest potential to be unprofitable or low profiting. Our study only considered 2014 since this was the only year where growing season imagery was available for our study area and we had yield data to validate our model. NAIP imagery is not always flown during the growing season, creating a potential issue when using this approach. Imagery for 2010, 2012, and 2016 in our study area was flown in late August or early September when most crops had been harvested. Using high resolution satellite imagery (e.g. QuickBird or Planet) might be a good alternative to ensure imagery is available during the growing season, though costs are associated with acquiring this imagery. We would also predict that running this model using satellite imagery would result in more accurate results since yield is typically modelled using satellite imagery as opposed to aerial imagery (Panda et al. 2010; Basso et al. 2013; Lobell et al. 2015). Publicly available imagery from moderate resolution satellites like Sentinel and Landsat would solve the problem of image availability during the growing season; however, image resolution might be insufficient to conduct a subfield scale analysis. Another concern is finding cloud free imagery during the growing season as pixel values from clouds can skew the distribution of MSAVI values within a field. Imagery acquired from UAV's could be an option for cloud free high resolution imagery.

Our approach also does not account for spatial eligibility requirements of the CRP program as low value MSAVI polygons are generated anywhere in the field. However, this issue is addressed in previous research where a DST was developed that can model CRP spatial eligibility (Meng 2019). An additional hindrance to this approach is the need for accurate field boundaries based off the year of the imagery being used. Field boundaries change regularly due to development (roads, farming infrastructure, etc.) and variations in areas planted and thus the field boundary layer would need to be updated for each year the model is ran. Depending on the scope of analysis, this could be a very time consuming task. Previous research developed a nationwide geospatial layer of field boundaries from satellite imagery that was shown to be 81% accurate when compared to digitized fields (Yan & Roy 2016). We estimate that our field boundaries need to be 95% accurate or better for our model to run properly meaning their boundaries were insufficient for the purposes of our study requiring us to digitize our field boundaries using the NAIP imagery. Research has shown parameters such as soil type, soil moisture, and slope are sufficient predictors of yield and thus a good predictor of profitability (Prasad et al. 2006; Holzman et al. 2014; Farmaha et al. 2016). These parameters could be implemented into the model to further increase accuracy. Future research should identify where low profit areas overlap with high conservation potential to simultaneously achieve natural resource conservation and producer's objectives. Conservation potential maps exist for many aspects of conservation (e.g. wildlife habitat, water quality, soil erosion) (Hauck et al. 2013). We recommend users incorporate our approach with spatially explicit conservation priority maps to evaluate potential overlap between economic and conservation opportunities.

Literature Cited

Atzberger, C. 2013. Advances in remote sensing of agriculture: Context description, existing operational monitoring systems and major information needs. Remote Sensing 5(2):949–981.

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

Bobryk, C. W., M. A. Yost, and N. R. Kitchen. 2017. Field variability and vulnerability index to identify regional precision agriculture opportunity. Precision Agriculture (2017):1–17.

Brandes, E., G. S. McNunn, L. A. Schulte, I. J. Bonner, D. J. Muth, B. A. Babcock, B. Sharma, and E. A. Heaton. 2016. Subfield profitability analysis reveals an economic case for cropland diversification. Environmental Research Letters 11(1):014009.

Capmourteres, V., J. Adams, A. Berg, E. Fraser, C. Swanton, and M. Anand. 2018. Precision conservation meets precision agriculture: A case study from southern Ontario. Agricultural Systems 167(May):176–185.

Castle, M. H. 2016. Has the Usage of Precision Agriculture Technologies Actually Led to Increased Profits for Nebraska Producers? Master thesis in Agricultural Economics. Master thesis (2016).

Claassen, R., A. Cattaneo, and R. Johansson. 2008. Cost-effective design of agri-environmental payment programs: U.S. experience in theory and practice. Ecological Economics 65(4):737–752.

Claassen, R., and E. Duquette. 2012. Additionality in U . S . Agricultural Conservation Programs: A Preliminary Analysis of New Data(May):1–33.

Crossman, N. D., and B. A. Bryan. 2009. Identifying cost-effective hotspots for restoring natural capital and enhancing landscape multifunctionality. Ecological Economics 68(3):654–668.

Dosskey, M. G., and D. E. Eisenhauer. 2005. Establishing conservation buffers using precision information. Journal of Soil and Water Conservation 60(6):349–354.

ESRI 2018. ArcGIS Desktop: Release 10.6 Redlands, CA: Environmental Systems Research Institute.

Evans, K. O., L. W. Burger, C. S. Oedekoven, M. D. Smith, S. K. Riffell, J. A. Martin, and S. T. Buckland. 2013. Multi-region response to conservation buffers targeted for northern bobwhite. Journal of Wildlife Management 77(4):716–725.

Farmaha, B. S., D. B. Lobell, K. E. Boone, K. G. Cassman, H. S. Yang, and P. Grassini. 2016. Contribution of persistent factors to yield gaps in high-yield irrigated maize. Field Crops Research 186 (2016):124–132.

Farrand, D. T., and M. R. Ryan. 2005. Impactof the Conservation Reserve Program on Wildlife Conservation in the Midwest. Fish and Wildlife Benefi ts of Farm Bill Programs: 2000–2005 Update 43(Usda 2003):41–62.

Glaser, L. K. 1985. Provisions of the Food Security Act of 1985. United States Department of Agriculture.

Hauck, J., C. Görg, R. Varjopuro, O. Ratamäki, J. Maes, H. Wittmer, and K. Jax. 2013. “Maps have an air of authority”: Potential benefits and challenges of ecosystem service maps at different levels of decision making. Ecosystem Services 4 (2013):25–32.

Holzman, M. E., R. Rivas, and M. C. Piccolo. 2014. Estimating soil moisture and the relationship with crop yield using surface temperature and vegetation index. International Journal of Applied Earth Observation and Geoinformation 28(1):181–192.

Homberger, B., J. Duplain, M. Jenny, and L. Jenni. 2017. Agri-evironmental schemes and active nest protection can increase hatching success of a reintroduced farmland bird species. Landscape and Urban Planning 161 (2017):44–51.

Johnson, K. A., B. J. Dalzell, M. Donahue, J. Gourevitch, D. L. Johnson, G. S. Karlovits, B. Keeler, and J. T. Smith. 2016. Conservation Reserve Program (CRP) lands provide ecosystem service benefits that exceed land rental payment costs. Ecosystem Services 18 (2016):175–185.

Kitchen, N. R., K. A. Sudduth, D. B. Myers, R. E. Massey, E. J. Sadler, R. N. Lerch, J. W. Hummel, and H. L. Palm. 2005. Development of a conservation-oriented precision agriculture system: Crop production assessment and plan implementation. Journal of Soil and Water Conservation 60(6):421–430.

Leroux, C., and B. Tisseyre. 2018. How to measure and report within-field variability: a review of common indicators and their sensitivity. Precision Agriculture(0123456789):1–29.

Li, C., L. M. Fultz, J. Moore-Kucera, V. Acosta-Martínez, J. Horita, R. Strauss, J. Zak, F. Calderón, and D. Weindorf. 2017. Soil carbon sequestration potential in semi-arid grasslands in the Conservation Reserve Program. Geoderma 294 (2017):80–90.

Lyle, G., B. A. Bryan, and B. Ostendorf. 2015. Identifying the spatial and temporal variability of economic opportunity costs to promote the adoption of alternative land uses in grain growing agricultural areas: An Australian example. Journal of Environmental Management 155(April):123–135.

MacGown, Joe, et al. “The Black Belt Prairie in Mississippi and Alabama.” *Mississippi Entomological Museum*, Mississippi State University, 6 Sept. 2018, mississippientomologicalmuseum.org.msstate.edu/habitats/black.belt.prairie/BlackBeltPrairie.htm.

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.

McConnell, M. D., L. W. Burger, J. Delgado, G. Sassenrath, and T. Mueller. 2016. Precision Conservation to Enhance Wildlife Benefits in Agricultural Landscapes 9740 (2016):1–28.

Miltner, R. J. 2015. Measuring the Contribution of Agricultural Conservation Practices to Observed Trends and Recent Condition in Water Quality Indicators in Ohio, USA. Journal of environmental quality 44(6):1821–31.

Morefield, P. E., S. D. LeDuc, C. M. Clark, and R. Iovanna. 2016. Grasslands, wetlands, and agriculture: the fate of land expiring from the Conservation Reserve Program in the Midwestern United States. Environmental Research Letters 11(9):94005.

Mulla, D. J. 2013. Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps. Biosystems Engineering 114(4):358–371.

Muth, D. 2014. Profitability versus environmental performance: Are they competing? Journal of Soil and Water Conservation 69(6):203–206.

Palm, C., H. Blanco-canqui, F. Declerck, L. Gatere, and P. Grace. 2014. Agriculture , Ecosystems and Environment Conservation agriculture and ecosystem services : An overview. “Agriculture, Ecosystems and Environment” 187 (2014):87–105.

Prasad, A. K., L. Chai, R. P. Singh, and M. Kafatos. 2006. Crop yield estimation model for Iowa using remote sensing and surface parameters. International Journal of Applied Earth Observation and Geoinformation 8(1):26–33.

Robertson, G. P., and S. M. Swinton. 2005. Reconciling agricultural productivity and environmental integrity : a grand challenge for agriculture. Frontiers in Ecology and the Environment 3(1):38–46.

Seelan, S. K., S. Laguette, G. M. Casady, and G. A. Seielstad. 2003. Remote sensing applications for precision agriculture: A learning community approach. Remote Sensing of Environment 88(1–2):157–169.

Sibley, A. M., P. Grassini, N. E. Thomas, K. G. Cassman, and D. B. Lobell. 2014. Testing remote sensing approaches for assessing yield variability among maize fields. Agronomy Journal 106(1):24–32.

Souza, E. G., C. L. Bazzi, R. Khosla, M. A. Uribe-Opazo, and R. M. Reich. 2016. Interpolation type and data computation of crop yield maps is important for precision crop production. Journal of Plant Nutrition 39(4):531–538.

Stull, J., C. Dillion, S. Shearer, and S. Isaacs. 2004. Using Precision Agriculture Technology for Economically Optimal Strategic Decisions: The Case of CRP Filter Strip Enrollment. Journal of Sustainable Agriculture 24(4):39–56.

Sun, W., B. Whelan, A. B. McBratney, and B. Minasny. 2013. An integrated framework for software to provide yield data cleaning and estimation of an opportunity index for site-specific crop management. Precision Agriculture 14(4):376–391.

Tilman, D., K. Cassman, P. Matson, R. Naylor, and S. Polasky. 2002. Agricultural sustainability and intensive production practices. Nature 418(August).

Tomer, M. D., K. M. B. Boomer, S. A. Porter, B. K. Gelder, D. E. James, and E. McLellan. 2015. Agricultural conservation planning framework: 2. Classification of riparian buffer design types with application to assess and map stream corridors. Journal of Environmental Quality 44(3):768–79.

Tullos, Allen. “The Black Belt.” *Southern Spaces*, Emory University, 19 Apr. 2004, southernspaces.org/2004/black-belt.

USDA ERS (2019) U.S. and State-Level Farm Income and Wealth Statistics. Retrieved from https://www.ers.usda.gov/data-products/farm-income-and-wealth-statistics/data-files-us-and-state-level-farm-income-and-wealth-statistics/

USDA NASS (2017). U.S. Farm Production Expenditures August 2018. Retrived from https://www.nass.usda.gov/Publications/Highlights/2018/2017_Farm_Production_Expenditures.pdf

USDA NASS (2019). Prices Received for Corn by Month - United States. Retrived from https://www.nass.usda.gov/Charts_and_Maps/graphics/data/pricecn.txt

USDA NRCS. (2015). Conservation Reserve Program, (Revision 1). Retrieved from http://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/index

Whiting, M. L., S. L. Ustin, P. Zarco-Tejada, A. Palacios-Orueta, and V. C. Vanderbilt. 2006. Hyperspectral mapping of crop and soils for precision agriculture. Remote Sensing and Modeling of Ecosystems for Sustainability III 6298(September 2006):62980B.

Wiens, J. 1995. Habitat fragmentation: island v landscape perspectives on bird conservation (1995).

Wilcove, D. S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying Threats to Imperiled Species in the United States. BioScience 48(8):607–615.

Xue, J., and B. Su. 2017. Significant remote sensing vegetation indices: A review of developments and applications. Journal of Sensors 2017 (2017).

Yan, L., and D. P. Roy. 2016. Conterminous United States crop field size quantification from multi-temporal Landsat data. Remote Sensing of Environment 172 (2016):67–86.

Yeiser, J. M., J. J. Morgan, D. L. Baxley, R. B. Chandler, and J. A. Martin. 2018. Private land conservation has landscape-scale benefits for wildlife in agroecosystems. Journal of Applied Ecology 55(4):1930–1939.

Zhou, X. V., B. C. English, J. A. Larson, D. M. Lambert, R. K. Roberts, C. N. Boyer, M. Velandia, L. L. Falconer, and S. W. Martin. 2017. Precision farming adoption trends in the Southern U.S. Journal of Cotton Science 21(2):143–155.

