Improving Agricultural Nitrogen use through Policy Incentivized Management Strategies: Precision Agriculture on the Palouse

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Water Resources

in the

College of Graduate Studies

University of Idaho

by

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July 2015

Authorization to Submit Thesis

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Abstract

Nutrient Management Plans (NMPs) incentivize precision fertilizer practices to address nitrogen loss issues, though their efficacy in the Palouse Region is unexplored. We used the CropSyst-Microbasin model to assess biophysical outcomes of precision fertilizer management. The model captures field-scale spatial and temporal differences in soil water retention and spatial variation in crop yield. We found a 21 kg reduction of N loss under precision management on a 10.9 hectare field. With improvements in crop growth algorithms under excess nutrient conditions, the model will be a useful tool for practical application. Precision practices are not common on the Palouse, thus, we also addressed barriers to adoption. We found that precision is profitable in the short term with assistance from NMPs and continues to be profitable after incentives cease. To overcome non-financial adoption barriers, NMPs should be reprioritized in relation to soil tillage programs, and should be supplemented with peer-to-peer outreach.

Acknowledgements

This work would not have been possible without assistance from numerous people. First and foremost, I have endless gratitude for my advisor Dr. Erin Brooks: for his ability to never stop asking great scientific questions; for his willingness to examine my data for hours on end when he has a million other things he needs to do; for his excitement to actually get out in the field and get his hands dirty; and for putting up with me, a river ecologist from Minnesota that arrived as a naïve graduate student with essentially no working knowledge of the Palouse, wheat farming, or upland hydrologic processes. I have learned so much from Erin about hydrology, soil physics, modeling, and science that I will carry with me for the rest of my career. For all of that, I cannot thank him enough.

My lab-mate Matt Yourek deserves most of the credit for Chapter 3. I would not have been able to move forward with the CropSyst-Microbasin modeling so quickly if it were not for him cleaning, organizing, and correcting our observed field data. He needed much of the same data for his own SMR modeling work, and after spending countless hours, days, weeks (maybe even months), he passed on the data to me in an easy-to-digest, clean form. There is no way I would be graduating right now without this wonderful work from Matt. I am forever grateful for Matt's Excel spreadsheet wizardry.

Dr. Kathleen Painter and her master's student, Hilary Davis, were instrumental in developing Chapter 4. The analysis done within Chapter 4 would not have been possible without access to their massive, detailed economic dataset. They provided excellent socio-economic guidance and perspective for my work. They were also so patient with my complete lack of social or economic training. Finally, they deserve additional thanks for being inspiring strong women in a male-dominated field. Thank you Kate and Hilary.

Thank you, thank you, thank you Fidel Maureira and Dr. Claudio Stöckle for your CropSyst-Microbasin expertise. I cannot even begin to count the questions I sent to Fidel over the last year as I learned to use CropSyst-Microbasin. Fidel was also very helpful in adjusting the model and the outputs to fix issues and provide more specific

information needed to answer my research questions. Thank you, Fidel, for your patience and support.

Thank you Dr. Jerry Long for providing a unique “outsider” perspective. I fully admire your view on what “interdisciplinary” research means and I strive to attain that level of understanding someday. In the meantime, I need more specific disciplinary knowledge before I can hope to bring disciplines together in a meaningful way. Thank you for providing unique insights to my research and for challenging me to think at a deeper level. Your Cronon-esque, though distinctively Long worldview is precisely the influence I needed in Idaho.

Thank you Spencer Plumb and Susie Irizarry for helping me to *start* to understand the social sciences. Thanks to the growers of the Palouse for allowing us to take countless measurements on their fields and interrogate them about their farming practices and annual budgets. Thanks to the ghosts of the Brooks lab past, so many people have come and gone contributing data to the greater good. Thank you to Audrey Squires for editing and writing advice. Thanks to other SCF researchers for contributions, advice, and general cheer: Dr. Dave Huggins, Dr. Dave Brown, Dr. Jan Eitel, Dr. Lee Vierling, Dr. Caley Gasch, Dr. Matteo Poggio, Dr. Troy Magney, and Sam Finch, J.D. Thanks to REACCH researchers for your various contributions of data and advice: Dr. Kristy Borrelli, Dr. Leigh Bernacchi, and Chad Kruger. Thank you to the local NRCS folks who so graciously answered my questions on Nutrient Management Plans, most notably Chris Johnson from the Moscow NRCS office.

Dedication

I dedicate this thesis to my loved ones that passed away while I was working toward my Master's degree. In a short 13 months, I lost two dear aunts, Irene Rygh and Cindy Morgan, and a long-time friend, Tim Rasmusson. They each lived uniquely inspiring lives and impacted me in ways they never knew. In their absence, they remind me to be truly thankful for time spent with friends and family, for professional and personal opportunities that arise, and for each and every day I live on this earth—whether the day is spent recreating in gorgeous Idaho, sitting on my computer "slaying the keys" in JML, or working in the wheat fields of the Palouse.

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Chapter 1. Introduction

The Nitrogen Problem

Some say we have entered a new geological epoch called the "Anthropocene" as a result of large magnitude, human-induced environmental changes worldwide (Crutzen, 2002). Both the land and oceans are now highly modified as a result of human resource extraction, food cultivation, and population growth (Lubchenco, 1998). These stressors have changed the major biogeochemical cycles of water, nitrogen, and carbon (Vitousek et al., 1997). Global changes to the nitrogen cycle are primarily due to the production and use of synthetic nitrogen fertilizers for agricultural production (Rockström et al., 2009). Since nitrogen is a necessary and often limiting nutrient for plant growth, the application of nitrogen fertilizers is a quick-fix to increase crop yields, but with 38% of the land in the world under agricultural production, its use has significant global impacts (World Bank, 2014). Scientists are documenting major environmental harm and coupled economic costs as a result of changes in the global nitrogen cycle, the full extent of which is likely yet to be realized (Vitousek et al., 1997).

The single largest change to the way nitrogen has been used in agriculture came with the development of the Haber-Bosch process in 1909, which provided the scientific understanding to mass produce synthetic nitrogen fertilizers. However, the US lacked the necessary infrastructure to make mass production an immediate reality. During the 1930s Dust Bowl, U.S. agriculture struggled with extended drought, unprecedented erosion, and low productivity. In the post-WWII boom years, available infrastructure made mass production of nitrogen fertilizers a reality and proved to be a saving grace to make up for soil deficiencies and produce high yields (Duffin, 2007). Primarily through the industrial production of synthetic fertilizers via the Haber-Bosch process, humans fix more nitrogen than all natural sources across the globe (Gruber & Galloway, 2008; Rockström et al., 2009; Vitousek et al., 1997).

Nitrogen fertilizers are widely used in agricultural production and are often applied in the absence of best management practices (Schillinger et al., 2003). Approximately 65% of the US cropland where nitrogen fertilizers were applied in 2006 lacked basic nutrient best management practices such as appropriate rate, method, and timing (Ribaudo et al., 2011b). Wheat production is second only to corn as the highest number of US acres treated with nitrogen fertilizers in the absence of best management practices of rate, timing, and method of fertilizer application.

Nitrogen fertilizers are usually over-applied on agricultural fields, resulting in excess nitrogen entering the environment and a disruption of nitrogen cycling in the field. Excessive nitrogen fertilizer application tends to suppress the natural nitrogen cycling of the soil and decrease the biologically active pools of nitrogen, furthering the need for additional nitrogen fertilizers (McCarty & Meisinger, 1997). In general, growers take a "safety-net" approach to nitrogen management, applying the maximum amount the field will need under the assumption that all other factors (precipitation, temperature, etc.) will be ideal (Ribaudo et al., 2011b). For example, if a given field of wheat usually uses 70 lb per acre of nitrogen fertilizer in an *average* year, then under *optimal* conditions for precipitation, temperature, disease, etc., the same field *could* use 90 lb per acre of nitrogen fertilizer. Since nitrogen application is one of the only factors that growers can control, they will tend to apply it as if it will be an *optimal* year every year. However, most years are not optimal, meaning that the crop does not have the proper water, temperature, etc. to be able to use all of the nitrogen fertilizer, resulting in even larger nitrogen losses to the environment (Ribaudo et al., 2011b).

Agricultural land is the primary source of reactive nitrogen into the environment (Ribaudo et al., 2011b). Farm management decisions including tillage operations and crop rotations have a major impact on the cycling of nitrogen within a field and the resultant transport of nitrogen into the surrounding environment. In cereal cropping systems, the organic nitrogen pool in the soil depends on the crop residue and tillage management practiced on a particular field. Nationally, agricultural soil management contributes 75% of nitrous oxide (N_2O, a powerful greenhouse gas) emissions and 54% of nitrate (NO_3^-) losses (US EPA, 2014; Ribaudo et al., 2011b).

Possible pathways for nitrogen loss from a farm field are through soil erosion, surface runoff, leaching, and volatilization. Volatilization is increased when organic or inorganic fertilizers are applied to the surface of the field and not immediately incorporated into the soil (Fox et al., 1996; Hutchinson et al., 1982). Runoff losses occur when fertilizers are applied on the surface and rain moves the nitrogen off the field before it has been incorporated into the soil, or when soil containing nitrogen is lost from a field and is suspended in the runoff (Duffin, 2007; Ribaudo et al., 2011b). Since nitrate is easily dissolved, downward water movement through the soil profile can result in high nitrate leaching (Ribaudo et al., 2011b). As the water and nitrate moves downward in the soil profile, it may end up in nearby surface waters in the presence of tile drain networks or lateral flow pathways. Nitrate leaching to tile drains may be the chief nitrogen loss pathway from crop soil to surface water (Ribaudo et al., 2011b).

Nationally, nitrogen additions to waterways are a major source of environmental harm. High levels of nitrate are toxic to humans; the allowable concentration for drinking water sources has been set at 10 ppm (Killpack & Buchholz, 2014). Excess nitrogen in waterways can cause eutrophication, toxic algal blooms, and anoxic conditions that make waters unsuitable for primary contact and negatively impact wildlife habitat, resulting in widespread biodiversity losses (Ribaudo et al., 2011b). For example, the dead zone in the Gulf of Mexico is largely attributed to nitrogen losses from the Corn Belt and greater Mississippi River Basin (Dodds, 2006).