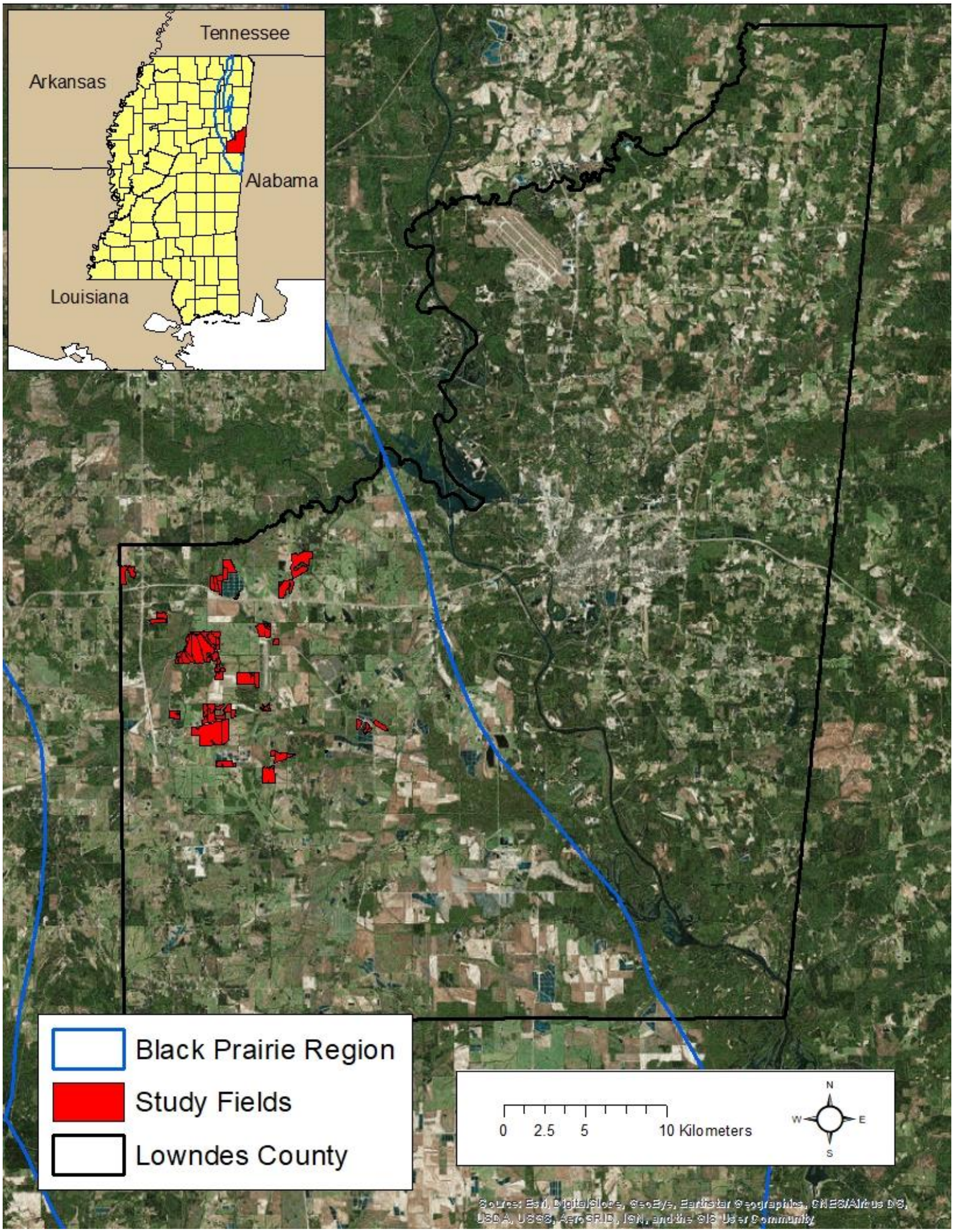


Figure 4.1 Location of Lowndes County, Mississippi, USA.

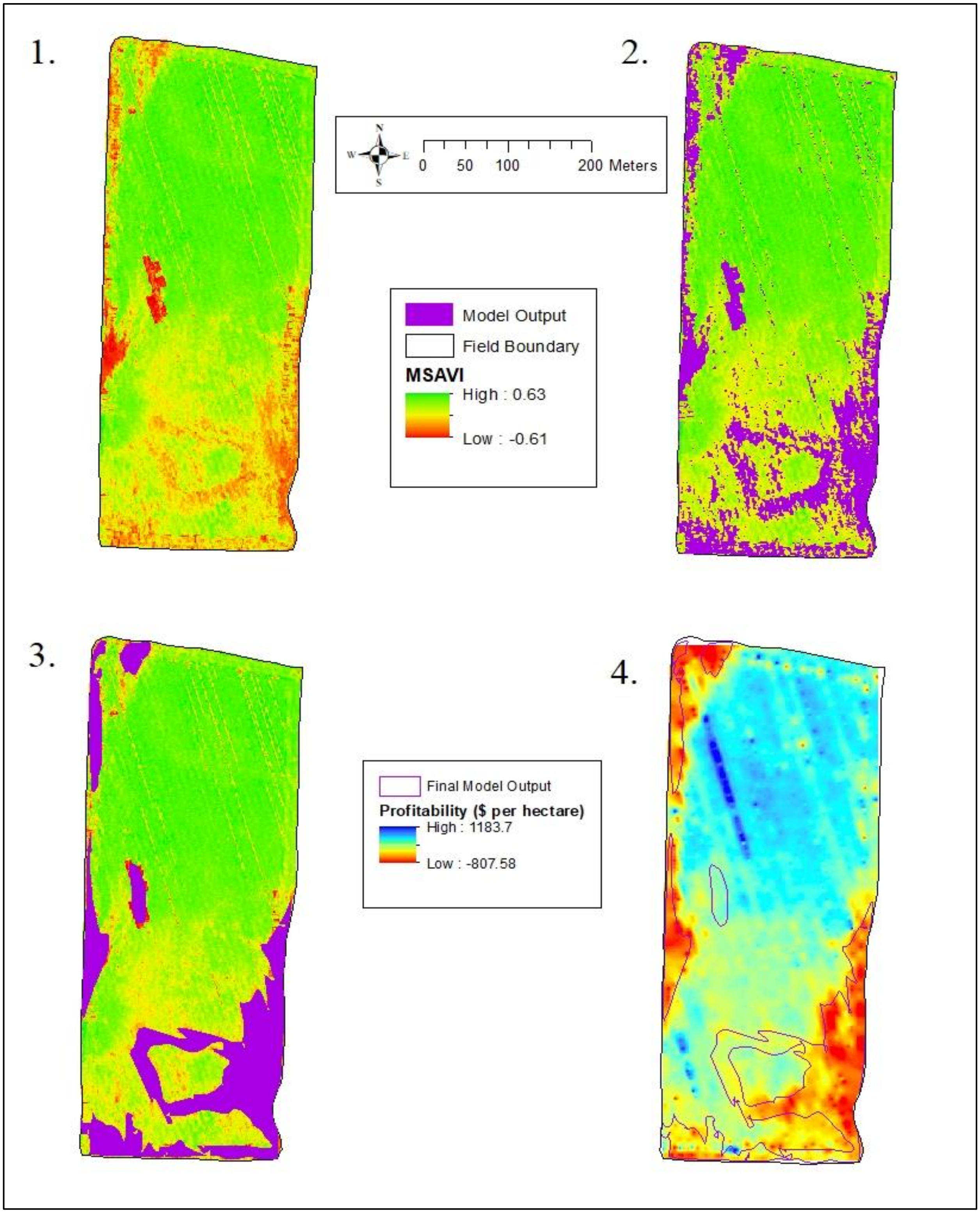


Figure 4.2 Example of model steps and overlap with profit surface. (1) MSAVI surface (2) Lower quartile of extracted pixels (3) Aggregated, simplified, and smoothed polygons (4) Final model output overlain with profit surface.

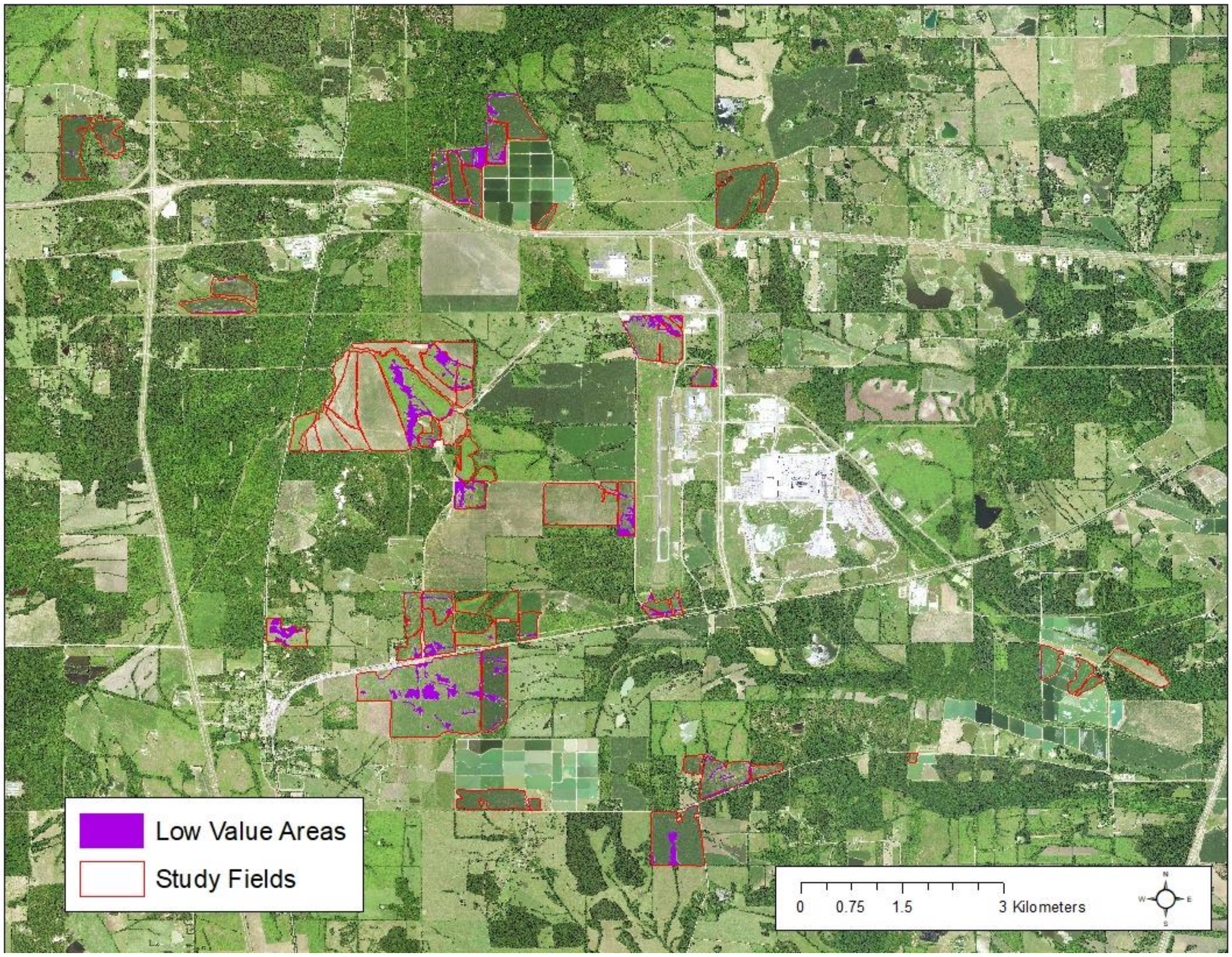


Figure 4.3 Study Farm Model Output: 91.5 hectares of low MSAVI value polygons were generated that could be potentially profitable under CRP enrollment.

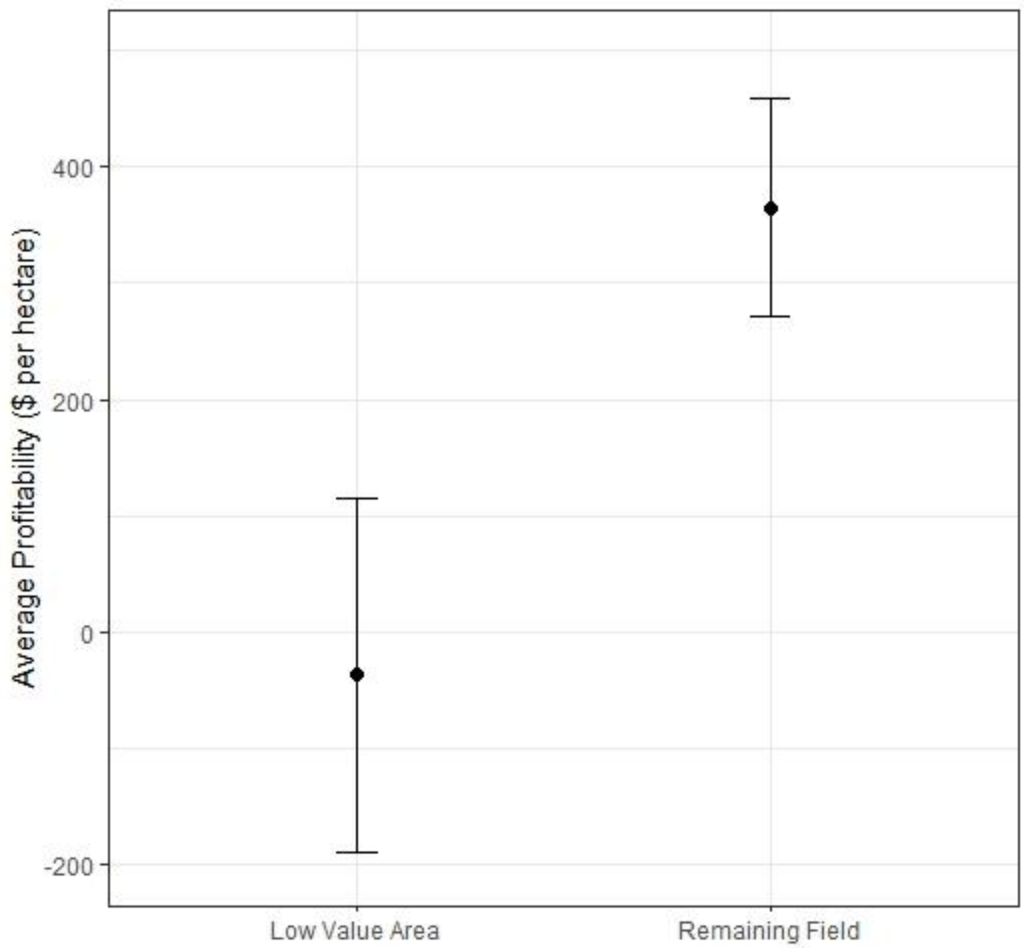


Figure 4.4 Average profitability of low MSAVI value areas and remaining field areas across all fields.

CHAPTER 5

CONCLUSION

A historical lack of targeted CRP enrollment addressing financial concerns has hindered conservation enrollment (McConnell & Burger 2011;McConnell et al 2016). Arming producers with economic information regarding the enrollment of a CRP practice will result in new acreage being enrolled, which in many cases will be the most environmentally vulnerable land (Muth 2014; Hamada et al. 2015; Muth 2015). Recent increases in CRP acreage and reduction in SRRs illustrates the need for strategic CRP enrollment of low profiting areas to utilize this acreage expansion. We have demonstrated the functionality of our DST, shown its application on a study farm, and created a remote sensing model to make this approach not reliant on spatially explicit yield data.

Chapter 2 demonstrated the functionality of our DST that allows users to determine the spatial eligibility of a given CRP practice and the financial tradeoff of converting an area to a CRP practice. Previous research using precision agriculture technology was lacking due to its inability to consider the financial tradeoff of implementing a CRP practice or not delivering a functional DST that could model all 35 CRP practices (Stull et al. 2004; McConnell & Burger 2011; McConnell et al. 2016; Capmourteres et al. 2018). We demonstrted how to conduct an elligibility and profitablity analysis, how to model various types of CRP practices (field buffer, riparian buffer, whole field, user defined area, and user defined wetland) as well as any aditional functionality of the tool. We also demonstarted the DST's ability to model non-CRP alternative practices. Future research should seek to model the environmental outcomes of CRP practices as well.

Chapter 3 demonstarted the application of our DST on a study farm with 52 fields in Lowndes County, Mississippi, USA. Previous research demonstarting similar frameworks did not have the scope of this study or mutiple years of yield data (Stull et al. 2004; Rao et al. 2007; McConnell & Burger 2011; McConnell et al. 2016; Capmourteres et al. 2018). We considered three management scenarios of maximum row crop production, maximum conservation enrollment, and targeted conservation enrollment. Our results show that a non targeted (maximum conservation) strategy was only more profitable than row crop agriculture in 14 of our 52 (27%) study fields, whereas targeted conservation was more profitable in 37 of our 52 (71%) study fields. This illustrates that conservation can be profitable with a targeted approach and that the traditional approach of non-targeted CRP enrollment is not financially sound for producers. The results further illustrated that this framework can be used to take marginal areas out of production and reduce the risk of farming while also identifying profitable fields that should continued to be farmed. This approach could also result in long-term, landscape level conservation benefits due to the decreased likelihood that CRP areas would be converted back into production due to increasing commodity prices. Future research should test this framework in other production systems and for a range of commodity prices.