Excess nitrogen application also contributes to climate change through the production of nitrous oxide (N_2O), a greenhouse gas which is roughly 300 times more potent than carbon dioxide (CO_2) per unit mass (US EPA, 2008). The majority of global nitrous oxide emissions are due to agriculture, and nitrous oxide is currently the main atmospheric pollutant responsible for ozone depletion (Ravishankara, Daniel, & Portmann, 2009). This further contributes to environmental decline through ozone-induced damages to crops, forests, and ecosystems (Ribaudo et al., 2011b).

Nitrogen losses from agricultural fields also have financial costs on farmers and those living nearby or downstream, though national estimates of the overall economic cost of nitrogen losses from agricultural land are lacking (Ribaudo et al., 2011b). If U.S. farmers were able to apply the precise amount of nitrogen that crops need without losing fertilizer to the environment, they would save $2.5 billion per year--in other words, an excess $2.5 billion dollars' worth of fertilizer is applied each year (Unnevehr et al., 2003). A review paper found that household willingness to pay to protect drinking water from nitrate contamination ranges from $43 - $169 per year (Crutchfield et al., 1995). The cost of eliminating nitrogen from all U.S. drinking water supplies is estimated at over $4.8 billion per year, with the amount due to agriculture estimated at $1.7 billion per year (Ribaudo et al., 2011b).

In summary, agricultural nitrogen management is a major factor in global nitrogen cycling. Agricultural producers around the globe use mass-produced synthetic nitrogen fertilizers to make up for the nutrient deficiencies that burden many cropping systems. These fertilizers are often used in the absence of best management timing, method, and rate information, resulting in an even greater excess of nitrogen entering the surrounding environment. Excess nitrogen degrades ecosystems and is an economic burden to society, and nitrogen fertilizers are a major cost to agricultural producers. Nitrogen management is an issue globally, but for the purpose of this study will be scaled locally.

Study Region

The Palouse Region is one of the world’s main dryland wheat producing regions (WWC, 2009). It is located in eastern Washington and the western Idaho panhandle. The region boasts some of the most fertile soils in the world, which were transported on prevailing southwesterly winds over 10,000 years ago (Duffin, 2007; WWC, 2009). The windblown soil created topography reminiscent of sand dunes, though these “dunes,” or Palouse hills, are comprised primarily of silt loam. The soil originated from Mount St. Helens in the west; the coarser, heavier particles were deposited in the western Palouse, and the finer, lighter particles deposited in the eastern portions of the region (Busacca et al., 1992). There is an elevation, precipitation, and soil gradient from west to east on the Palouse, with Haploxerolls in the lower elevation, drier, western portion of the region and Fragixeralfs in the higher elevation, wetter, eastern portion of the region (Brooks et al., 2012).

In addition to variability across the region, there is increased variability at the hillslope scale. Palouse hill ridge tops generally follow a southeast-northwest line, with longer, shallower southwest facing slopes (up to 35% slope steepness) and shorter, steeper northeast facing slopes (45-55% slope steepness). Each Palouse hill is roughly 100 to 200 feet high, with high variability in effective precipitation and solar radiation between low and high elevation locations and the north versus south facing slopes (Brooks et al., 2012).

Dryland farming is practiced on the Palouse, which is an agricultural management regime that uses no irrigation inputs. While the Palouse receives roughly 70% of its annual precipitation during the winter months, when crops are not growing (Brooks et al., 2012), the high water holding capacity of the fine loess soil is able to carry the crops through the growing season on water stored from the winter and spring months with no need for irrigation. In the eastern, high precipitation zone, crops are grown annually and the land is usually managed in a 3-year rotation of winter wheat, spring wheat, and a legume. Common crops in the region include barley, wheat, lentils, garbanzo beans, canola, and mustard (Schillinger et al., 2003). The specific varieties and species used in the rotation are dependent on market prices, environmental conditions, and farm policy. The use of legumes in the cropping rotation fixes soil nitrogen, but local farmers still rely heavily on inorganic nitrogen fertilizer inputs for non-legume production as the nitrogen needs of the high-yielding cereal crops cannot be met by legume nitrogen fixation alone.

The study site is located on the eastern side of the Palouse, in the high precipitation zone. The soils around the study site have well-developed argillic or fragipan layers, which were formed through leaching processes as a result of the high annual precipitation (Brooks et al., 2012). The dense argillic and fragipan layers (bulk densities of roughly 1.65Mg m^{-3}) restrict water flow, promoting perched water tables and lateral flow (Brooks et al., 2012), which may influence the redistribution of nitrogen after it is applied.

With the region's spatial gradient and high hillslope heterogeneity, nitrogen needs vary widely depending on location within the region and specific slope position in a field. In the western low precipitation zone, earlier drying of the surface soil results in less surface root activity and less nitrogen uptake. With less rainfall in the western zone (and less overall water movement), nitrate is less likely to be lost due to leaching, generally remaining in the soil until the next growing season. In the eastern high precipitation zone, N leaching is a much greater concern since more water is moving through the soil, carrying the nitrate with it (Pan et al., 2006). Uniformly high fertilizer applications on the Palouse result in over application on many parts of the field.

The Palouse Region is an ideal place to study agricultural nitrogen management issues. The region's world record wheat yields depend heavily on synthetic nitrogen fertilizers. The environmental condition of the region has been impacted by nitrogen losses from the agricultural fields: commercial fertilizers were estimated to contribute 87% of the total nitrogen in the Palouse River in 1994 (Puckett, 1994). The region also experiences the financial burden of nitrogen use since nitrogen is the single greatest variable input cost to Palouse growers per unit area (Kate Painter, pers. comm., March 2014). The region- and field-scale variability makes for a unique landscape to manage agricultural nitrogen losses.

Potential Solution for the Palouse

The Farm Bill has voluntary conservation cost-share programs set up to subsidize the implementation of conservation practices, including improvements to nitrogen fertilizer management (NRCS, 2014). Two of the current programs are the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP) (USDA, 2014). Within the EQIP and CSP programs, financial incentives are available to farmers that implement new nutrient management techniques such as precision fertilizer application as a part of a Nutrient Management Plan (NMP).

The incentivized practice of precision fertilizer application falls under the larger suite of management practices referred to as "precision agriculture." Precision agriculture arose in recognition of the variability in physical factors and crop needs within a field. It is defined as "managing each crop production input – fertilizer, limestone, herbicide, insecticide, seed, etc., on a site-specific basis to reduce waste, increase profits, and improve the quality of the environment (Morgan & Ess, 1997)."

Precision fertilizer application (also called "variable rate" or "site-specific") has particular promise in the heterogeneous Palouse landscape. Yields can vary widely within a Palouse wheat field (Figure 1). The yield patterns generally follow topographical and soil type differences, though the precise mechanisms driving the field scale variability are not fully understood. The field-scale variability can be seen during senescence of the wheat crops in mid to late summer, because the drier areas of the field tend to senesce earlier than the low-lying wetter areas (Figure 2).

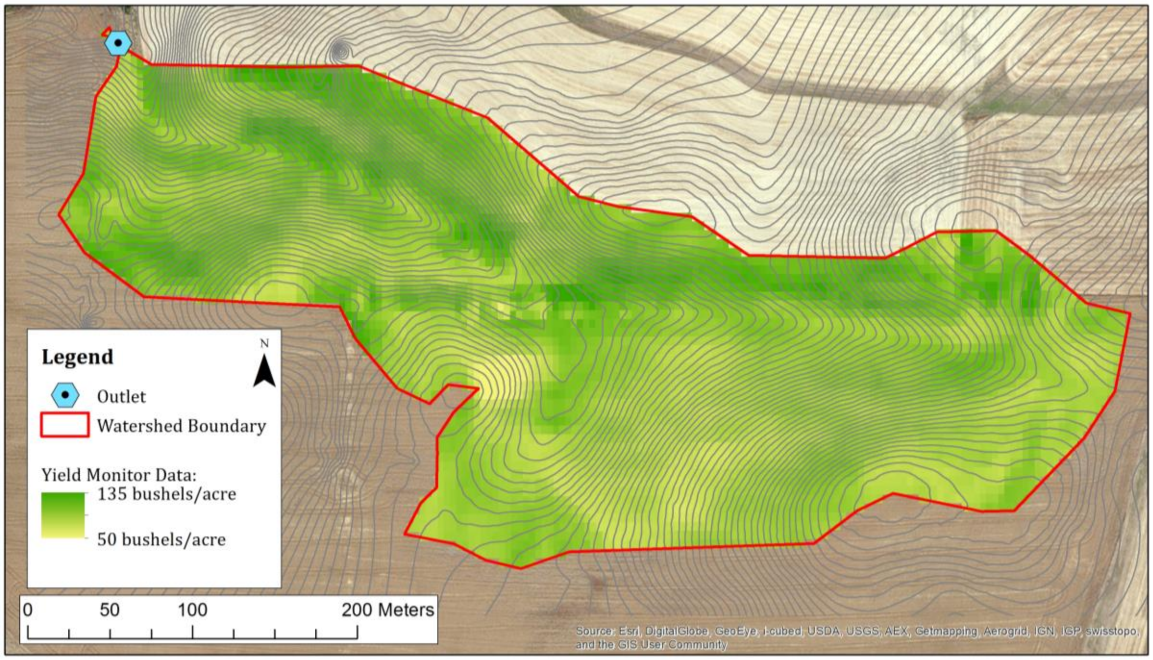
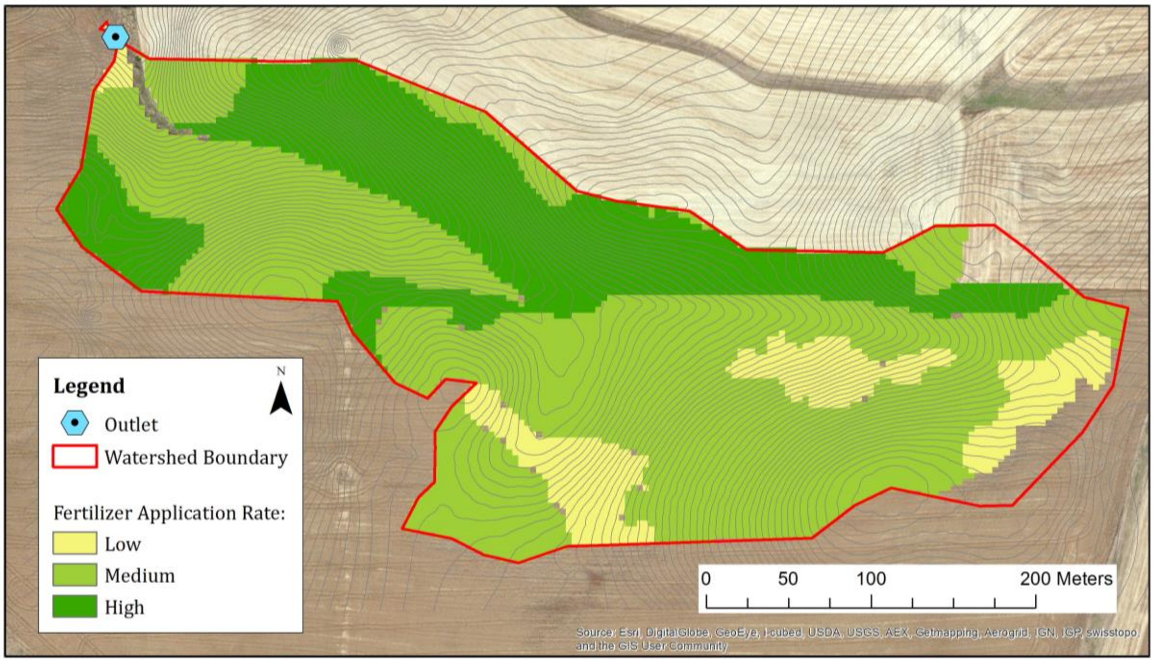


Figure 1. Yield variation across a field.

Figure 2. Varying rate of crop senescence in a Palouse wheat field.

Precision fertilizer application involves applying a varying rate of fertilizer across a field according to varying crop yield potential. Under precision management, the low yielding areas of the field receive less fertilizer than the high yielding areas (see example from study site in Figure 3, a variable rate fertilizer map based on the yields observed in Figure 1). The result is a lower total amount of applied fertilizer while maintaining yield, a win-win for growers and the environment. In the highly heterogeneous Palouse, variable rate fertilizer application has the potential to significantly decrease nitrogen inputs, while lowering fertilizer costs to the grower and decreasing nitrogen loss to the environment.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 3. Variable rate fertilizer zones at the study site.

Advanced technologies have made precision fertilizer application easier to implement than when it was first introduced several decades ago, but there are still significant financial and technical barriers to its widespread adoption. New technologies such as GPS guided tractors, improved yield monitors, and variable rate application controls have made variable rate fertilizer application very effective in actually targeting different yield goals across a field (Huggins, 2010). These new and advanced pieces of equipment mean that start-up costs for precision farming can be quite high. Also, to successfully apply a variable rate of fertilizer, the grower must understand field scale variability in crop yield potential, nitrogen availability, and nitrogen uptake (Huggins, 2010). Then the grower must decide how many management zones the field should be broken into and what rate of fertilizer each zone should receive in order to increase nitrogen use efficiency and maximize profits. When deciding the exact rate of fertilizer application, the grower must weigh the cost savings of lower fertilizer application with the chance of having an unusually good weather year in which the fertilizer, rather than water, may be the primary limiting nutrient. All of this requires detailed biophysical and economic information for a grower to make sound precision management decisions. These financial and information barriers to precision fertilizer adoption must be overcome in order for this potential solution to have widespread success on the Palouse.

Currently, precision fertilizer practices are not commonly used on the Palouse even though it is an outwardly promising method to maintain high agricultural yields while decreasing environmental harm from nitrogen loss. To date, there has been no local assessment of how effectively the NMPs promote adoption of precision practices and no quantification of the decreases in nitrogen loss under precision fertilizer management. The following section describes the interdisciplinary approach used in this study to assess the effectiveness of NMPs in addressing nitrogen loss issues through the promotion of precision fertilizer practices in the Palouse Region.

Interdisciplinary Approach

Improving agricultural nitrogen management on a large scale (beyond one farm) is a very complex issue. It starts with each individual farmer, working within a set of agriculture policies, and acting within the region's culture. Also, the specific management practices implemented on a farm and the agricultural policies affecting a farm may (or may not) be influenced by biophysical or social science research from a university. Thus, in order to address nitrogen management on a regional scale, all of these levels and interactions must be addressed, from the individual farmer, to the scientific understanding, to the policies written in Washington DC.

A method to approach complex problems is interdisciplinary problem solving, which is cognizant of the inextricable links between human, natural, and social systems (Repko, 2012). An interdisciplinary approach focuses on examining how components of the system interact to come up with real-world, workable solutions to complex problems. This is in contrast to multi-disciplinary work, which explores multiple components of a problem, but not necessarily how they interact, and also in contrast to strictly disciplinary work, which addresses only the components that lie within one research field. In improving agricultural nitrogen management, an interdisciplinary approach is needed because it is at the intersection of policy, sociology, economics, and biophysics that the solution will be found.

Interdisciplinary research has four main steps (Repko, 2012). The first step is to agree on the problem: nitrogen management needs to be improved. The second step is to find common ground among the representative disciplines: precision agriculture as a possible solution, which is recognized by economists, policy makers and implementers, agronomists, and water resource researchers. Step three is to write an integrating question to guide the research (see "Research Goal") and step four is to develop a unified and comprehensive plan and analysis (see "Research Objectives" and methods sections for each chapter).

Research Goal

The goal of this research is to assess the environmental effectiveness of precision nitrogen management and overcome barriers to adoption for these practices in the high precipitation zone of the Palouse. The following interdisciplinary question guided the research:

How effective are Nutrient Management Plans (NMPs) at lowering agricultural nitrogen loss through the promotion of precision fertilizer practices in the high precipitation zone of the Palouse?

Addressing whether NMPs are effective is an interdisciplinary inquiry because <u>effective</u> NMPs must <u>decrease nitrogen lost to the environment</u> (*Hydrology*) and must <u>be adopted</u> (*Social Studies & Economics*).

To understand the effectiveness of the NMP policy tool in addressing nitrogen loss through the promotion of precision fertilizer practices, we must first understand the other relevant policies impacting on-farm decisions (Chapter 2). Then we must understand the environmental (biophysical) outcomes of adopting precision practices to know if this practice is indeed effective on Palouse wheat fields (Chapter 3). If precision practices are a viable solution to the environmental issue (i.e. it actually decreases nitrogen loss and maintains high agricultural productivity), we then must address potential barriers to adoption (Chapter 4). A detailed understanding of the environmental effectiveness of precision practices and socio-economic barriers to adoption will provide insights as to how the NMP policy tool may be more effective in the future (Chapter 5).

Research Objectives

1. Quantify changes in crop yield and nitrogen loss as a result of adopting precision fertilizer practices (Chapter 3)
2. Assess financial and social barriers to adoption of precision NMPs (Chapter 4)
3. Using insights from Objective 1 & 2, evaluate the effectiveness of Nutrient Management Plans (NMPs) in lowering agricultural nitrogen loss through the promotion of precision fertilizer practices in the high precipitation zone of the Palouse (Chapter 5)

This thesis research was funded through the Site Specific Climate Friendly Farming (SCF) research grant (USDA-AFRI award number 2011-67003-30341). SCF is an interdisciplinary, multi-institutional study aimed at understanding nitrogen, carbon, and water variability at the field scale through time. Through collaboration between the University of Idaho and Washington State University researchers, SCF examines the wheat-based cropping systems of the Palouse region and focuses on developing tools to improve nitrogen and water use efficiency. The SCF project brings together specialists in soils, agronomy, remote sensing, economics, hydrology, and modeling. The driving goal of the research is to “provide growers with economically viable site-specific climate-friendly farming guidance (Brown et al., 2011).”

Chapter 2. A 2014 Farm Bill Primer: From D.C. to the Palouse

The Farm Bill programs, including conservation incentives, crop insurance offerings, and eligibility requirements significantly influence on-farm management decisions. An understanding of the limitations, boundaries, and opportunities created through these Farm Bill programs provides a needed background and insight into why a grower may or may not adopt conservation practices, such as precision fertilizer application. This chapter provides a brief history of US farm policy, outlines relevant components of the national farm bill, and describes the implementation of conservation-cost share programs. The aim of this chapter is not to generate an exhaustive examination of how farm policy impacts on-farm management decisions, but rather to provide an introduction to how farm policy is currently influencing farm management decisions.

History

The first farm bill, passed in 1933, created price support programs to carry growers through the trying times of the Great Depression and the Dust Bowl (Sumner, 2007). In 1936, conservation incentives programs were initiated to address soil erosion problems. Since the 1933 and 1936 bills were passed there have been many iterations of the farm bill, though the basic structure of the policy remains the same. In recent decades the farm bill has been revisited and modified every 5-7 years, and though there has never been an overhaul of agricultural policy in the United States, significant environmental changes occurred in 1985. This is when the soil conservation incentives were expanded to include conservation of wetlands and wildlife habitat (Becker & Womach, 2002). The 1985 bill also linked commodity payment eligibility with conservation compliance provisions. The specific soil conservation practices in the conservation compliance provisions were directly influenced by up-to-date agricultural research (Kok et al., 2009).

The most recent iteration of the farm bill was signed into law on February 7th as the Agricultural Act of 2014. The colloquial name for the bill is the Food, Farm and Jobs Bill (USDA, n.d.-d). This bill, and each of its iterations, includes policies for commodity production, conservation, nutrition, food stamps, rural development, and research. The farm bill promotes certain types of crops (corn, soybeans, wheat) over others (fruits and vegetables) through crop subsidy programs (Monke, 2008). The farm bill promotes or mandates certain types of management practices, and can alter market prices (Hecht, 2008). The next section outlines some of the relevant policies most affecting the bottom line of the farm and daily farming decisions.

Relevant Components of 2014 Bill

The components of the farm bill described below are: direct payments, commodity payments, crop insurance, and conservation cost-share programs.