Chapter 4 showed the use of remote sensing technology to remove the need for yield data in this framework and allow for the identification of unprofitable areas in fields on a landscape level. Previous research was able to identify unprofitable or environmentally vulnerable areas of fields on a landscape scale, though were lacking due to accuracy and complexity issues with their models (Farmaha et al. 2016; Bobryk et al. 2017). We developed a simple model using NAIP imagery that identified unprofitable subfield areas in our study farm in Lowndes County, Mississippi, USA. Our approach generated low MSAVI value polygons on 8.46% of the total farmable area and a t-test showed a significant difference in profitability between low MSAVI polygons and the remaining field area ($p<0.001$). Average profitability within the low MSAVI value polygons was -$36.97 per hectare (95% CI: -$188.71 - $114.75), whereas average profitability in the remaining field area was $364.84 per hectare (95% CI: $271.17 - $458.52). The absolute difference in profitability between the two ranged from $459.88 to $343.77 per hectare. Future research should identify consistently unprofitable areas in a field by analyzing multiple years of imagery to see where these consistently unprofitable areas overlap with conservation potential maps to identify both economic and conservation opportunities.

Literature Cited

Bobryk, C. W., M. A. Yost, and N. R. Kitchen. 2017. Field variability and vulnerability index to identify regional precision agriculture opportunity. Precision Agriculture (2017):1–17.

Capmourteres, V., J. Adams, A. Berg, E. Fraser, C. Swanton, and M. Anand. 2018. Precision conservation meets precision agriculture: A case study from southern Ontario. Agricultural Systems 167(May):176–185.

Hamada, Y., H. Ssegane, and M. C. Negri. 2015. Mapping intra-field yield variation using high resolution satellite imagery to integrate bioenergy and environmental stewardship in an agricultural watershed. Remote Sensing 7(8):9753–9768.

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.

McConnell, M. D., L. W. Burger, J. Delgado, G. Sassenrath, and T. Mueller. 2016. Precision Conservation to Enhance Wildlife Benefits in Agricultural Landscapes 9740 (2016):1–28.

Muth, D. 2014. Profitability versus environmental performance: Are they competing? Journal of Soil and Water Conservation 69(6):203–206.

Muth, D. J. 2015. Improving Economic and Environmental Performance through a Precision Business Plan (2015).

Stull, J., C. Dillion, S. Shearer, and S. Isaacs. 2004. Using Precision Agriculture Technology for Economically Optimal Strategic Decisions: The Case of CRP Filter Strip Enrollment. Journal of Sustainable Agriculture 24(4):39–56.

APPENDIX A: DECISION SUPPORT TOOL USER GUIDE

Profitable Conservation Decision Support Tool

User Guide

Introduction

Agricultural intensification represents one of the greatest threats to global biodiversity. Conservation opportunities in the Farm Bill provide a means of mitigating negative environmental consequences of agricultural production. To that end, the Conservation Reserve Program (CRP) was established in 1985 to encourage farmers to remove environmentally vulnerable land from production and return it to a conservation land cover (eg. wetland, grassland, forest). The environmental benefits of CRP are well documented and include, but are not limited to, improving water quality, increasing wildlife habitat, controlling erosion, and providing a myriad of other ecosystem services. However, removal of land from production imposes opportunity costs to producers. The eligibility criteria and voluntary enrollment nature of these programs only marginally contribute to targeting of practices to those areas that produce the greatest environmental benefits with the most positive economic outcomes for producers. Effective conservation delivery is dependent on the ability to simultaneously visualize and quantify conservation and economic opportunities. We developed this spatially explicit decision support tool to help agricultural producers and natural resource professionals make informed decisions regarding agricultural land use decisions. The overarching purpose of this tool is to provide producers with spatially explicit information on the eligibility and profitability of implementing CRP practices on their farm so they can make informed land use decisions. Use of the tool requires an operational knowledge of Arcmap; programmatic understanding of the CRP and associated practices; and experience with spatially explicit yield data. It should be noted that this users guide has been updated to reflect the changes to CRP from the 2018 Farm Bill.

Our tool enables two primary functions:

1. The eligibility function of the tool allows the user to determine the spatial eligibility and soil rental rate (SRR) of the CRP buffer practices (CP-21, CP-22, CP-29, CP-30, CP-33). This can be run over an entire farm or watershed, depending on the user's objectives, to visualize each practice's spatial eligibility.

2. The profitability function of the tool uses spatially explicit yield data, along with basic economic variables (input cost, grain price, government subsidies) to create a profit surface map. It can also spatially model all CRP practices in a given field(s), generating an estimate of the contract-specific SRR and incentive payments a producer would be expected to receive for a given practice. An output graph, shapefile, and rasters allow the user to visualize and quantify the financial tradeoff of regular row crop production vs. CRP practice establishment. Another capability of the tool is to consider the financial tradeoff of implementing an alternative practice that is not CRP related. For example, enrolling an area into the Environmental Quality Incentives Program (EQIP) or converting an area to grassland for cattle grazing. This tool will allow producers to identify consistently low profitability areas of their field and evaluate the economic impact of enrolling these areas in a CRP or alternative practice.

Downloading Data

The decision support tool utilizes a number of user-provided or public geospatial data layers to generate eligibility and profitability outputs. The field boundary and yield shapefiles must be provided by the user. The other geospatial data is the National Hydrologic Dataset (NHD) (wetland, river, stream) shapefiles and can be downloaded for free via the NRCS's Geospatial Gateway. The NHD data is needed only to run riparian buffer practices (CP-21, CP-22, CP-29, and CP-30). We will provide step-by-step instructions on downloading this data.
The link to get to the Geospatial Data Gateway is below:
https://datagateway.nrcs.usda.gov/
In the box in the bottom right corner (Figure 1), click **Order by County/Counties**.

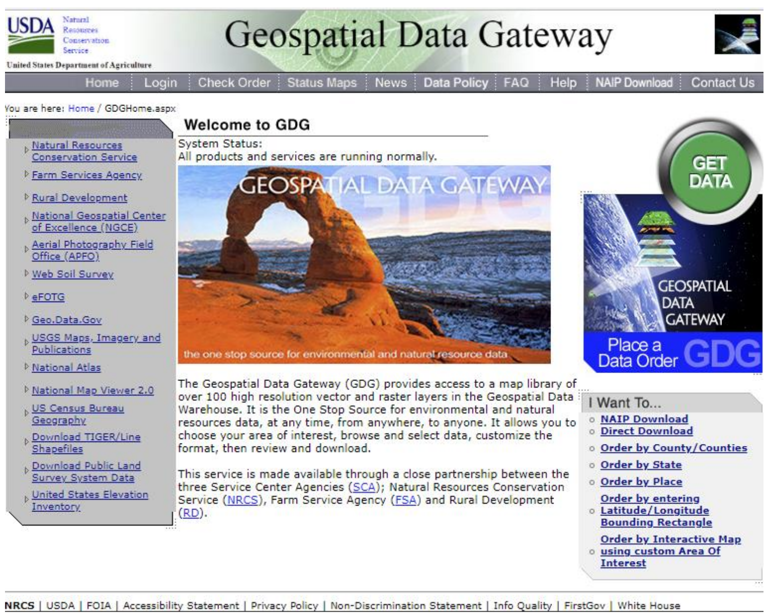


Figure 1: Geospatial Data Gateway

In the **Select State for order** box (Figure 2) click the down arrow and select the state for the farm you will be analyzing. This will bring up another dialog box where you can select the county where your farm is located. Choose your county and click **submit selected counties.**

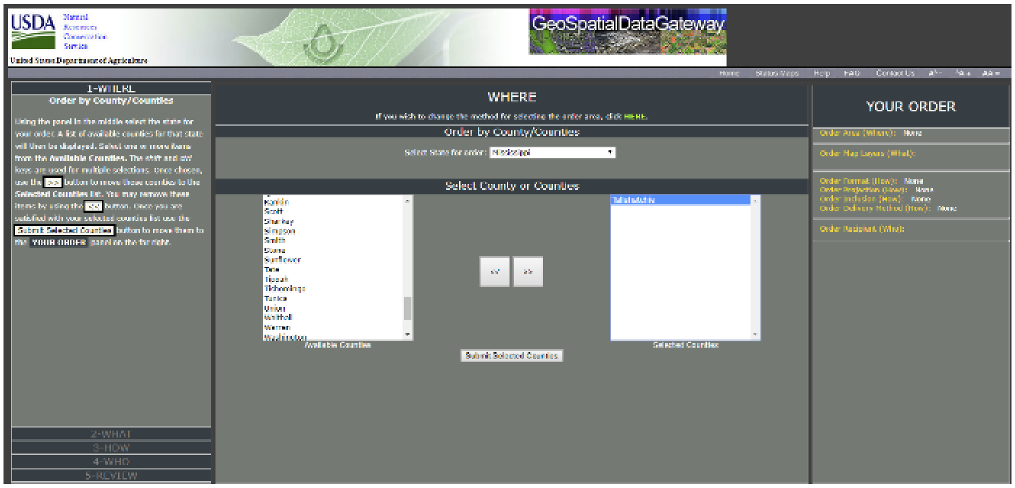


Figure 2: Select County

This will bring you to the option of various data to download (Figure 3). Under Hydrography check **National Hydrography Dataset**. Click **continue**. Under Format, change to **ESRI Shape** (Figure 4). Under Projection change to either **UTM Zone ** NAD83** or **State Plane ******** NAD83** (UTM zone and State Plane district will vary depending on the location being analyzed). This option changes the projection of the NHD data. For more information regarding UTM Zone and State Plane projections, as well as the WGS84 coordinate system, refer to the glossary.

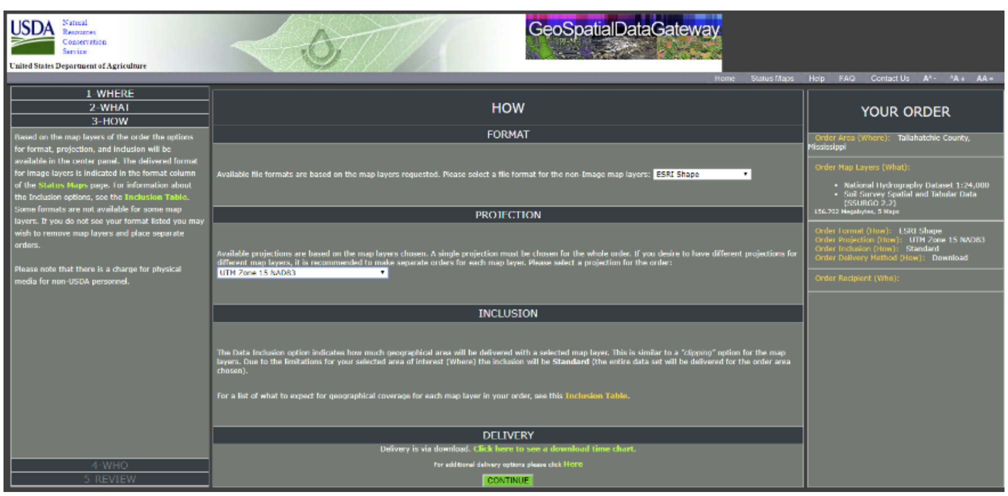


Figure 3: Select Data to Download

Figure 4: Select Data Projection and Format

Click **Continue**. Specify your email and click **Continue** again. In the left pane click **PLACE ORDER**. When the order is finished it will be sent to your email. In this email under **Ordered Items**, click the hyperlinks to start downloading your data. After your data is downloaded, navigate to the zipped files (most likely in the Downloads folder) and right click them one at a time and click **Extract All.** Navigate to the folder you would like to save your data. Extract the correct data into each. This will create a **hydrography** folder. The NHD data will come with more files than you need. There are three hydrography shapefiles that are needed. This example is for Washington County Mississippi, but the name of your shapefiles should be similar other than the state and county code (ms151) (Figure 5). For example:

nhd24kst_l_ms151**.shp** = steams,
nhd24kar_a_ms151**.shp** = rivers,
nhd24kwb_a_ms151**.shp** = wetlands.

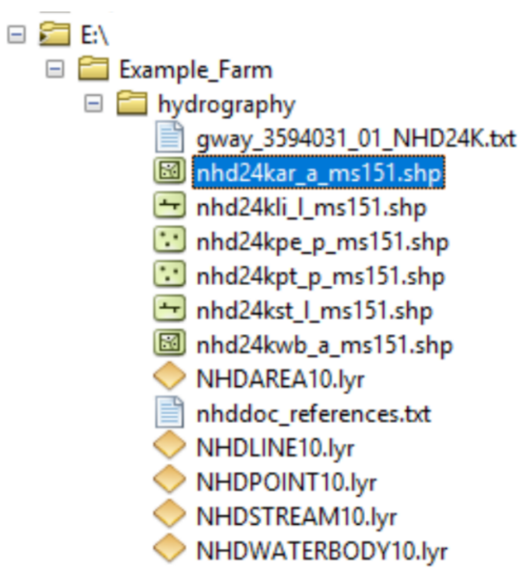


Figure 5: NHD Shapefiles

Now that you have downloaded all the needed geospatial data you are ready to inspect the data for accuracy and then run the tool.

Inspecting Data

The next step is to open a new session of ArcMap. **ArcMap 10.5 or higher is required to run the tool**. The Spatial Analyst extension is required as well.

Field Boundary Layer

Add your field boundary polygon into the map. Go to the properties and make sure it is projected into the correct UTM Zone or the correct State Plane. The field boundaries need to be checked for accuracy. Zoom into the specific field you will be analyzing. Add a satellite basemap layer or a county National Agriculture Imagery Program (NAIP) image into the map. Use this basemap, as well as your knowledge of the field, to verify the field boundaries for accuracy. If a significant inaccuracy exists, the field boundary shapefile should be edited. If the field boundary needs to be edited go into editor mode and use the **Edit Feature Tool** to reshape the polygon to more accurately represent the true field boundary. Make sure to stop editing and save your edits when you are complete. Make sure there are no duplicate polygons of the same field. In editor mode, delete any duplicates if they exist.

Yield Data Layer

If you have yield data and intend to compute profitability, add the yield data layer to the data frame. The yield data should already be cleaned. Cleaning involves removing yield data points that have dry yield volume values that are outliers and thus assumed to be errors (eg. turn row yield points, zero yield values from data collection over previously harvested portions of the field, etc). A variety of techniques are used to clean yield and many yield monitor software packages have suggested cleaning routines (http://nmsp.cals.cornell.edu/publications/extension/ProtocolYieldMonitorDataProcessing2_8_2018.pdf). Make sure the points correctly align with the field boundary. Go to the properties of the yield layer and then click the **symbology** tab. Click the **quantities** tab in the left side of the pane and then change the value to the field that has data for the Dry Yield Volume. You can choose as many classes as you would like (around 12 works well). You can also select your preferred color ramp. Click **Ok**. This will symbolize the points based on their yield value. This allows the user to visualize if clusters of low yielding areas exist and strategize what CRP practice would fit well in those low yielding areas.

NHD Data Layer

If running a riparian buffer practice (CP-21, CP-22, CP-29, CP-30), add the wetland (**nhd24kwb_a**_ms151**.shp**), river (**nhd24kar_a**_ms151**.shp**), and stream (**nhd24kst_l**_ms151**.shp**) shapefiles to the map. Confirm that they correctly align with the rest of the data. Check these layers for accuracy against the imagery as well as your knowledge of the area. In many occasions, there are streams, rivers, and wetlands that are not identified by the NHD layers. In this case, the error should be corrected in editor mode as mentioned earlier. The **Create Feature** button in the Editor Toolbar can be used to add streams, rivers, or wetlands that were not included in the original NHD layer. At this point you are ready to run the tool. In the Catalog navigate to the folder containing the tool. Double click the **MSU Precision Conservation** script tool in the MSU Precision Conservation 90 toolbox (Figure 7). Make sure the help pane is visable by clicking the **Show Help** button at the bottom of the tool.

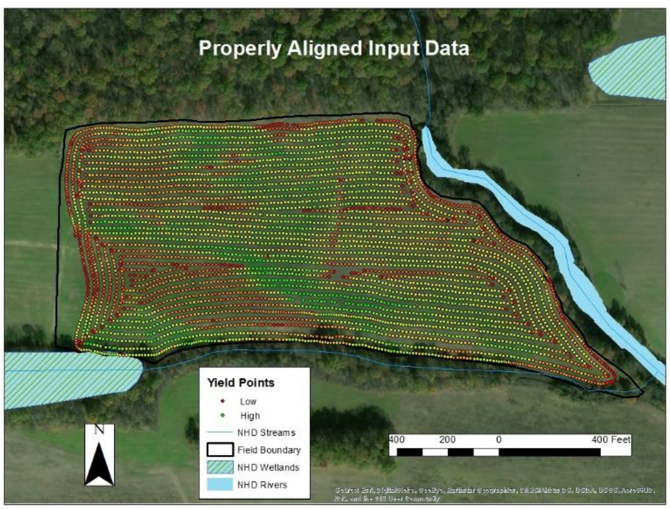


Figure 6: Properly Aligned Input Data

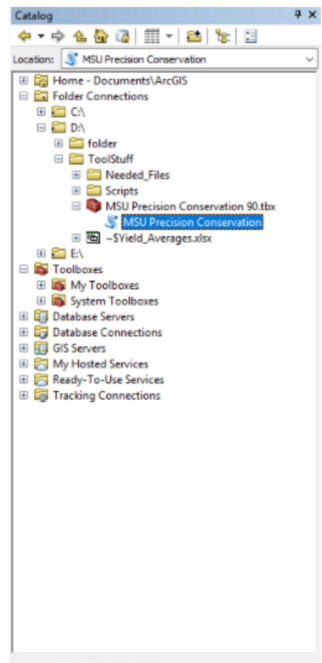


Figure 7: Location of Script Tool

Fill out all the required parameters for the practice you want to analyze. Each parameter will have help documentation in the help pane to guide you. Additional information about each parameter is in the Tool Parameters section.

Warning (Clicking in a parameter that has a list of options and trying to scroll up and down the tool interface will scroll through the list of options in the selected parameter and could cause you to inadvertently change a parameter).

A detailed example of how to run the tool for each type of CRP practice is provided below to give you an idea of how to fill out the parameters and run the tool.

CRP Practice Examples

Riparian Buffer Practice (CP-21)

Conservation Practice-21 (CP-21), Filter Strips is a riparian buffer practice that reduces sediment transport and improves water quality. We will walkthrough step-by-step directions for running the tool on this practice. Other riparian buffer practices that are largely the same to run include CP-22, CP-29, and CP-30. The first step in the workflow is to run an eligibility analysis to determine what areas in our field are eligible for the practice. To get started, first open ArcMap and then open the DST and make sure the help pane is showing.

Leave the **Analyze Profit Using Own Extent** parameter unchecked for the time being. We will discuss what this does later. In the **CRP Practice** parameter select CP21 from the dropdown menu. The **Project Name** should not include the name of the CRP practice since that is automatically appended. The name should uniquely identify your current iteration of the tool or the farm/field you are analyzing. *Do not start the name with a number or use any spaces*. *Also avoid names longer than 13 characters and names you've already used*. The **Project Folder** is the location of all tool outputs that will be saved. It is best practice to create a folder to save all outputs.

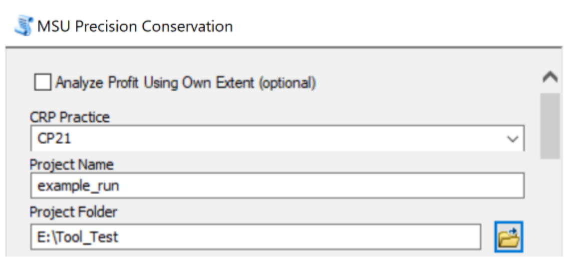


Figure 8: CP-21 Input Parameters

Input the three NHD layers you downloaded. Also input your farm field boundary shapefile. All these layers should have already been checked for accuracy. Refer back to the **Inspecting Data** section if they aren't. The eligibility analysis can be ran for a single field, as well as over an entire farm or watershed depending on the user's need. Figure 9 shows an example of what NHD layers look like.

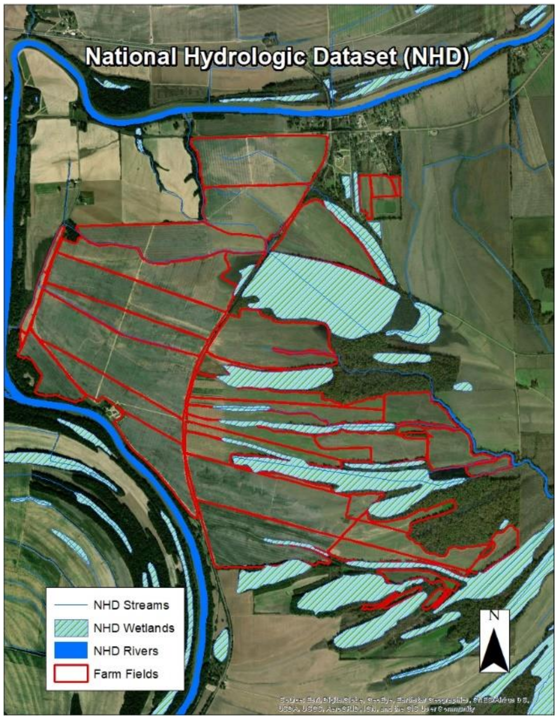


Figure 9: Farm wide NHD Shapefiles

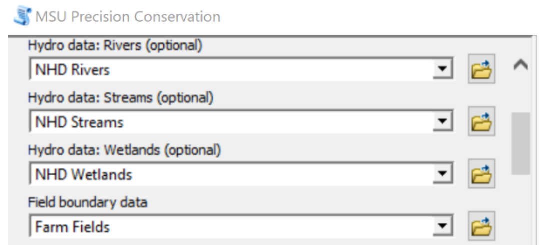


Figure 10: CP-21 Input Parameters

A soil rental rate (SRR) table is included with the tool in the **Needed_Files** folder (Figure 12). This file includes the average soil rental rate ($) for each county, which will be used to calculate the total CRP rental rate. The **Soil Rental Rate State** and **Soil Rental Rate County** are needed to select the correct SRR. Select your state from the dropdown menu. A list of counties in your selected state will be displayed. Select your farm's county from the list. The **Average Stream Width** is the distance in feet that the streamlines will be buffered to more accurately represent an actual stream. The default is 10 feet. The **Compute profitability?** box will automatically be checked. To run only an eligibility analysis without the profitability functions, uncheck this box. This will disable the rest of the parameters in the tool.

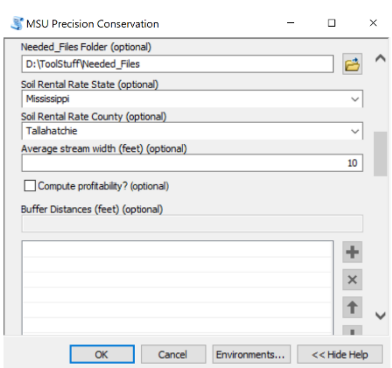


Figure 11: CP-21 Input Parameters

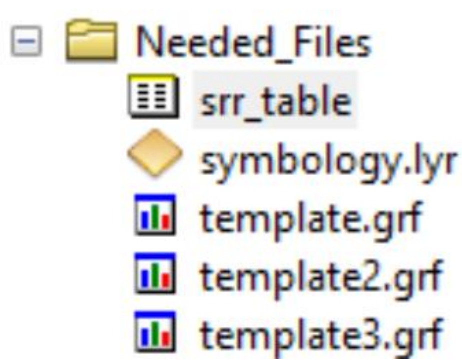


Figure 12: Location of Soil Rental Rate Table

At this point you are ready to run the tool. When the tool finishes running you should get a shapefile called CP21_Elligibility (Figure 13). This shapefile includes the maximum area eligible in the study area for CP21. The SRR and total acres eligible is also included in the attribute table. You now know the area within fields that are eligible for CP21. You can use this information to decide which field(s) you would like to investigate financially by running a profitability analysis.

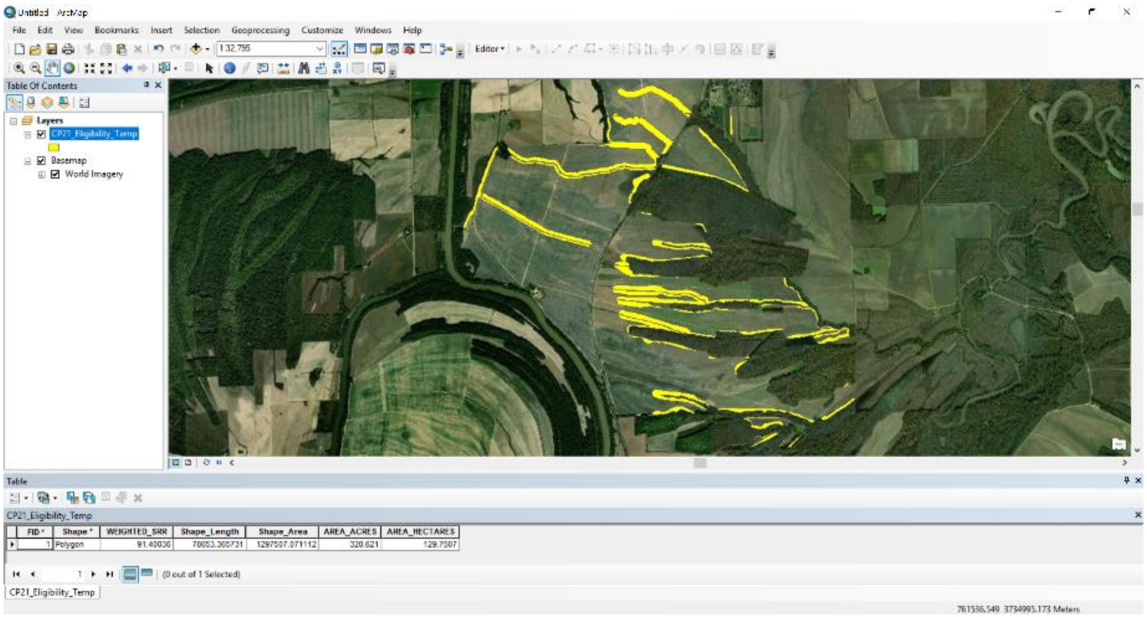


Figure 13: Eligibility Analysis Output Shapefile

Profitability Analysis

After having analyzed which fields are eligible across the entire farm, the user can identify a specific field with eligible area that they would like to analyze. They will need to have spatially explicit yield data for the field they would like to analyze for economic comparisons. The first parameters can be filled out exactly as they were for the eligibility analysis. The **Compute profitability?** parameter should be left checked and all parameters below it filled out.
In the **Buffer Distances (feet)** parameter, buffer distances can be entered by typing them in the dialog box and clicking the **+** symbol to add the value to the list. The help dialog will show you which range of buffer distances are allowed for the given practice. The tool will automatically consider the maximum allowed distance. In the **Yield data** parameter, the yield data can be entered. It should already be cleaned and inspected for accuracy. Figure 14 shows an example of a yield layer.

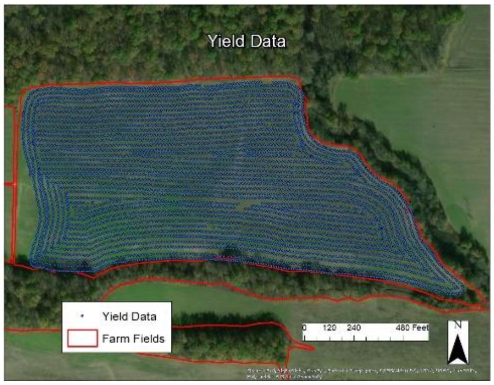


Figure 14: Yield Shapefile

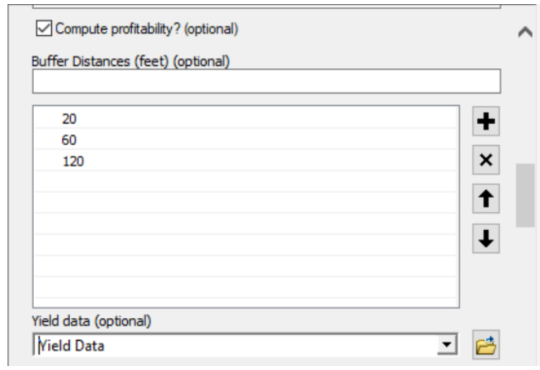


Figure 15: CP-21 Input Parameters

If you have a multi-feature shapefile, the polygon that distinguishes the specific field you would like to analyze needs to be identified. **Field unique identifier** is the header (column) in the fields attribute table that uniquely identifies each field or polygon in the shapefile. **ID of field with yield data** is the specific value within that field that will be used to select the correct field polygon. Use the **Identify** tool to click on the field boundary you would like to analyze. This will bring up an Identity window that will allow you to decide the correct value to uniquely identify your field (Figure 16). If you have a single shapefile for each field, these two parameters can be ignored. **Commodity price** is the dollar value ($$/bu) of the crop for the year that the yield data was obtained. In our example, the yield data is for soybeans, so we'll use $8 a bushel as our value; however, we encourage users to experiment with multiple commodity prices to determine at what price a low-yielding area of a field is no longer profitable. **Government Payments** is the dollar amount per acre received in government subsidies. Consult the **Tool Parameters** section under Government Payments for more information. **Production Costs** is the entire cost per acre to produce the given crop. If this value is unknown refer to the state-specific crop production budgets for estimates by crop type and farming method. For this example, we used $250/acre for production costs to reflect the year-specific cropping system for that region of Mississippi. Your state's land grant university extension service has likely produced crop production budget estimates for major crops and cropping systems in your state.