Direct Payments

The 2014 farm bill eliminates direct payments (*Agricultural Act of 2014*). Direct payments were originally called "production flexibility contracts" and were written into law in 1996 (*Agricultural Market Transition Act*, 1996; Schneider, 2012). The stated purpose of these contracts was to "support farming certainty and flexibility while ensuring continued compliance with farm conservation and wetland protection requirements (*Agricultural Market Transition Act*, 1996)." The first objective, to "support farming certainty and flexibility" was addressed by de-linking subsidies with market conditions. The second objective, "compliance with farm conservation" was addressed by making conservation provisions a mandatory requirement for eligibility of payments (*Agricultural Market Transition Act*, 1996). In this way, the grower was guaranteed subsidies (payments through the production flexibility contracts) and could make current planting decisions based solely on the market prices, a concept dubbed "freedom to farm." However, this freedom to farm was limited by numerous cropping and management stipulations embedded in the "freedom" given to the grower.

Although not explicitly stated in the 1996 farm bill, many researchers, growers, and analysts interpreted the bill to have the intent of weaning growers off of government payments and transitioning the agricultural market towards a more laissez-faire system by 2002, hence the name, Agricultural Market Transition Act of 1996 (Keeney, 2011; Schneider, 2012). Most people considered the payments a temporary crutch the grower could rely on while re-aligning the crop choices on the farm with current market trends. Regardless of whether production flexibility contracts were *intended* to be phased out over the 7 years or not, they remained at a constant level for 18 years.

In the 2002 farm bill, the production flexibility contracts were maintained essentially as-is and re-labeled "direct payments." The payments were fixed for the duration of the farm bill and were extended again with the 2008 farm bill. The 2014 bill eliminated the direct payment program, bringing an end to consistent annual farm support payments. However, the new crop insurance premium subsidies will replace direct payments (described under "Crop Insurance") (Keeney, 2011).

Commodity Payments

In addition to direct payments, other types of commodity payment in previous versions of the farm bill included Counter-Cyclical Payments (CCP), Average Crop Revenue Election (ACRE) and Supplemental Revenue Assistance (SURE). These programs aim to reduce the annual variation in farm incomes, essentially as crop or price insurance for small (not catastrophic) losses. In the 2014 bill, CCP has been replaced with a very similar program called Price Loss Coverage (PLC), and ACRE has been replaced with a very similar program called Agriculture Risk Coverage (ARC). Growers now have to choose whether they will participate in PLC or ARC for the duration of this farm bill. In the past, all types of commodity payments were available to any grower with eligible crops (Fraas, 2014). PLC protects the grower from low market prices, and ARC protects growers from low market prices in combination with shallow production loss. "Shallow production loss" is when small, but not catastrophic, yield losses result in lost revenue. To trigger an ARC payment, total revenue loss must be greater than 14%, but total ARC payment will not exceed 10% of expected revenue (*Agricultural Act of 2014*).

PLC participants are also eligible for Supplemental Coverage Option (SCO) in Title XI (Crop Insurance) of the Farm Bill (described in the following section, "Crop Insurance") (*Agricultural Act of 2014*). These new commodity payment programs are directly tied to market conditions and production losses. PLC and ARC are essentially lower-end crop insurance that protect against shallow losses, generating relatively consistent farm incomes. For catastrophic losses, crop insurance programs are triggered rather than ARC, PLC, or SCO (*Agricultural Act of 2014*).

Crop Insurance

The 2014 farm bill puts much greater emphasis on crop insurance programs than previous farm bills, signifying a shift in policy toward risk management and away from price and income support (National Crop Insurance Services, n.d.). The 2014 bill expands crop insurance coverage and provides larger premium subsidies than previous bills. Part of the reason crop insurance premiums are heavily subsidized is to promote high enrollment rates. Although variations of crop insurance have been around in limited geographical regions and for limited crops since the 1930's (USDA, n.d.-c), modern crop insurance was established in the Federal Crop Insurance Act of 1980. Participation in the new crop insurance programs remained well below 50% and was often below 30% through 1993 (Glauber, 2004). Throughout this time, there were numerous years when the government passed emergency farm support legislation for un-enrolled growers impacted by droughts or floods. This emergency support essentially provided crop insurance to un-enrolled growers, providing the impetus to promote higher crop insurance participation and alleviate un-budgeted emergency government spending. In the late 80's and early 90's, political and economic analysts estimated that in order to achieve a 50% participation rate, premiums would need to be 50% subsidized. Additional premium subsidies were written into the Crop Insurance Reform Act of 1994 and again in the 2000 Agricultural Risk Protection Act. Arguably as a result of the increased subsidies, the crop insurance programs had an 80% participation rate in 2004 (Glauber, 2004).

The 2014 farm bill expands crop insurance coverage, further increases premium subsidies, and provides a new Supplemental Coverage Option (SCO). SCO essentially replaces the old ACRE commodity program; it covers shallow losses due to lower production or lower market prices. Across the various types of crop insurance, premiums are subsidized between 38 and 80% (Effland, 2014). The 2014 bill gives new growers a 10% higher premium subsidy than continuing growers (*Agricultural Act of 2014*). Limited resource, beginning, and socially disadvantaged growers receive at least a 50% discount on insurance premiums (*Agricultural Act of 2014*). Insurance subsidies are decreased by at least 50% for the first 4 years when a grower plants on virgin farmland, but this only applies to native sod acreage in Minnesota, Iowa, North Dakota, South Dakota, Montana, and Nebraska (*Agricultural Act of 2014*). The 2014 farm bill provides new crop insurance options for peanut, cotton, livestock, bioenergy crops, specialty crops, and organic growers (Effland, 2014). If a farm diversifies their crops or adds livestock to the mix, they are eligible for new opportunities for insurance and premium discounts (*Agricultural Act of 2014*).

Conservation Provisions

The 2014 farm bill links eligibility for crop insurance with conservation provision compliance (*Agricultural Act of 2014*). The farm bill has required growers to comply with conservation provisions in order to receive commodity payments since 1985, and the conservation provisions were linked with direct payments for their entire tenure from 1996 to 2014. With the elimination of the direct payment program, conservation provisions are now linked to eligibility for crop insurance.

Conservation provisions apply to fields labeled as “highly erodible land” (HEL). HEL is characterized by an erodibility index of 8 or greater. A field unit is labeled HEL if 1/3 of the field or 50 or more acres of the field are HEL. An approved and implemented conservation plan is required to farm on HEL fields (*Agricultural Act of 2014*). The conservation measures in an approved conservation plan work to reduce soil erosion to an acceptable level (USDA NRCS, 2012). A major shortcoming of the conservation provisions has been a lack of regulatory follow-through.

Prevented Planting

If a grower is unable to plant their crop at the appropriate time because of weather, at some point they will generally forgo planting the crop altogether because it will be unprofitable to do so. Crop insurance provisions typically have a cut-off date for planting after which the original policy will be invalid. In these circumstances, growers can file for an insurance payout called “Prevented Planting.” These payouts apply when weather or other adverse conditions outside of the grower’s control prevent a grower from being able to plant in the spring before the predetermined final plant date (USDA, 2013). The final plant date is calculated as the last planting date with sufficient growing season length to produce a profitable crop. The exact date cutoffs vary from county to county and crop to crop (USDA, 2013).

Growers have several options if they do not plant their crops before the cut-off planting date. These include: 1) plant the crop anyway and forgo payment or receive payment reductions; 2) leave the field fallow and receive payments under the Prevented Planting provision; 3) plant a cover crop and receive Prevented Planting payments (with various restrictions, including no haying or grazing before Nov. 1) (USDA, 2013). If the acreage is designated HEL, there must be adequate cover to prevent erosion (Aakre, 2011), however there is usually no financial incentive to do so and generally no regulatory follow-through. These options are in place in order to insure that growers will not receive a crop insurance payout as well as some benefit from another crop planted on the same field in the same crop year. If the grower did benefit from a crop on land for which they had already claimed prevented planting acres, including any financial benefit from a cover crop, it would be in violation of the Federal Crop Insurance Act of 1980.

Conservation Cost-Share

The 2014 farm bill has a few programs set up to subsidize the implementation of conservation practices, in addition to providing technical assistance. All of these programs are voluntary and designed to promote the sustainable management of farmland. The names, scope, and specific rules governing farm bill conservation programs have changed since the first conservation payments where initiated in the Soil Conservation and Domestic Allotment Act of 1936 (P.L 74-461) (Sumner, 2007). The three current programs are the Environmental Quality Incentives Program (EQIP), the Conservation Stewardship Program (CSP), and the Agricultural Management Assistance (AMA) (USDA, 2014). The programs can be used to address energy saving needs and to improve soil, water, plant, air, and wildlife habitat resources.

The AMA program is only available in 16 states that have had historically low participation in the Federal Crop Insurance Program; it is not available in Idaho or

Washington. EQIP is available to agricultural producers, owners of non-industrial private forestland, and Tribes. Generally, the program payments are made after the grower has implemented the agreed upon conservation provisions. However, socially disadvantaged growers are eligible for advance payments of up to 50% of the total payment for start-up costs such as materials and machinery needed to implement the conservation practice. Through EQIP, a grower cannot receive more than $450,000 for the five-year period from 2014 through 2018 (USDA, n.d.-b). CSP is focused on maintaining existing farm conservation practices and implementing new and improved practices. There are few eligibility requirements for CSP; essentially any grower in any state producing any crop can apply. If a grower has enrolled previously, they must agree to take on additional conservation measures in order to enroll again. They cannot simply be continuing previous actions, although the grower does get credit for maintaining such actions. Through CSP, a grower cannot receive more than $200,000 for the five-year period from 2014 through 2018 (USDA, n.d.-a).

Within the EQIP and CSP programs, financial incentives are available to growers that implement nutrient management techniques such as precision fertilizer application as a part of a Nutrient Management Plan (NMP). EQIP will provide payments ranging from $8.75 per acre to $30.72 per acre to growers that implement nutrient management techniques such as precision fertilizer application. The amount of payment is dependent on which specific techniques the grower adopts (Chris Johnson, *NRCS* pers. comm.).

Policies that improve the nitrogen use efficiency of farms while improving annual profitability have the potential to contribute to a long-term solution for nitrogen issues on the farm. Recognizing that policies influencing farm profitability while promoting conservation can provide landscape scale conservation of land and water resources on private land, as has been demonstrated through soil erosion abatement programs (Burger et al., 2006), this research incorporated an understanding of the local implementation of NMPs through the EQIP and CSP programs.