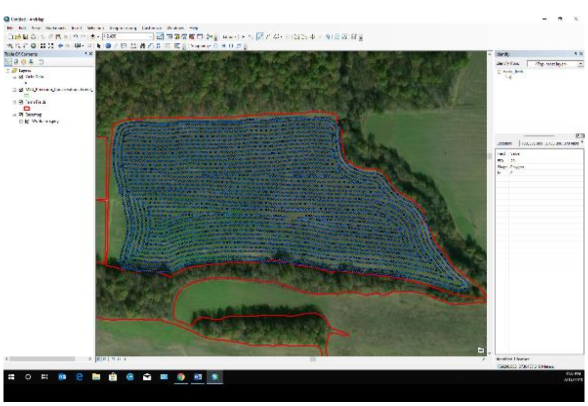


Figure 16: IDing Unique Polygon in Shapefile

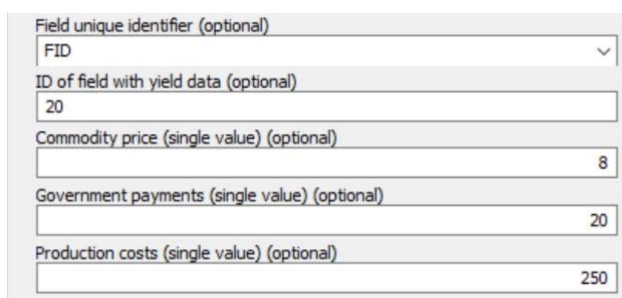


Figure 17: CP-21 Input Parameters

Dry yield volume field is the field within the attribute table of the yield shapefile containing dry yield volume in bushels per acre. In most cases it will be named **Yld_Vol_Dr** or something similar. A dropdown list will provide available fields within the yield shapefile. **CRP establishment costs** is the total cost in dollars per acre to establish the given CRP practice. This value will be divided by the CRP contract length (years) to get an establishment cost per acre per year. We considered $186 for our example. **CRP maintenance costs** is the total cost in dollars per acre to maintain the given practice. This value is also divided by the CRP contract length. We considered $100 for our example. **Maintenance Rate Incentive** is the dollar amount per acre per year provided to help shoulder the cost of maintaining a practice. We considered $5 for our example. **CRP Contract or Alternative Practice Length** is the CRP contract length in years. This parameter is only enabled when a practice allows both 10 and 15 year contracts. Other parameters in the image above are disabled because they don't apply to this practice.

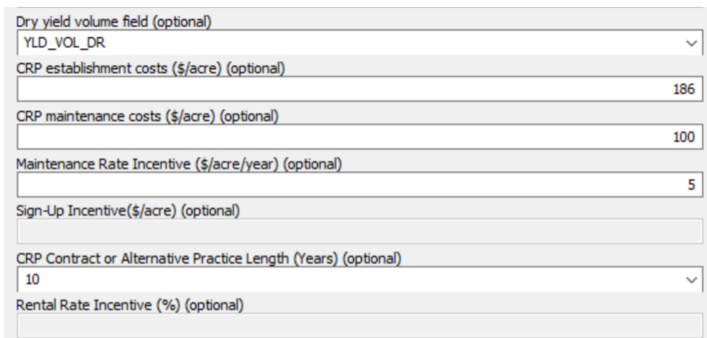


Figure 18: CP-21 Input Parameters

To generate an original profit surface raster and CRP profit raster check the **Generate profit surface raster?** box. Otherwise only a Profitability shapefile will be output. **Raster cell size** defines the cell size that all raster related processes will use, as well as the cell size of the output rasters if you choose to generate them. A dropdown list provides a list of common cell size values. If no value is input, Arcmap will automatically generate a cell size based off the input data. At this point all needed parameters should be filled out and the tool should be ready to run (Figure 19). Outputs from this profitability analysis can be seen in the **Tool Outputs** section.

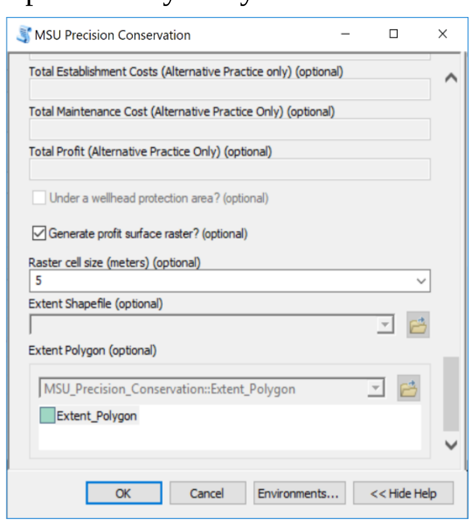


Figure 19: CP-21 Input Parameters

After analyzing the areas of low profitability from the Original Profit Surface raster and the financials of establishing a CRP practice, the user can decide from a variety of different scenarios. One option is to analyze non-uniform buffer widths. To do this fill out all the parameters for the profitability analysis as you had before (remember to use a different **Project Name**), though this time checking the **Analyze Profit Using Own Extent** box (Figure 20). This will enable the **Extent Polygon** and **Extent Shapefile** parameters at the very bottom of the tool dialog (Figure 21). This will allow you to draw your own non-uniform buffer in your field. If one exists, the user can also enter a shapefile defining the extent of the practice. The benefit of this function is that it allows users to consider only enrolling unprofitable acres. It also allows the user more flexibility to create buffers that would be easier to manage and farm around, for example field edges could be squared off to remove irregular edges. Using the eligibility shapefile as a reference, make sure that the polygon you draw doesn't go outside the eligible area in your field (Figure 21).

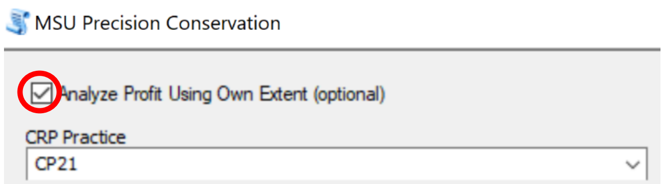


Figure 20: Enabling Ability to Draw Own Extent

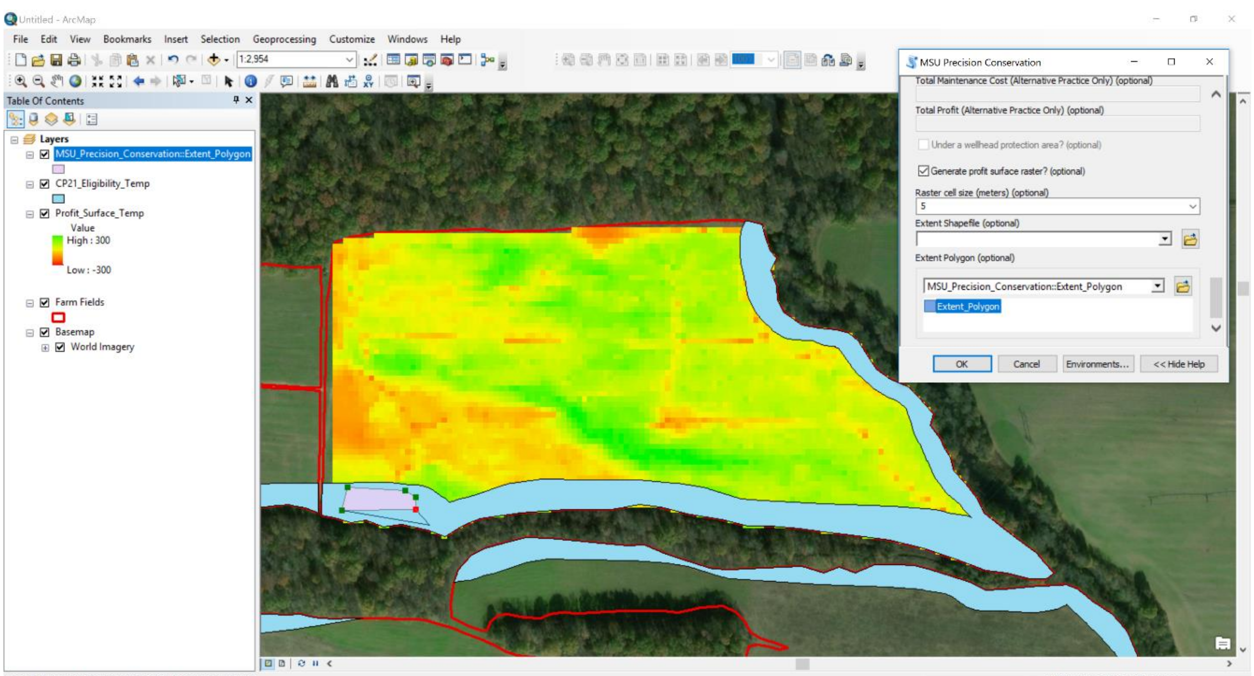


Figure 21: Drawing Own Extent Example

The Compute Profitability function can be rerun and the profitability of these non-uniform buffers analyzed. Additionally, the user can consider different eligible CRP practices and scenarios, which we will discuss later, as well as analyze yield data for different years until they have decided the best management option. Examples of different types of CRP practices will be shown as well. You can rerun the tool quickly using different parameters or yield data by accessing the Geoprocessing Results pane. To access this pane, click the **Geoprocessing** tab (Figure 22). Next click **Results** to bring up the Results pane. Double click the latest iteration of the tool you've ran. This will bring up the tool dialog with the parameters filled out. From there you can change whatever parameter you desire. Make sure to change the project name or the tool will fail. It is not recommended that you use this method to change the CRP practice you're running. This will cause a host of issues related to enabling and disabling of parameters for each practice.

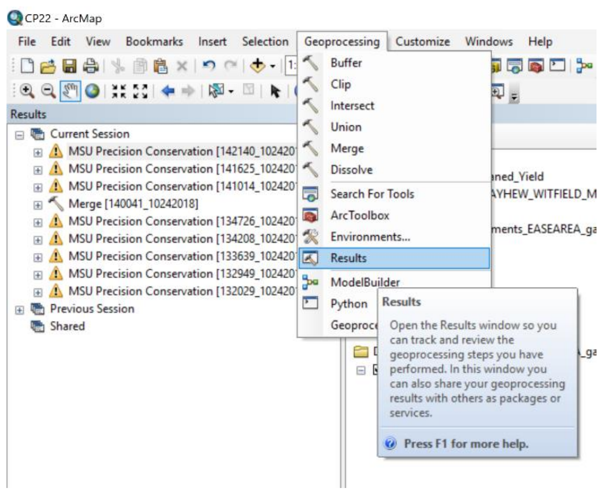


Figure 22: Navigating to Geoprocessing Results

Field Buffer Practice (CP-33)

Conservation Practice-33 (CP-33) Upland Bird Habitat is the one field buffer practice in the CRP program. Native warm season grasses, forbs, legumes and shrubs can be established in buffer widths ranging from 30 to 120 feet from the edge of the field. The purpose of this practice is to increase bobwhite quail habitat in agricultural landscapes, though other wildlife benefit as well. CP-33 does not require NHD data to be input. It is recommended that an eligibility analysis be run first to analyze the whole farm eligibility of CP-33. Refer to **Riparian Buffer Practice (CP-21)** for more information on how to run an eligibility analysis. Profitability can be run next on a specific field to analyze the financial tradeoff of establishment of a CRP practice. This practice also has the option to consider non-uniform buffer widths across the field. Refer to the **Tool Output** section for information regarding the tool outputs.

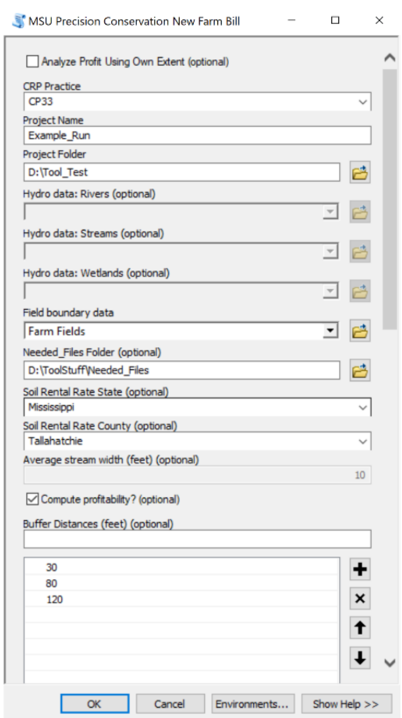


Figure 23: CP-33 Input Parameters

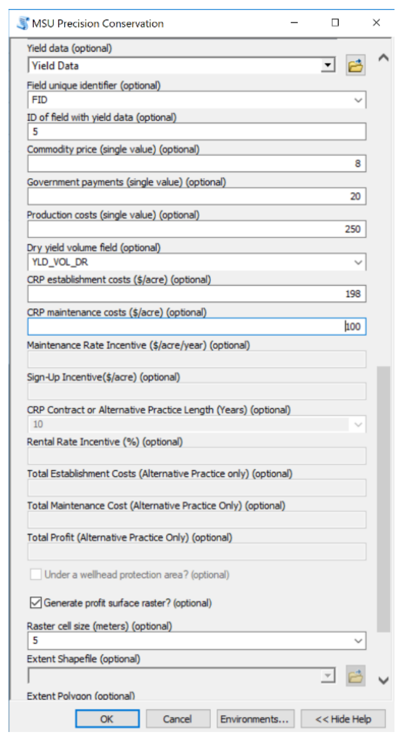


Figure 24: CP-33 Input Parameters

Whole Field Practice (CP-2)

Conservation Practice-2 Native Grass, Forb, and Legume Establishment is a practice that establishes a native land cover. It is an example of a whole field practice. The purpose of this practice is to prevent soil loss, create wildlife habitat, improve water quality, and sequester carbon. Other whole field practices that are largely the same to run include CP-1, CP-3, CP-3A, CP-4D, CP-25, CP-31, and CP-36. You can only run a profitability analysis on whole field practices. The spatial eligibility of whole field practices is any field polygon on the farm, thus an eligibility analysis is not needed. However, fields must meet CP-specific general or continuous CRP eligibility criteria such as Highly Erodible Land, conservation priority area (e.g. Longleaf pine CPA), or state-specific SAFE (CP-38) regional priority areas. There is no need to manually draw the field boundary because the extent of the practice will be the field polygon provided.