Local Implementation of Conservation Cost-Share

NMPs are a federal policy, with largely the same framework across the entire United States. Given the highly diverse agricultural landscapes of the US and the different farming that takes place across the country, these policies may work with differing levels of efficacy in different regions. To fully understand how this national farm policy affects on-farm management decisions, an understanding of the local implementation is necessary, as implementation often varies from state to state and county to county (Chad Kruger, pers. comm., July 2014). Thus far, there has been no evaluation of how the NMP policy works for growers on the Palouse.

Latah County (Idaho)

This description of the implementation of EQIP and CSP programs (and the NMPs therein) is based on multiple communications with Chris Johnson, an Idaho NRCS District Conservationist based out of the Moscow Field Office.

The EQIP and CSP programs have distinctly different purposes. The EQIP program uses a bottom-up approach by identifying a problem locally and finding grower based solutions to solve it. The decision of exactly what to implement on the field comes down to the landowner decision (with NRCS approval to fund the practice). This bottom-up approach recognizes that the policy makers in Washington DC do not know what is best for Latah County, giving the program flexibility to be implemented as local workers see fit. There are “local work groups” created through the Farm Bill to address the local implementation of EQIP. The CSP program, on the other hand, is more rigid. It was created to “pat farmers on the back” for what they are already doing (Chris Johnson, pers. comm.). It provides financial incentives for growers to maintain already implemented conservation practices. The CSP program is not implemented locally in any unique way; it is based on national job sheets and is a very top-down program, with the same eligibility and practice evaluation software applied everywhere.

Generally, grower interest in the programs starts by word-of-mouth from previous participants in the area. Once a grower is interested in joining, they approach the NRCS to join the program. The Moscow area office currently receives more interested growers than they can fund in a year. They are using all of the allocated budget and fund approximately 90% of the applications each year. Roughly 20% of the EQIP contracts in Latah County have associated NMPs, a relatively low participation rate.

There are four main types of NMPs: Basic, Enhanced, Precision, & Adaptive. The level of financial incentive for implementing a NMP is based on the specific type of practices being implemented on the farm (Table 1). The payments are on a per acre basis (with the exception of Adaptive NMPs), with an annual cap of $10,000 per year and a limit of three years of participation. For the lowest level of incentive (Basic NMP), the annual financial cap is reached if it is implemented on 1,143 acres, whereas for the highest level of incentive (Enhanced NMP), the annual financial cap is reached if it is implemented on 309 acres. Usually the cap is reached for each type of NMP since the average farm size in the region is 2500 acres. These payments are very general and remain the same across several states.

Table 1. Nutrient management plan options.

Type	Incentive (max 3 yrs, $10,000/yr)	Primary Practice
Basic	$8.75/ac.	4 R's: **R**ight Source, Time, Rate, Method
Enhanced	$32.44/ac.	Split application; post-harvest soil sampling
Precision	$22.27 – 30.72/ac.	Variable rate fertilizer application
Adaptive	$1303.67 each	Test plots on farm

All NMPs are based on the NRCS Practice Standard 590: Nutrient Management. The 590 definition is: "Managing the amount (rate), source, placement (method of application), and timing of plant nutrients and soil amendments." With regard to nitrogen fertilizer application, the 590 Standard requires that: 1) nutrients may not be surface-applied if nutrient transport from field are likely, and 2) nutrient applications rates may not exceed Land Grant University recommendations. The four basic categories of NMPs were developed from the 590 baseline, and the requirement for each are as follows:

1. Basic Nutrient Management Plan
    a. Requires compliance with 590 Standard

    b. Develop a Nutrient Management Plan that identifies the need for a higher level of nutrient management with more emphasis on the "4 R's"
        i. 4 R's: **R**ight source of nutrients, **R**ight time of application, **R**ight rate, and **R**ight method of application
        ii. Pre-plant soil tests to create annual nutrient budget
        iii. Record keeping
        iv. Post-harvest soil test and/or tissue tests to establish efficiency
    c. Implement mitigating or companion practices including crop rotations, grassed waterways, filter strips, riparian buffers, and/or residue management

2. Enhanced Nutrient Management Plan
    a. Applied to area in absence of NMP or where only a Basic NMP has been implemented
    b. Requires compliance with 590 standard
    c. Includes use of split applications, nitrogen stabilizers, inhibitors and controlled release fertilizers used with tissue tests, side-dress, post-harvest soil testing, and methods of application that allow for more appropriate fertilizer applications
3. Adaptive Nutrient Management Plan
    a. Requires compliance with 590 standard
    b. Develop a NMP meeting all Basic NMP requirements
    c. Conduct paired, replicated test plots (minimum of 7) to inform future nutrient application rates and methods
        i. Pre-plant, side or top-dress and post-harvest soil testing and/or tissue testing
    d. Further minimization of nitrogen loss risk may be addressed through use of soil survey maps or other simple techniques to establish zones
    e. Adjust annual fertilizer practices based on outcomes of previous field trials
4. Precision Nutrient Management Plan
    a. Requires compliance with 590 standard
    b. Develop a NMP meeting all Basic NMP requirements
    c. Pre-plant and post-harvest soil testing and/or tissue testing
    d. Identify variability in the field, making precise management zones based on soil maps, GPS soil sampling, aerial maps, remote sensing (such as NDVI), or yield monitors
    e. Attend a nutrient management workshop
    f. Use GPS technology to apply fertilizer

Within each NMP, the grower works with a NRCS conservationist to decide exactly which practices to implement. Idaho uses a "Nutrient Transport Risk Assessment Tool" to help inform what is needed on a particular field. The tool is an interactive excel macro file. The tool assigns a rating and point value for basic site characteristics such as: current soil nutrient concentrations, current fertilizer methods, runoff risk, current "Best Management Practices," and distance to surface water (for specific examples, see Table 2). Basic fertilizer rate, timing, and method information is added to the tool, followed by a determination of "runoff class" based on slope steepness and soil saturated hydraulic conductivity.

Table 2. Example characteristic ratings to assess field nutrient loss risk.

Site Characteristic	Very low (0)	Low (1)	Medium (2)	High (4)	Very high (8)
Soil N (ppm) 0-12"	<5	5-10	10-20	20-30	>30
Soil N (ppm) 12-24"	<2	2-5	5-10	10-15	>=15
N application rate (% of crop requirement)	<40	40-60	60-100	100-120	>120

The tool then provides an assessment report, providing risk categories and associated mitigating practices for each piece of nutrient management. The assessment report indicates if a practice is recommended or required to meet minimum conservation standards. Required practices for a site with a high risk of nutrient loss include: 1) soil testing and compliance with University of Idaho fertilizer guides, 2) change nitrogen timing by using split fall/spring applications when soil temperatures are below 50 degrees Fahrenheit, 3) change nitrogen method of application by placing fertilizer with a planter or injecting the fertilizer greater than 2 inches below the surface, and 4) reduce tillage operations and/or add conservation practices that trap and/or filter nutrients.

Locally, an important gap in understanding is related to the timing of nitrogen transport from a field to a waterway. There is a great need to better understand the fate and transport of nitrogen in fields which have been historically over-fertilized, including the lag-time (or legacy effects) of over-fertilization.

Spokane and Whitman Counties (Washington)

The following description of the implementation of EQIP and CSP programs (and the NMPs therein) is based on email responses and supporting documents (job sheets and nutrient risk assessments) provided by local NRCS soil conservationists.

The EQIP and CSP programs are implemented following the same approach in Spokane and Whitman counties, though the NRCS workers are unaware of how implementation of these programs differs in Idaho. The team usually spends the entire annual budget for the programs (including all land uses and practices incentivized). It is estimated that 80-90% of all the producers in their region (not just program participants) use a basic NMP with soil tests and a nutrient budget. Only 5-10% of CSP applicants include precision application as an enhancement.

Participation in the programs generally begins with a grower approaching the NRCS to see if assistance is available after they have been introduced to a new technology from agriculture seminars and workshops. The offices have outreach news releases but most of the participation interest originates through word of mouth.

Summary

An understanding of the limitations, boundaries, and opportunities created through these Farm Bill programs provides a needed background and insight into why a grower may or may not adopt conservation practices, such as precision fertilizer application. The 2014 bill eliminated the direct payment program, and puts a much greater emphasis on crop insurance programs. Commodity programs reduce the annual variation in farm incomes and supplement crop insurance policies for catastrophic loss by providing coverage for small (not catastrophic) losses due to low yield or market prices. The 2014 farm bill links eligibility for crop insurance with conservation provision compliance, which was previously linked with direct payments. Conservation cost-share programs provide growers with opportunities to adopt improved conservation practices with financial assistance. The basic structure of farm bill commodity programs, crop insurance, and conservation incentives are important in understanding the greater context of farm management decisions, explored throughout this thesis.

Chapter 3. Use of CropSyst-Microbasin to assess precision fertilizer management practices in Palouse wheat production

Abstract

Precision fertilizer management is a promising method to maintain high agricultural yields while using less fertilizer inputs in the highly heterogeneous Palouse region. This study assessed the use of CropSyst-Microbasin as a tool to inform fertilizer management practices. First, a highly-instrumented field site was used to parameterize CropSyst-Microbasin; the model accurately simulated spatial and temporal changes in soil water content (simulated v. observed RMSE = 0.03 m^3/m^3), total surface runoff (NSE = 0.62), and average crop yield (observed = 92 bu/ac, simulated = 89 bu/ac). In the 2013 winter wheat production year, variable rate fertilizer application decreased overall nitrogen losses by 21 kg-N in a 10.9 ha field. Hillslope simulations demonstrated no decrease in N loss under a yield-based variable rate fertilizer application and a 12.3% reduction in N loss under a CropSyst optimum fertilizer scenario, highlighting a potential use of the model to inform fertilizer management. The hillslope scenarios also demonstrate the capacity of CropSyst-Microbasin to simulate the contribution of lateral redistribution of nitrogen to down-slope yields. Errors in model processes of nitrogen transport and crop yield under excess nutrient levels were identified and will be corrected in future model versions; these current limitations may influence the comparison between variable and uniform application strategies.