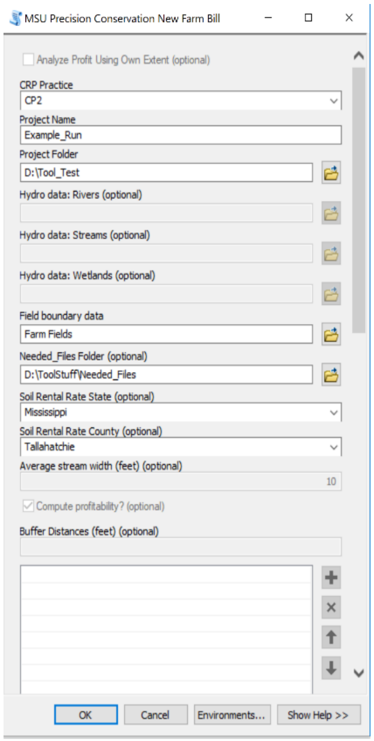


Figure 25: CP-2 Input Parameters

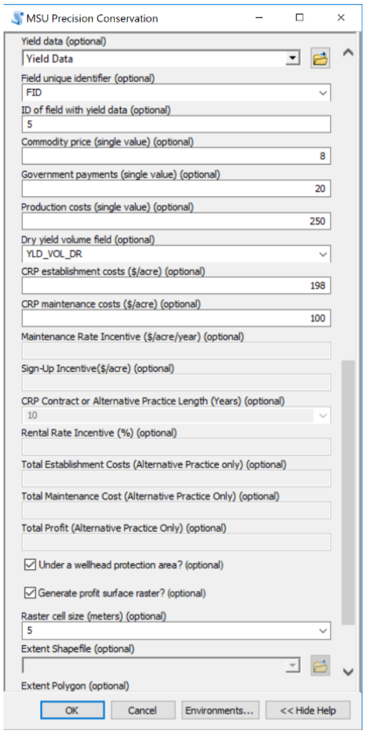
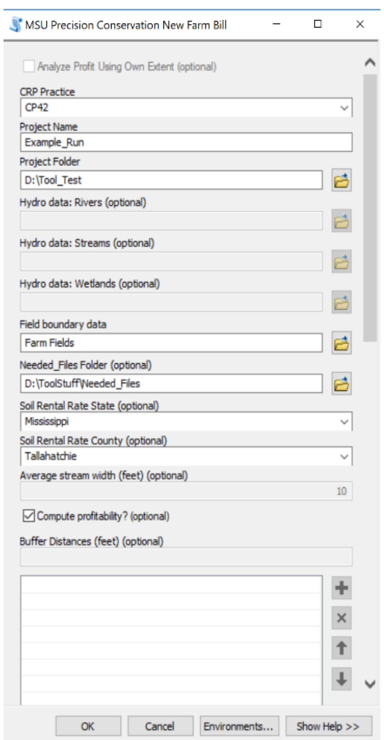


Figure 26: CP-2 Input Parameters

User Defined Extent Practice (CP-42)

Conservation Practice-42 (CP-42) Pollinator Habitat Establishment is a practice that establishes and maintains diverse pollinator friendly habitat. This is an example of a user defined practice. You can only run a profitability analysis for user defined extent practices. The extent of the practice is defined by the user within the field (Figure 28). In the case of CP-42, the total area of the practice must be larger than .5 acres, and strips must be a least 20 feet wide. If the user draws an extent that breaks these rules an error message will occur when the tool is ran. Other practices with a user-defined area that are mostly similar to run are CP-4B, CP-5A, CP-8A, CP-12, CP-15A, CP-16A, CP-17A, CP-18B, CP-24, and CP-38. Each of these practices have different spatial requirements. Refer to the **CRP Practices** section for more information.



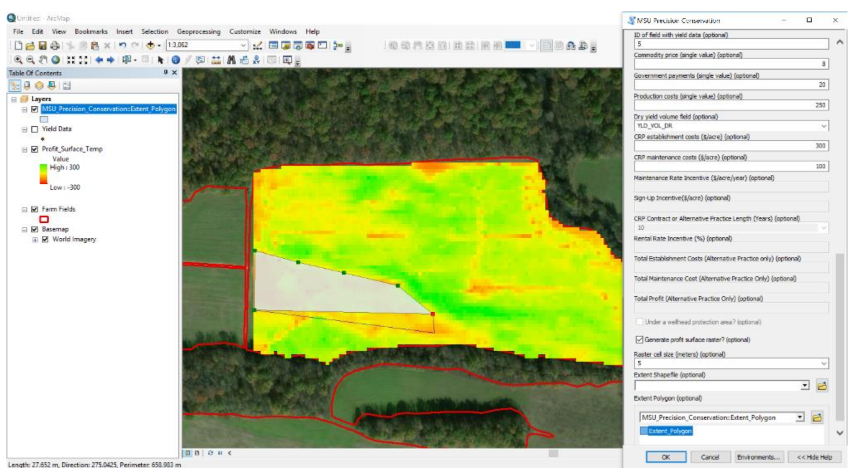


Figure 27: CP-42 Input Parameters

Figure 28: Drawing Own Extent Example

Wetland with Grassland Buffer Practice (CP-9)

Conservation Practice-9 (CP-9) Shallow Water Areas for Wildlife establishes a wetland 6-18 inches deep with the goal of creating wildlife habitat, while improving water quality and flood control. This is one example of a wetland practice. All wetland practices are required to have a grassland buffer around the wetland. CP-9's buffer can be from 20 to 120 feet wide. Other wetland and wetland buffer practices include CP-23, CP23A, CP-27, CP-28, CP-37, CP-39, CP-40, and CP-41. Each practice has different required wetland areas, as well as grassland area and buffer widths. Refer to the **CRP Practices** section for more information. The tool returns an error if any of these requirements are broken. For example, the buffer size of Conservation Practice-23 (CP-23) cannot exceed three times the size of the wetland. The tool will calculate the area of the buffer and the wetland, if the buffer is three times larger than the wetland an error will appear instructing the user to consider either a larger wetland or smaller buffers. Only profitability analysis can be run on wetland practices. The user must define the extent of the wetland and the buffer distances to be considered (Figure 30).

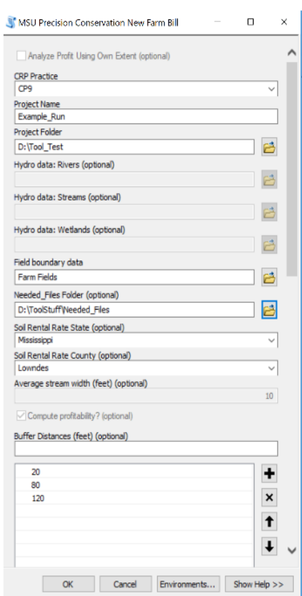


Figure 29: CP-9 Input Parameters

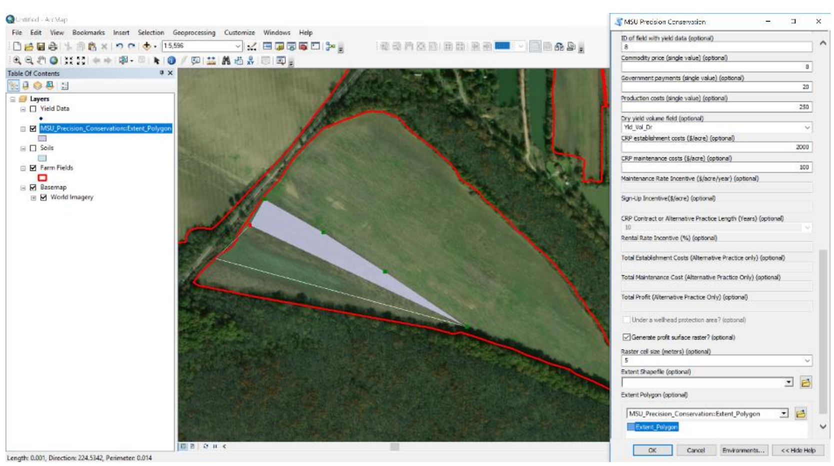


Figure 30: Drawing Wetland Example

Alternative Practice

The tool also allows for the user to consider a non-CRP related alternative practice (Figure 31). The user can manually draw the extent of this alternative practice in their field. This requires the user to enter basic economic values for their alternative practice. These include **Total Establishment Costs**, **Total Maintenance Cost**, and **Total Profit** (Figure 32). The user must also input the number of years considered for all the costs in the **CRP Contract or Alternative Practice Length (Years)** parameter. Any CRP related parameters are disabled when this option is selected. The financial tradeoff of this alternative practice vs. regular row crop agriculture can be analyzed. Environmental Quality Incentives Program (EQIP) and Wetland Reserve Program (WRP) practices could also be modeled and analyzed as an alternative practice.

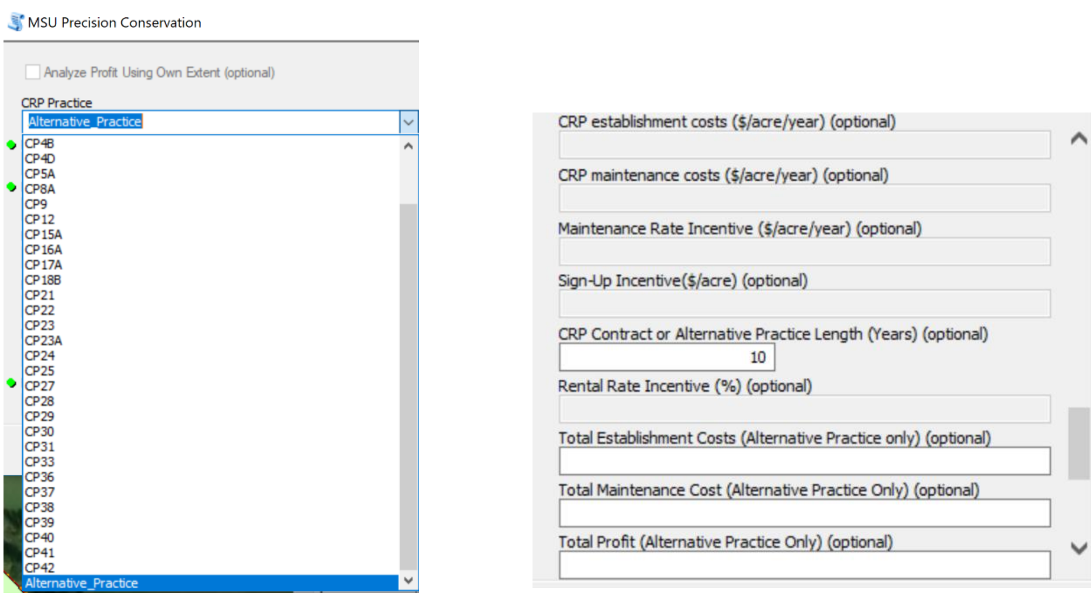


Figure 31 and 32: Alternative Practice Input Parameters

Tool Outputs

Profitability Graph

- The tool will output a graph comparing the original profitability (traditional whole field row crop production) vs the overall profitability (row crop production with CRP practice) (Figure 33). Extra bars are added for practices that consider multiple buffer distances. This graph is created in PDF format and will automatically open up a web browser to display the graph.

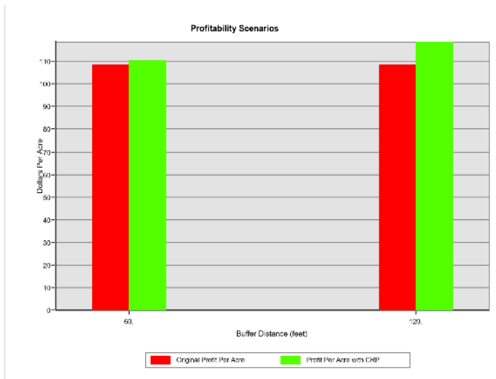


Figure 33: Profitability Graph

Profitability Shapefile

- A shapefile is output with the spatial extent of the given CRP practice (Figure 34). Practices that consider multiple buffer distances will have separate polygons within the shapefile for each buffer distance. The fields included in the attribute table vary from practice to practice. This layer will automatically be added to the Table of Content as a layer file. A layer file is only for viewing purposes, the actual shapefile will be in the geodatabase.

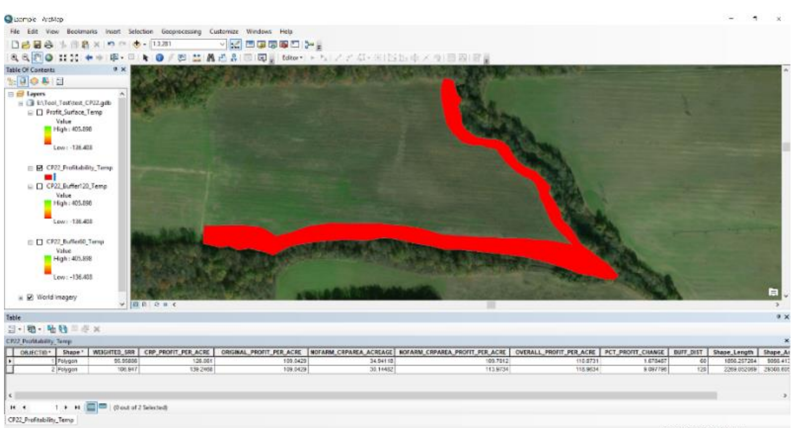


Figure 34: Profitability Shapefile

Profitable Buffer Shapefile

- Only for CP-21, CP-22, CP-29, CP-30, and CP-33. A cell level analysis is conducted comparing the Original Profit Surface raster to the CRP Profit Surface raster (Figure 35). Cells where CRP is more profitable are extracted, aggregated, and converted to vector format to generate a profitable buffer shapefile.

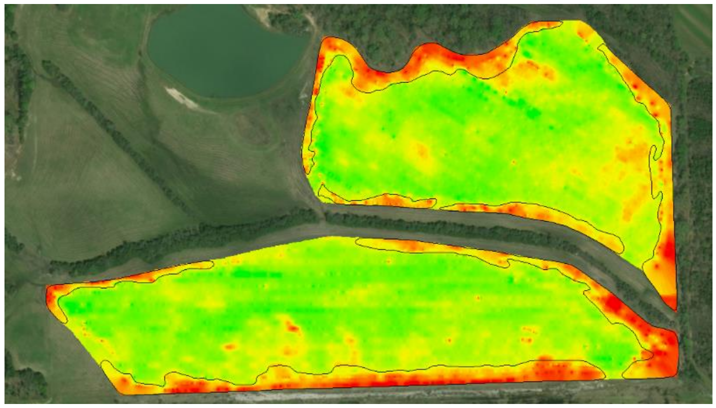


Figure 35: Profitable Buffer Shapefile

Eligibility Shapefile (Eligibility Analysis Only)

- A shapefile is output with the spatially eligibility across the whole farm or watershed for the given practice (Figure 36). This layer will automatically be added to the Table of Content as a layer file. A layer file is only for viewing purposes, the actual shapefile will be in the geodatabase. Fields within the attribute table include the soil rental rate for all the eligible area, and total acreage.

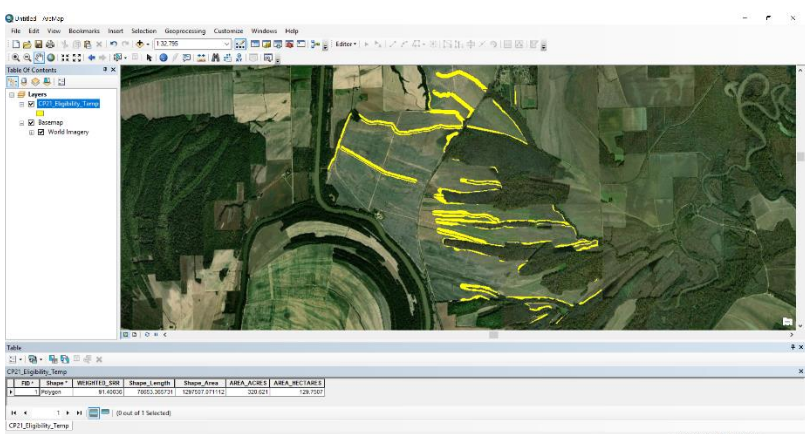


Figure 36: Eligibility Shapefile

Original Profit Surface Raster

- Interpolating the yield data and doing basic economic calculations generates a profit surface raster (Figure 37). The cell size of the raster can be determined by ArcMap or input by the user. This layer will be automatically added to the Table of Contents as a layer file with default symbology. A layer file is only for viewing purposes, the actual raster will be in the geodatabase. This layer allows the user to visually identify low profitability areas and decide the best course of action.

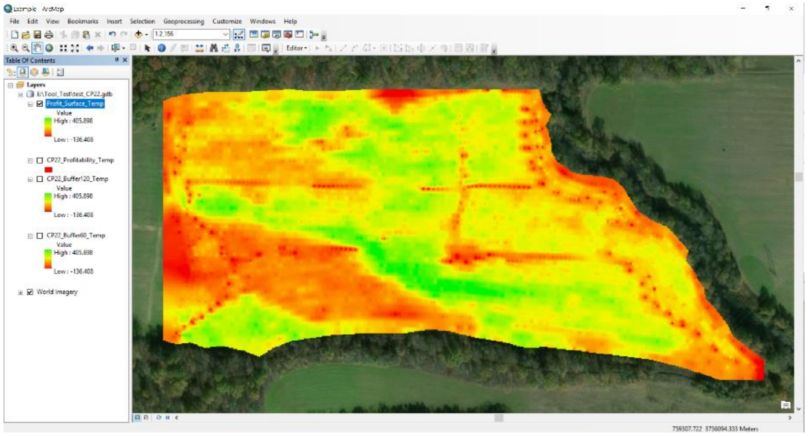


Figure 37: Original Profit Surface Raster

CRP Profit Surface Raster

- Overlaying a raster with the profit of the CRP practice onto the original profit surface raster creates the CRP profit surface raster (Figure 38). This layer will be automatically added to the Table of Contents as a layer file with default symbology. A layer file is only for viewing purposes, the actual raster will be in the geodatabase. This layer allows the user to visualize what the profit across their field would look like if they implemented a CRP practice.

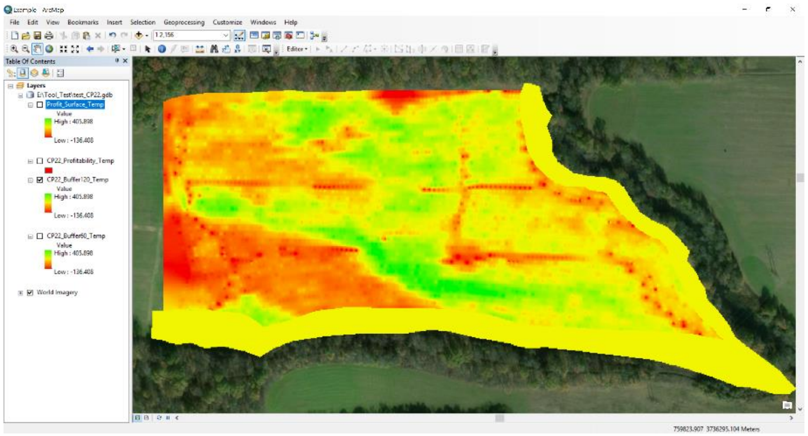


Figure 38: CRP Profit Surface Raster

Common Errors

Field boundary shapefile is in a geographical coordinate system.

- The tool will crash if the field boundary shapefile is in a geographical coordinate system (eg. WGS 84). A geographical coordinate system is not appropriate for a field boundary shapefile. Use the Project tool to convert the shapefile to a projected coordinate system (UTM Zone ** or State Plane)

(CP21, CP22, CP29, CP30) there are no eligible areas in your field

- The wetland, river, and stream buffers created have no area in the field you are trying to analyze. It is best practice to run an eligibility analysis first to make sure there are eligible areas within the field you are wanting to analyze before running a profitability analysis on the field.

(CP4B, CP5A, CP8A, CP12, CP15A, CP16A, CP17A, CP18B, CP24, CP38, CP42, Alternative Practice) User must draw their own CRP practice extent

- These practices require the user to draw the extent of the practice to be considered. Rerun the tool, making sure to draw the practice extent or enter a shapefile defining the extent.

Arcmap has bugs in some of their tools

- There are certain Arcmap tools (most commonly Clip and Extract by Mask tool) used in the workflow of this tool that tend to crash through no fault of the user. If you are absolutely sure that you are running the tool correctly, try closing and reopening ArcMap and running the tool again.

Project Name has already been used

- Every time you run the tool use a project name that hasn't been used.

(CP9, CP23, CP23A, CP27, CP28, CP37, CP39, CP40, CP41) User must provide buffer distance(s)

- At least one buffer distance must be entered for these practices to be modeled. Make sure the buffer distance(s) fall within the allowed distances for each practice

For a field shapefile containing multiple polygons, the unique identifier of the field to be analyzed was not correctly defined.

- Make sure the correct field and unique identifier were input. Make sure the unique identifier is truly unique and that another polygon doesn't have the same ID. Using unique numbers assigned in the FID field is a good option to assure each polygon has a unique ID.

Tool Parameters

Analyze Profit Using Own Extent

- (CP-21, CP-22, CP-29, CP-30, CP-33) Allows the user to draw their own buffers of non-uniform size, as long as they fall within the spatial eligibility of the buffer practice. This is often run as the second iteration of the practice, after uniform buffer distance scenarios have been previously generated.

CRP Practice

- The CRP practice to analyze. This parameter determines which other parameters will be activated or not. There is also an "Alternative_Practice" option that allows the user to consider a non-CRP option.

Project Name

- The name of the geodatabase that will be created to store all spatial outputs. It is also the name of the folder created to store the output graph. It should be the name of the field or some other unique identifier. It should not be the name of the CRP practice, which will automatically be appended to this name.

Project Folder

- The folder where the output geodatabase and graph will be created. It is a good practice to create a special folder for all outputs.

Hydro data: Rivers

- (CP-21, CP-22, CP-29, CP-30) Input the polygon type shapefile representing the rivers. You can either add it to the map and fill the parameter from the dropdown menu or navigate to the location of the shapefile by clicking the folder icon.

Hydro data: Streams

- (CP-21, CP-22, CP-29, CP-30) Input the polyline type shapefile representing the streams. You can either add it to the map and fill the parameter from the dropdown menu or navigate to the location of the shapefile by clicking the folder icon.

Hydro data: Wetlands

- (CP-21, CP-22, CP-29, CP-30) Input the polygon type shapefile representing the wetlands. You can either add it to the map and fill the parameter from the dropdown menu or navigate to the location of the shapefile by clicking the folder icon.

Field boundary data

- The polygon type shapefile that delineates the field boundaries of the farm. This layer must be provided by the user and should be projected into the appropriate UTM Zone or State Plane. It should also be checked for accuracy as mentioned earlier in the documentation.

Needed Files Folder

- A folder included with the download of the tool. The soil rental rate table and other needed files are in this folder.

Soil Rental Rate State

- The state of the field(s) being analyzed. A drop down list will provide all 50 states. This input is used to query the soil rental rate table.

Soil Rental Rate County

- The county of the field(s) being analyzed. A dropdown list of counties by state will be provided. This input is used to query the soil rental rate table.

Average stream width (feet)

- (CP-21, CP-22, CP-29, and CP-30 only) If desired, specify a distance in feet corresponding to the average width of streams on and adjacent to the property being analyzed. Flow line features will be buffered by half this distance before beginning analysis. The default is 10 feet.

Compute profitability?

- Check this box if profitability analysis is desired. This box will be checked by default for most practices. Only CP-21, CP-22, CP-29, CP-30, and CP-33 give you the option to uncheck the box and only run an eligibility analysis.

Buffer Distance (feet)

- The user can enter one or more buffer distances for certain practices. At least one value must be entered in for wetland buffer practices (CP-9, CP-23, CP-23A, CP-27, CP-28, CP-37, CP-39, CP-40, CP-41). Restrictions on buffer distances are seen below:

    - CP-9: (20-120)
    - CP-21: (20-120)
    - CP-22: (35-100)
    - CP-23: No larger than 3x the area of the wetland
    - CP-23A: No larger than 4x the area of the wetland
    - CP_27/CP_28: No larger than 4x the area of the wetland
    - CP-29: (20-120)
    - CP-30: (20-120)
    - CP33: (30-120)
    - CP-37: Must be larger than 4x the wetland, but no larger than 10x the wetland
    - CP-39: No larger than 4x the area of the wetland

For CP-21, CP-22, CP-29, CP-30, and CP-33 the maximum buffer distance will automatically be considered.

Yield data

- The point type shapefile containing yield data for the field being analyzed. This layer should have been added to the map and checked for accuracy. It should also be cleaned (outliers removed).

Field unique identifier

- The attribute field (column header) in the field boundary shapefile that contains a unique value for each individual field or polygon. If there is no attribute field that uniquely identifies each field, the FID attribute field can be used. This is used to select the specific field or polygon that the user will be analyzing. This is only for when the field boundary layer provided contains multiple fields or polygons, otherwise leave the parameter blank.

ID of field with yield data

- Enter the unique record in the attribute field (column header) that identifies the field or polygon to be analyzed. This is used to select the specific field or polygon that the user will be analyzing. This is only for when the field boundary layer provided contains multiple fields, otherwise leave the parameter blank.

Commodity price (single value)

- The commodity price ($) of the grain for the year the yield data was recorded. It is recommended that the user play around with this value to determine how sensitive the profitability of conservation enrollments is to this value.

Government payments (singe value)

- The government subsidies per acre for the year the yield data was recorded. This is all types of government payments received, including Price Loss Coverage (PLC) and Agriculture Risk Coverage (ARC). PLC provides subsidies when the market falls below a reference price. ARC provides subsidies when county crop revenue averages fall below the county benchmark price. The 2014 Farm Bill ended fixed annual payments from Direct Payments (DP) that were based on historical production.

Production costs (single value)

- The production costs ($) per acre to produce the crop corresponding to the yield data. It is recommended that the producer provides this information, though this value can also be acquired from university crop budgets.

Dry yield volume field

- The attribute field (column header) in the yield shapefile containing values for dry yield volume. A drop down list of the fields in the yield shapefile will be provided.

CRP establishment costs ($/acre)

- The cost to establish the given CRP practice through the life of the contract in dollars per acre.

CRP maintenance costs ($/acre)

- The cost to maintain the given CRP practice through the life of the contract in dollars per acre.

Maintenance Rate Incentive ($/acre/year)

- The maintenance rate incentive (MRI) provides financial assistance to maintain a CRP practice through the life of the contract. The parameter will be disabled if the selected practice does not provide a maintenance rate incentive. Currently allowed values are between $2 and $7 per acre per year.

Sign-Up Incentive ($/acre)

- Only CP-38 has a varying sign-up incentive (SIP) depending on the state and conservation practice. This is the total SIP per acre through the life of the contract. All continuous practices have a SIP that is 32.5% of the rental rate

Rental Rate Incentive (%)

- Only CP-38 has a varying rental rate incentive (RRI) depending on the state and conservation practice. The RRI is the additional percentage of the Soil Rental Rate (SRR) added to the original SRR. Typical values range from 10% to 20%.

Total Establishment Costs (Alternative Practice Only)

- The total cost ($) to establish the alternative practice.

Total Maintenance Cost (Alternative Practice Only)

- The total cost ($) to maintain the alternative practice.

Total Profit (Alternative Practice Only)

- The net profit ($) of the alternative practice.

Under a wellhead protection area?

- For CP-1, CP-2, CP-3, CP-3A, CP-4B, CP-4D only. Check this box if your field is under a wellhead protection area. If this is the case, an extra 10% RRI is added to the soil rental rate.

Generate profit surface raster?

- Check this box to generate a raster layer depicting profitability under original row crop production and profitability with a CRP practice. If the box is left unchecked no layers will be output into the ArcMap's table of contents. Only a profitability shapefile will be created.

Raster cell size (meters)

- The cell size used for all raster analysis processes. If no cell size is specified, Arcmap will use a default cell size which is calculated based off the yield data being interpolated.

Extent Shapefile

- Only an option for certain practices. Enter an existing shapefile that defines the extent of the practice. If none exists manually draw the extent in the Extent Polygon parameter.

Extent Polygon

- Only an option for certain practices. Click the colored squared to draw your own polygon defining the spatial extent of the CRP practice. The tool will result in an error message if no polygon is created for a practice that requires one.

CRP Practices

The conservation goal, practice requirements, economic incentives, and spatial eligibility of each practice will be discussed. Information is subject to change with future Farm Bills. CP-6 Diversion, CP-26 Sediment Control Structure, and CP-34 Flood Control Structure were inapplicable to this tool and thus not considered.