Introduction

The inefficient use of nitrogen fertilizers in agriculture has been well documented (Houlton et al., 2013; Howarth et al., 2002; Ribaudo et al., 2011a), along with coupled financial and environmental consequences (Carpenter et al., 1999; Galloway et al., 1995; Houlton et al., 2013; Ribaudo et al., 2011a; Rockström et al., 2009; Vitousek et al., 1997). In cereal grain production, commonly less than 50% of the nitrogen fertilizer applied is recovered in aboveground crop biomass (Cassman et al., 2002). As a result, these agricultural systems contribute significant amounts of nitrogen to the surrounding environment (Ribaudo et al. 2011a). Nitrogen "best management practices" aim to improve fertilizer recovery efficiency and decrease the amount of nitrogen loss from a field by improving the timing, method, source, and rate of fertilizer application (Ribaudo et al., 2011a). However, the extent to which these practices actually decrease nitrogen loss has been little documented. Additionally, the "best" nitrogen management practices are likely unique to specific regions, soils, and types of agricultural production (Rittenburg et al., 2015).

This study aims to improve nitrogen management understanding in the Palouse Region of eastern Washington and northern Idaho. The region boasts world record wheat yields, which are heavily dependent on the use of nitrogen fertilizers. As with most agricultural systems, the Palouse has felt the financial and environmental burden of inefficient fertilizer use. Fertilizers were estimated to contribute 87% of the total nitrogen in the Palouse River (Puckett, 1994) and nitrogen is the single greatest variable input cost to Palouse growers per unit area (Kate Painter, personal communication, March 2014). Nitrogen management on the Palouse is especially challenging given the unique landscape. The Palouse is characterized by large rolling loess hills that generate topographic, microclimate, and soil heterogeneity within each field. Nitrogen needs can vary widely depending on specific slope position and aspect in a field.

Given the spatial heterogeneity of the Palouse, "precision fertilizer application" (also known as "variable rate application"), is a particularly promising strategy for the region's growers to decrease overall fertilizer inputs while maintaining high yields. Precision fertilizer application involves breaking a field into multiple zones and applying a different rate of fertilizer according to the site-specific crop nutrient needs and limitations (Pierce & Nowak, 1999; Robert, 1999). The standard practice in the region is to apply a uniformly high rate across the field, but most fields have areas with extremely shallow soils or clay knobs that can never make use of the high rate of fertilizer. If a grower applies a lower rate of fertilizer to those parts of the field, he may greatly reduce fertilizer inputs and see no loss in yield. Through variable rate fertilizer application, nitrogen fertilizer efficiency will likely be improved on the field as a whole. A major obstacle in implementing effective precision fertilizer practices on the Palouse is a limited understanding of the spatial and temporal drivers of crop production in this highly heterogeneous landscape. Physically based models, used in conjunction with field-collected data, can contribute to a more holistic understanding of physical and environmental controls on these systems.

CropSyst-Microbasin is a newly developed 3D version of CropSyst, designed to examine the impact of farm management practices on environmental and crop production outcomes in small agricultural watersheds with high heterogeneity (Stöckle et al., 2014). We specifically chose CropSyst-Microbasin because of its unique ability to capture: 1) the spatial variability on small agricultural watersheds, 2) in-season and harvest crop growth, stress, transpiration, and nutrient uptake, and 3) a large spectrum of hydrologic processes, including subsurface lateral flow, which is a key, but often overlooked, driver in the redistribution of moisture within a landscape (Brooks 2003). This is the first assessment of CropSyst-Microbasin as a tool to inform fertilizer management, though previous research has assessed the 1-dimensional version of CropSyst for the same purposes (Singh et al., 2008). To accurately assess the model, outputs must be analyzed alongside observed field data and practical knowledge (Palosuo et al., 2011).

This study uses data collected over 2 years at a heavily instrumented field site in conjunction with CropSyst-Microbasin simulations to assess the use of this model in making fertilizer management recommendations. The specific objectives of this study were to: 1) assess the accuracy of CropSyst-Microbasin predictions of field-scale variability in water transport and crop production to observed field data, and 2) to quantify changes in yield, nitrogen loss, and farm profitability as a result of adopting variable rate fertilizer practices as predicted by CropSyst-Microbasin.

Model Description

CropSyst-Microbasin was developed by Washington State University researchers with the purpose of examining how farm management, climate, and soils affect environmental outcomes and crop production on small agricultural watersheds with highly variable landscapes (Stöckle et al., 2014). This fully distributed model provides detailed hydrologic (e.g. soil water content, surface runoff, drainage, etc.), nutrient cycling (e.g. residue production and decomposition), and crop production (e.g.

yield, phenology, nitrogen uptake, etc) information at daily or hourly time-steps. The user chooses the grid size according to the site; this study used 10 m x 10 m grid cells. Each grid cell is assigned an elevation value to determine water routing, along with detailed soil files (2.2 m deep soils with 13 layers in this study) and user specified crop management. The ability to apply unique management to each grid cell enables the user to apply different farming practices across the field, such as applying a variable rate of fertilizer.

The water flow through the soil is calculated according to a simple cascading approach, and allows for free drainage below the modeled 2.2 m soil depth (though the model is capable of using a numerical solution to the Richards equation and the user can specify no free-drainage below the modeled soil depth). Subsurface lateral flow algorithms follow the approach used in the Soil Moisture Routing model (Brooks et al., 2007; Frankenberger et al., 1999). Evapotranspiration (ET) is calculated according to the Penman-Monteith equation and requires daily maximum and minimum temperature, solar radiation, maximum and minimum relative humidity, and wind speed. An ET crop coefficient is used to relate potential ET to actual ET for specific crop types when water availability is high, and crop ground cover partitions between crop transpiration and soil evaporation. ET is then limited by water availability in the surface and root zone soil layers (Stöckle et al., 2003).

The nitrogen routines in CropSyst include soil nitrate and ammonium concentrations for each soil layer at a daily time-step, calculated using N transformations, sorption, fixation, and crop N uptake. Microbial N transformations occur in the top 30 cm and are calculated according to irreversible first order kinetics. Net mineralization is a function of soil water content, mineralizable N, and a temperature dependent mineralization rate constant. Nitrification and denitrification is calculated as a first order rate function of soil water content, temperature, available ammonium or nitrate, and a rate constant (Stöckle and Campbell 1989). Crop N uptake is limited by potential nitrogen uptake and crop nitrogen demand. Nitrogen transport is simulated using the water transport routines (Stöckle et al., 2003).

Crop phenology and development is based on thermal time (accumulation of average daily air temperature above a growth cut-off temperature). Water stress accelerates accumulated thermal time (Stöckle et al., 2003). Biomass accumulation is a function of potential transpiration, a biomass-transpiration coefficient, and vapor pressure deficit. At low vapor pressure deficits, the biomass-transpiration coefficient approach is a poor prediction, thus biomass production at low vapor pressure deficit is based on the crop radiation-use efficiency and the amount of crop-intercepted photosynthetically reactive radiation (Stöckle et al., 2003). Transpiration and crop growth is also limited by nitrogen concentrations and water availability as further described in Stöckle et al., (2003). Yield is determined from simulated biomass by using the harvest index, a simple ratio of the amount of harvestable yield to aboveground biomass.

Methods

Site Description and Observed Data

The study site is located near Leland, Idaho in the annual cropping zone of the Palouse. The annual cropping zone of the Palouse is characterized by receiving greater than 18 inches (457 mm) of annual precipitation. The study site is located on the eastern edge of the Palouse and PRISM estimates of annual precipitation range from 32 to 39 inches (813 – 990 mm), our field observed annual precipitation from 2011 – 2013 ranged from 19 – 29 inches (476 – 733 mm) (Table 3).

Table 3. Field-observed precipitation; Calendar year is Jan. 1 - Dec. 31; Water year is Oct. 1 of the previous year through the following Sep. 30.

Time Period	Precipitation (mm)	Precipitation (inches)
2011 Calendar Year	615	24
2012 Calendar Year	733	29
2013 Calendar Year	476	19
2012 Water Year	638	25
2013 Water Year	604	24
Jan 1 – Aug 1, 2011	457	18
Jan 1 – Aug 1, 2012	487	19
Jan 1 – Aug 1, 2013	284	11

The land is managed as most regional farms, using dryland practices (no irrigation) with a 3-year rotation of winter wheat, spring wheat, legume (Table 4). The annual cropping zone of the Palouse boasts world record winter wheat yields, averaging 90-100 bushels per acre and commonly exceeding 135 bushels per acre (Schillinger et al., 2003). The study site yields range from 50-135 bushels per acre, generally averaging 90-100 bushels per acre.

Table 4. Plant and harvest dates at study site 2009 - 2013.

Crop	Plant Date	Harvest Date
Winter Wheat	Fall 2009	Late Summer 2010
Spring Wheat	April 16th, 2011	August 15th, 2011
Garbanzo Beans	May 22nd, 2012	September 5th, 2012
Winter Wheat	October 10th, 2012	Last week of Aug, 2013

The grower uses precision fertilizer management (using Urea Ammonium Nitrate Solution 32-0-0) by breaking the fields into three zones: high, medium, and low (Figure 4). During the 2013 soft white winter wheat production year, 44 kg-N per hectare of fertilizer was applied as broadcast spring top-dress across the entire field; the fall soil-incorporated application of N fertilizer in the high, medium, and low zone was 101, 78, and 56 kg-N per hectare, respectively.