CP-1: Introduced Grass and Legume Establishment
- Establishes non-native grasses
- Prevents soil loss, create wildlife habitat, improves water quality, sequesters carbon
- 10 years of annual rental payments
- 10% Rental Rate Incentive if enrolled under a wellhead protection area
- Payments covering up to 90% of the eligible costs of establishing practice
    - 50% from Cost Share Program
    - 40% from a Practice Incentive Payment (PIP)
- Mid-Contract Management Cost Share
- Whole field practice

CP-2: Native Grass, Forb, and Legume Establishment
- Establishes native grasses
- 10 years of annual rental payments
- 10% Rental Rate Incentive if enrolled in a wellhead protection area
- Payments covering up to 90% of the eligible costs of establishing practice
    - 50% from Cost Share Program
    - 40% from a Practice Incentive Payment (PIP)
- Mid-Contract Management Cost Share
- Whole field practice

CP-3: Tree Plantings
- Softwood tree plantings to benefit soil and water quality, income from timber after practice expires
- 10 years of annual rental payments
- 10% Rental Rate Incentive if enrolled in a wellhead protection area
- Payments covering up to 90% of the eligible costs of establishing practice
    - 50% from Cost Share Program
    - 40% from a Practice Incentive Payment (PIP)
- Mid-Contract Management Cost Share
- Cost share is approved to plant native grass and/or shrubs within the 10 to 20 percent openings
- Whole field practice

CP-3A: Hardwood Tree Planting
- Hardwood tree plantings to benefit soil and water quality, income from timber after practice expires
- 10 years of annual rental payments
- 10% Rental Rate Incentive if enrolled in a wellhead protection area

- Payments covering up to 90% of the eligible costs of establishing practice
    - 50% from Cost Share Program
    - 40% from a Practice Incentive Payment (PIP)
- Mid-Contract Management Cost Share
- Cost share is approved to plant native grass and/or shrubs within the 10 to 20 percent openings
- Whole field practice

CP-4B: Wildlife Habitat Corridors
- Vegetation that provides shelter and travel paths for a variety of wildlife
- 10 or 15 years of annual rental payments
- 10% Rental Rate Incentive if enrolled in a wellhead protection area
- Payments covering up to 90% of the eligible costs of establishing practice
    - 50% from Cost Share Program
    - 40% from a Practice Incentive Payment (PIP)
- Must be at least 66 feet wide in linear strips

CP-4D: Permanent Wildlife Habitat
- Food source and cover for a variety of wildlife
- 10 years of annual rental payments
- 10% Rental Rate Incentive if enrolled in a wellhead protection area
- Payments covering up to 90% of the eligible costs of establishing practice
    - 50% from Cost Share Program
    - 40% from a Practice Incentive Payment (PIP)
- Mid-Contract Management Cost Share
- Whole field practice

CP-5A: Field Windbreak Establishment
- Protect crops from wind erosion and adding protection to crops, livestock, and homesteads
- Important wildlife habitat
- Sign-up Incentive (SIP) 32.5% of the rental payment
- 10 or 15 years of annual rental payments
- 20% Rental Rate Incentive
- Maintenance Rate Incentive
- Land needs to be suitable for planting trees
- The maximum width of field windbreaks will be the minimum needed to reduce cropland erosion
- The windbreak will be oriented perpendicular to the troublesome winds

CP-8A: Grass Waterway
- Designed to move water across a field minimizing erosion and reducing the delivery of sediment to lakes, streams, and rivers
- 10 years of annual rental payments with an additional 20% Rental Rate Incentive
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Cannot exceed a maximum width of 100 feet

- The width of the grassed waterway depends upon several factors including the slope of the field, the soil type, the drainage area, and the conservation practices used in the field.

CP-9: Shallow Water Areas for Wildlife

- Establishes wetlands with a depth of 6-18 inches, not a pond or wetland
- 10 years of annual rental payments
- An upland buffer at least 20 feet wide, and up to 120 feet wide, is required to protect water quality and provide wildlife habitat
- The total acreage including buffers can't exceed 10 acres per tract

CP-12 Wildlife Food Plot

- Provide food for winter wildlife
- 10 or 15 years of annual rental payments
- May be in conjunction with the following practices only CP-1, CP-2, CP-3, CP-3A, CP-4D, and CP-25
- Cannot exceed 5 acres
- Can be relocated each year

CP-15A: Grass Contour Strip

- Permanent strips of vegetative cover located on cropland and follow natural contours
- 10 years of annual rental payments
- Payments covering up to 90% of the eligible costs of establishing the grass practice
    - 50% from the Cost-Share Payment and
    - 40% from the Practice Incentive Payment (PIP)

CP-16A Shelterbelt Establishment

- Planting rows of trees and shrubs on the edges of cropland, landowners and farmers create a natural wind barrier
- 10 or 15 year annual payments
- Payments covering up to 90% of the eligible costs of establishing the grass practice
    - 50% from the Cost-Share Payment and
    - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Maintenance Rate Incentive

CP-17A Living Snow Fences

- Planting rows of trees or shrubs on cropland to reduce the damaging impacts of snowdrift
- Oriented perpendicular to prevailing winds
- Must have at least a minimum of 3 rows or plants with at least 2 of the rows in conifers
- 10 or 15 years of annual rental payments
- 90% of the eligible costs of establishment
    - 50% cost share
    - 40% PIP
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Maintenance Rate Incentive
- Mid-Contract Management Cost Share

CP-18B: Salinity Reducing Vegetation Establishment

- Establishing a vegetative cover made up of salt tolerant grasses to lower shallow water table to prevent salt accumulation
- 10 years of annual rental payment
- Payments covering up to 90% of the eligible costs of establishing the grass practice
  - 50% from the Cost-Share Payment and
  - 40% from the Practice Incentive Payment (PIP)
- Mid-Contract Management Cost Share
- Land must be in saline seep and recharge area

CP-21: Filter Strip

- Grass filter strips planted adjacent to perennial and seasonal streams, wetlands, lakes, and ponds
- 10 or 15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the grass practice
  - 50% from the Cost-Share Payment and
  - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Maintenance Rate Incentive
- Mid-Contract Management Cost Share
- The buffer will be a minimum of 20 feet from the edge of the eligible body of water, and a maximum of 120 feet from the edge of the eligible water body

CP-22: Riparian Buffers

- A strip of tress bordering perennial or seasonal streams, water bodies or wetland
- 10 or 15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the grass practice
  - 50% from the Cost-Share Payment and
  - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Maintenance Rate Incentive
- Mid-Contract Management Cost Share
- Buffer shall not be less than 35 feet and not more than 100 feet

CP-23: Wetland Restoration (Floodplain)

- Restoring former or creating new wetlands that have been converted from agricultural use
- 10 or 15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the grass practice
  - 50% from the Cost-Share Payment and
  - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Maintenance Rate Incentive
- Mid-Contract Management Cost Share
- Musts be located within the 100-year floodplain of a permanent river or stream
- The buffer size cannot be more than 3 times the size of the wetland

CP-23A: Non-Floodplain Wetland Restoration

- Restoring former or creating new wetlands that have been converted from agricultural use
- 10 or 15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the grass practice
    - 50% from the Cost-Share Payment and
    - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Maintenance Rate Incentive
- Mid-Contract Management Cost Share
- Must be outside the 100-year floodplain of a permanent river or stream
- The ratio of buffer to wetland will not exceed 4 to 1

CP-24: Cross Wind Trap Strips

- Areas of herbaceous cover resistant to wind erosion, established in one or more strips across fields and perpendicular to the prevailing wind erosion direction
- The minimum strip width is 15 feet, maximum is 25 feet
- No more than 10% of the field can be enrolled as cross wind trap strips

CP-25: Rare and Declining Habitat

- Restores and protects critically endangered and threatened habitat and ecosystems
- 10 or 15 years of annual rental payments
- Cost-Share payments covering up to 50% of the eligible costs of establishing the habitat restoration practice
- Mid-contract management Cost Share
- Whole Field

CP-27: Farmable Wetland (Wetland) and CP-28: Farmable Wetland (Buffers)

- Retire chronically wet cropland to restore to original wetlands
- Must enroll with CP-28 (Buffers)
- 10 or 15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the wetland restoration practice
    - 50% from the Cost-Share Payment
    - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Mid-Contract Management Cost Share
- Wetland size should not exceed 40 acres
- Maximum size of the associated buffer shall not exceed 4 times the size of the wetland

CP-29: Wildlife Habitat Buffer (Marginal Pasture)

- Buffers for marginal pastureland adjacent to streams, wetlands, and other water bodies
- 10 or 15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the wetland restoration practice
    - 50% from the Cost-Share Payment
    - 40% from the Practice Incentive Payment (PIP)

- Sign-up Incentive (SIP) 32.5% of the rental payment
- Mid-Contract Management Cost Share
- Maintenance Rate Incentive
- Buffer will not be less than 20 feet and not more than 120 feet in width

CP-30: Wetland Buffer (Marginal Pasture)
- Buffers for marginal pastureland adjacent to streams, wetlands, and other water bodies
- 10 or 15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the wetland restoration practice
    - 50% from the Cost-Share Payment
    - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Mid-Contract Management Cost Share
- Maintenance Rate Incentive
- Buffer will not be less than 20 feet and not more than 120 feet in width

CP-31: Bottomland Hardwood Tree Establishment
- Bottomland hardwood tree forests on wetlands
- 10 or 15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the wetland restoration practice
    - 50% from the Cost-Share Payment
    - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Mid-Contract Management Cost Share
- State Acreage Cap

CP-33: Upland Bird Habitat Buffer
- Fields edge buffers for upland bird habitat
- 10 years of annual rent payments
- Payments covering up to 90% of the eligible costs of establishing the wetland restoration practice
    - 50% from the Cost-Share Payment
    - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Mid-Contract Management Cost Share
- 30-120 foot buffers around crop fields

CP-36: Longleaf Pine Establishment
- Restoring and managing longleaf pine forests from cropland
- 10 or 15 years of annual rental payments
- Payments covering up to 90% of the eligible costs of establishing the wetland restoration practice
    - 50% from the Cost-Share Payment
    - 40% from the Practice Incentive Payment (PIP)

- Sign-up Incentive (SIP) 32.5% of the rental payment
- Mid-Contract Management Cost Share
- Whole Field

CP-37: Duck Nesting Habitat

- Wetlands for duck nesting and habitat
- Eligible only for certain counties in Iowa, Minnesota, Montana, North Dakota, and South Dakota
- 10 or 15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the wetland restoration practice
    - 50% from the Cost-Share Payment
    - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Mid-Contract Management Cost Share
- Located outside of the 100-year floodplain
- A protective grassland buffer around the wetland shall be enrolled with a minimum of 4:1 and maximum of 10:1 ratio

CP-38: State Acres for Wildlife Enhancement

- Only certain eligible geographic areas
- 10 or 15-year contract
- Incentives and cost sharing programs (Vary State to State)
- Will pay up to 90% of establishment costs
- SAFE program gives acreage allocation
- Sign-up Incentive (SIP) 32.5% of the rental payment

CP-39: Farmable Wetland Program (Constructed Wetland)

- 10 or 15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the wetland restoration practice
    - 50% from the Cost-Share Payment
    - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Mid-Contract Management Cost Share
- At least 25% of the offered land's upstream watershed must be row cropped
- The size of the wetland plus associated buffer cannot exceed 40 acres
- The maximum size of the associated buffer cannot exceed 4 times the size of the wetland

CP-40: Farmable Wetland Program (Aquaculture Wetland)

- 10 or 15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the wetland restoration practice
    - 50% from the Cost-Share Payment
    - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment

- Mid-Contract Management Cost Share
- Constructed wetland must be devoted to commercial pond-raised aquaculture in any one of the past five years
- Enrolled land cannot exceed:
    - 40 acres for wetlands or constructed wetlands
    - 20 acres for intermittently flooded prairie wetlands
    - 40 acres per tract for eligible wetlands and buffers

CP-41: Farmable Wetland Program (Flooded Prairie Wetland)

- 10 or 15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the wetland restoration practice
    - 50% from the Cost-Share Payment
    - 40% from the Practice Incentive Payment (PIP)
- Sign-up Incentive (SIP) 32.5% of the rental payment
- Mid-Contract Management Cost Share
- Constructed wetland must be devoted to commercial pond-raised aquaculture in any one of the past five years
- Enrolled land cannot exceed:
    - 40 acres for wetlands or constructed wetlands
    - 20 acres for intermittently flooded prairie wetlands
    - 40 acres per tract for eligible wetlands and buffers

CP-42: Pollinator Habitat Establishment

- 10 years of annual rental payments
- Payment covering 50% of the eligible costs of establishing the pollinator practice
- Sign-up Incentive (SIP) 32.5% of the rental payment if enrolled in continuous sign-up
- 50% Cost Share Payment for mid-contract management
- Can be planted anywhere in the field
- Habitat areas must be at least .5 acres each
- Strip planting must be a least 20 feet wide
- Additional technical requirements

Glossary

CLU
Common Land Unit. A geospatial layer delineating field boundaries that can be acquired from a Farm Service Agency (FSA) office.

CRP
Conservation Reserve Program.

EQIP
Environmental Quality Insurance Program. A program administered by the NRCS that provides financial resources and one on one planning assistance to implement conservation practices. This includes a wide variety of practices that is geared towards working farms, ranches, and forests.

MRI
Maintenance Rate Incentive. Some practices provide financial assistance to maintain a practice through the life of its contract. It is calculated in dollars per acre per year and can range from $2 to $7.

NHD
National Hydrological Dataset. Includes wetland, river, and stream shapefiles. Needed for CP-21, CP-22, CP-29, and CP-30. Instructions for downloading this data are in the Downloading Data section.

NRCS
Natural Resources Conservation Service. An agency of the Department of Agriculture that provides technical assistance to farmers and other private landowners.

RRI
Rental Rate Incentive. The extra percentage added on the SRR for some practices. Normally between 10% and 20%.

SIP
Sign-up Incentive. Some practices include extra money per acre as a sign-up bonus. The SIP for all continuous practices is 32.5% of the rental rate.

State Plane Coordinate System
A set of 124 geographic zones designed for specific regions of the US. Each state normally contains more than one state plane zone. The map of zones is seen below in Figure 39.

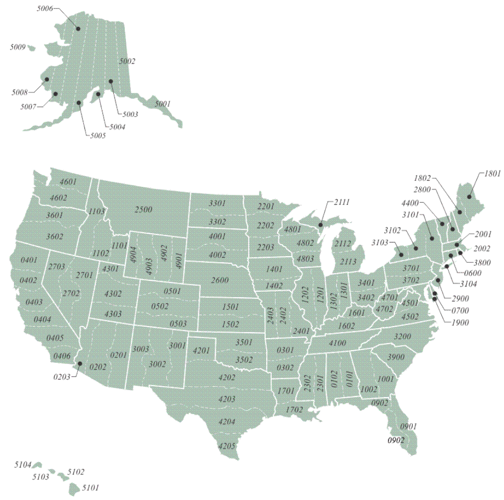


Figure 39: Map of State Planes

SRR
Soil Rental Rate. The rental rate excluding incentives. The SRR of each practice is the county's average SRR.

UTM Zone
Universal Transverse Mercator conformal projection. A commonly used coordinate system broken into various zones. The zones are seen below in Figure 40.

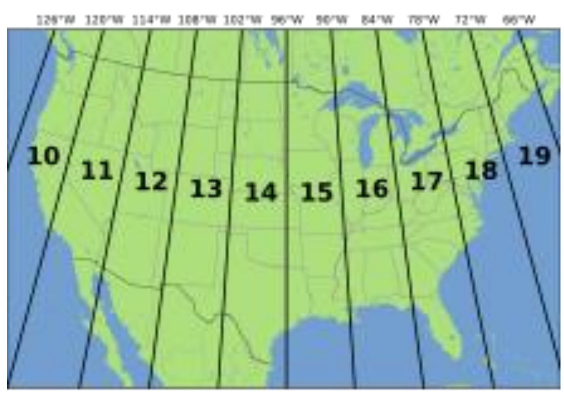


Figure 40: Map of UTM Zones

Wellhead Protection Area
A surface and subsurface area regulated to prevent the contamination of a public water system.

WGS 84
World Geodetic System. An earth-centered reference system and geodetic datum. This geographic coordinate system is commonly used for coordinate points. Most yield data come in this coordinate system. Your field boundary shapefile should **not** be in this coordinate system.

WRP
Wetland Reserve Program. A voluntary program administered by the NRCS offering landowners the opportunity to protect, restore, and enhance wetlands on their property.