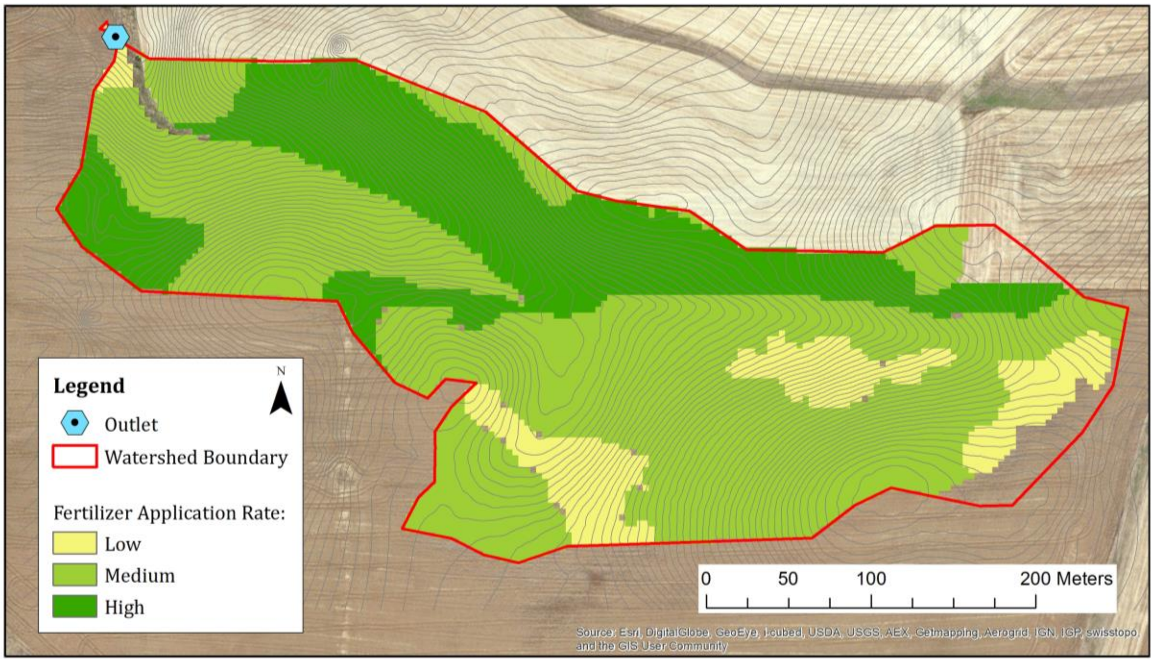
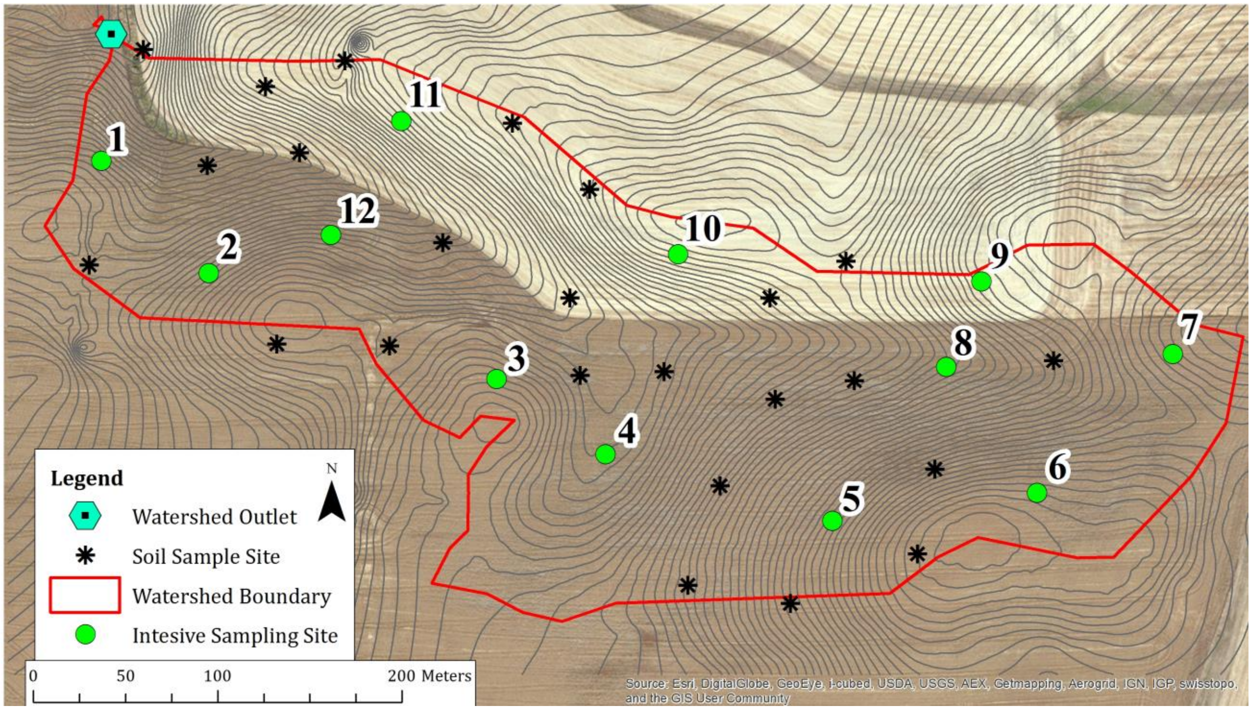


Figure 4. Variable rate fertilizer zones at study site.

The study site has Southwick soil, characterized by a hydraulically restrictive horizon. This restrictive horizon forms perched water tables during the winter and spring months and likely contributes to the lateral movement of water through the watershed. The maximum slope in the watershed is 7.2%, with an average of 3.8%.

Data collection at the field site included both high frequency automated sampling as well as seasonal crop and soil manual sampling. Automated sensors were installed during the fall of 2011 including in-field Decagon Devices soil moisture sensors at 12 locations (intensive sampling sites 1-12), direct soil samples, and 15 minute surface runoff measurements at the watershed outlet (Figure 5). Soil moisture and temperature were monitored at 10 of the 12 sites using Decagon Devices 5TM soil probes, which read every hour at 0.3 m increments down to 1.5 m from November 22nd, 2011 to present. Decagon Devices 5TE sensors, which provide bulk apparent electrical conductivity in addition to soil moisture and temperature, were installed at the remaining 2 sites at the same depth increments. In addition, two passive capillary drain gauges (Decagon Devices) were installed to a depth of 1.5 m at the 5TE sites to monitor root zone drainage as well as temperature and EC of the leachate passing through the 1.5 m soil core. Leachate samples were taken to the lab and analyzed for nitrate concentrations following storm events. Direct soil measurements were taken at the 12 sites with Decagon sensors and at 24 additional sites. These soil measurements include water content, bulk density, texture analysis, total soil nitrogen and carbon measurements, and spring and fall soil nitrate and ammonium concentrations.

Surface runoff is measured at the watershed outlet in a 6 inch Parshall flume using a 0 – 2.5 psig range pressure sensor (Instrumentation Northwest) connected to a CR200 (Campbell Scientific) data logger. An ISCO Automatic Water Sampler collected runoff event water samples based on stage threshold sampling triggered by the CR200 data logger. From the depth readings and the water samples collected at the flume, we obtain the watershed discharge and instantaneous measurements of pH, EC, and nitrate in the water samples. Additionally, a HOBO (Onset Corporation) weather station was installed at the field site and provided hourly air temperature, relative humidity, wind speed, solar radiation, and precipitation. Finally, four 1m by 1m hand harvested crop samples were collected each year from each of the 12 intensive sampling locations, which were analyzed for crop biomass, yield, grain protein, and residue and grain nitrogen. See Figure 5 for a map of the study site.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 5. Map of study site.

Objective 1: Model Assessment

The non-calibrated inputs to CropSyst-Microbasin included weather, watershed delineation and distributed elevation, and farm management practices. The weather data was taken from the field-site weather station, with data gaps filled using linear regressions with nearby stations. The management file was adjusted according to on-site farm practices and machinery. The grower practices variable rate fertilizer application according to zones identified in Figure 6. The distributed elevation was attained using a base station and GPS.

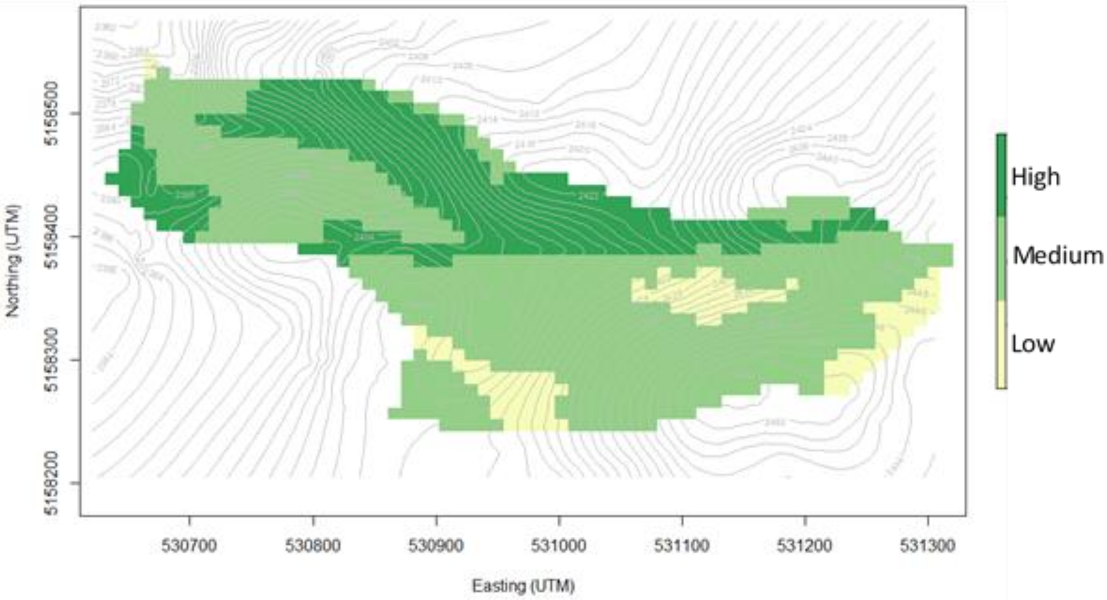


Figure 6. Variable rate fertilizer management zones; High: 145 kg-N/ha, Medium: 123 kg-N/ha, Low: 100 kg-N/ha.

The calibrated inputs included detailed soil files and establishment of crop growth parameters. The crop growth parameters were taken from ranges found in the literature and then adjusted according to observed in-season and harvest measurements (Table 5). Seventeen different soil files were generated through the parameterization process. Each soil was broken into 15 layers to 2.2 meters deep, where each layer was provided unique characteristics including clay content, bulk density, and saturated conductivity (Table 6). Given the difficulty in obtaining fine-scale soil profile data distributed across the watershed (10m by 10m resolution), the soil files were extrapolated from observed data at 36 locations spread across 109,300 m^2 (10.93 hectares) and then calibrated to reach a best estimate of distributed soil characteristics.

Table 5. Crop parameter values and associated sources.

Parameter	Value	Source
*Radiation Use Efficiency (g/MJ PAR)	2.2	Adjusted from standard value of 2 (Monteith, 1977) according to observed field data
Water Use Efficiency at 1kPa (g/kg)	5.1	Adjusted within range of Tanner & Sinclair (1983) citation within Stockle, (2003)
Slope of Water use Efficiency	-0.59	Adjusted within range of Tanner & Sinclair (1983) citation within Stockle, (2003)
Optimum Mean Daily Temperature for Growth (°C)	16	Standard CropSyst value for Winter Wheat
Initial Canopy Ground Cover (0-1)	0.02	Standard CropSyst value for Winter Wheat
Max. Canopy Ground Cover (0-1)	0.94	Standard CropSyst value for Winter Wheat
Total Canopy Ground Cover at Maturity	0.93	Standard CropSyst value for Winter Wheat
Maximum Crop Height (m)	1.3	Observed at field site
Leaf Water Potential that Begins Reducing Canopy Expansion (J/kg)	-1100	Standard CropSyst value for Winter Wheat
Leaf Water Potential that Stops Canopy Expansion (J/kg)	-1500	Standard CropSyst value for Winter Wheat
Max. Rooting Depth (m)	1.6	Standard CropSyst value for Winter Wheat
*Max. Surface Root Density at Full Rooting Depth (cm/cm^3)	7	(Martinez, Fuentes, Silva, Valle, & Acevedo, 2008; Nosalewicz & Lipiec, 2014)
*Curvature of Root Density Distribution (0.001 – 3)	2	(Nosalewicz & Lipiec, 2014)
Root Length Per Unit Root Mass (km/kg)	80	Standard CropSyst value for Winter Wheat
Root Growth Sensitivity to Stress (0-1)	1	Parameterized according to observed field data
Base Temperature for Development (°C)	0	Standard CropSyst value for Winter Wheat
Max. Temperature for Development (°C)	22	Standard CropSyst value for Winter Wheat
C-days at Emergence	100	Adjusted according to in-season site crop data
C-days at Flowering	1147	Adjusted according to in-season site crop data
C-days at Start of Grain Filling	1310	Adjusted according to in-season site crop data
C-days at End of Canopy Growth	1500	Adjusted according to in-season site crop data
C-days at Start of Senescence	1750	Adjusted according to in-season site crop data
Crop ET Coefficient	1.15	Standard CropSyst value for Winter Wheat
*Max. Water Uptake (mm/day)	11.8	Agrimet Idaho Charts & (Shi & Zuo, 2009)
Leaf Water Potential at the Onset of Stomatal Closure (J/kg)	-1500	Standard CropSyst value for Winter Wheat
Wilting Leaf Water Potential (J/kg)	-1800	Standard CropSyst value for Winter Wheat
Max. N Uptake (kg/ha/day)	4	(Malhi, Johnston, Schoenau, Wang, & Vera, 2006); adjusted w/in range according to observed data
Plant Available Water at which N limitation begins (0-1)	0.4	Parameterized according to field data
*Soil [N] that limits N uptake (ppm)	50	(Shi & Zuo, 2009)
Soil N not available for Uptake (ppm)	1	Standard CropSyst value for Winter Wheat
Standard Root [N] (kgN/kgDM)	0.0043	(Andersson & Johansson, 2006)
Grain N Coefficient	1	Standard CropSyst value for Winter Wheat
Unstressed Harvest Index	0.55	Max of CropSyt range for Winter Wheat

*Parameter was found to be sensitive in attaining modeled values of yield and nitrogen uptake within the range of observed field data at the study site.

Table 6. Soil properties averaged across all 17 soil files. FC = field capacity; PWP = permanent wilting point; Ksat = saturated hydraulic conductivity.

Depth Increment (m)	Clay (%)	Organic Matter (%)	Bulk Density (g/cm^3)	Saturation (m^3/m^3)	FC (m^3/m^3)	PWP (m^3/m^3)	K_{sat} (kg s /m^3)	Lateral K_{sat} (kg s/m^3)
0.025	29.3	3.9	1.30	0.51	0.33	0.14	0.0028	0.0024
0.075	29.3	3.7	1.30	0.51	0.34	0.14	0.0018	0.0019
0.1	32.2	3.3	1.40	0.47	0.35	0.16	0.0017	0.0019
0.1	31.6	2.9	1.38	0.48	0.35	0.15	0.0015	0.0017
0.1	32.7	1.9	1.42	0.47	0.35	0.16	0.0012	0.0015
0.1	35.4	1.7	1.51	0.44	0.35	0.16	0.0011	0.0013
0.1	36.7	1.5	1.56	0.43	0.36	0.16	0.0010	0.0013
0.1	37.2	1.2	1.58	0.42	0.35	0.17	0.0007	0.0011
0.1	37.2	1.1	1.58	0.42	0.35	0.17	0.0007	0.0010
0.1	37.3	1.0	1.58	0.42	0.35	0.17	0.0006	0.0009
0.1	39.0	0.7	1.64	0.39	0.34	0.20	0.0003	0.0006
0.3	39.1	0.6	1.64	0.39	0.34	0.20	0.0003	0.0005
0.3	39.8	0.5	1.67	0.38	0.34	0.22	0.0002	0.0002
0.3	40.8	0.2	1.70	0.36	0.33	0.23	4.2E-7	1.6E-5
0.3	40.8	0.2	1.70	0.36	0.33	0.23	4.2E-7	1.6E-5
Average above restrictive layer	33.6	2.2	1.45	0.46	0.35	0.15	0.0014	0.0017
Average in restrictive layer	40.7	0.5	1.7	0.36	0.33	0.23	2.5E-6	2.1E-5

The soil characteristics (clay content, bulk density, organic matter, initial water content), were first based on soil cores taken from the 36 soil sample locations and the 12 intensive sampling locations. Saturation was calculated from bulk density (assuming particle density of 2.65 g/cm^3). Field capacity, permanent wilting point, and saturated hydraulic conductivity were calculated from bulk density using locally collected soil sample relationships. For each depth at each of the 12 sites with continuous season and accurate soil moisture probe data, the saturation, field capacity, and permanent wilting point was adjusted (generally within 0.04 m^3/m^3 of calculated values) to match probe measurements. Soil air entry potential and Campbell B values were estimated using locally measured soil relationships (Holtan et al., 1968).

Using bulk density measurements from the 36 soil sampling locations, collaborators Dr. Caley Gasch and Dr. Matteo Poggio generated bulk density maps of the field for each 0.3m increment to 1.5m of depth with a 10m by 10m grid resolution. The maps were generated using automated 3D regression-kriging, based on Hengl et al. 2014. The bulk density maps provided a basis for the spatial distribution of soil types in the watershed. An important factor in soil type at the site is depth to restrictive layer. We classified the restrictive layer as any soil depth with a bulk density above 1.65 g/cm^3. The depth of possible root growth was limited to no deeper than the top layer of the restrictive soil depths. Saturated soil hydraulic conductivity was first calculated based on locally collected soil water retention samples, with hydraulic conductivity assumed to be near zero with bulk densities above 1.65 g/cm^3 (Figure 7; Holtan et al., 1968).

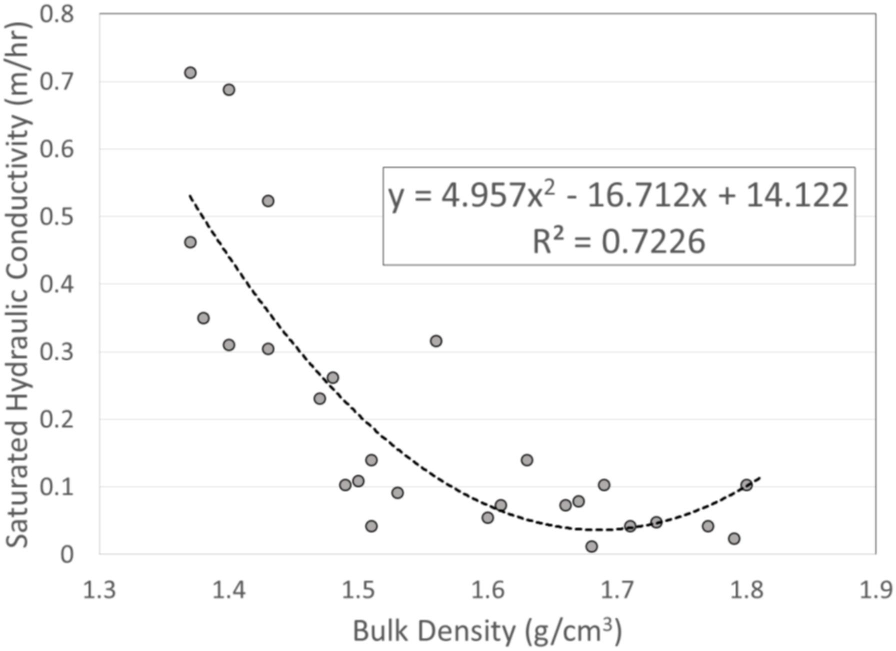


Figure 7. Soil bulk density and saturated hydraulic conductivity relationship.

We conducted a soil calibration in order to more accurately capture the spatial variability across the watershed. The soil input data was extrapolated from a course resolution of 36 sample sites in the 109,300 m^2 (10.9 hectare) watershed, and soil water retention and conductivity values were calculated using bulk density relationships (such as in Figure 7) with associated error. Therefore, the input values for soil characteristics described thus far are extrapolated estimates, and we wanted to incorporate other observed data to calibrate the values and capture the spatial variability to the best of our ability. We acknowledge that calibrating a single parameter runs the risk of masking deficiencies in the model structure. Therefore we provide clear calibration steps in Appendix A. A map showing the spatial distribution of soil files and tables of calibrated soil parameters used at the study site is in Appendix B.

Objective 2: Fertilizer Management Scenarios

The effect of variable rate fertilizer strategies on overall crop yield, nitrogen loss, and net profit was assessed at the field and hillslope scales. The field scale scenarios were specific to the Leland study site. The hillslope scale experiments explored steeper soils with higher lateral conductivities, characteristic of those observed in the region (Brooks & Boll, 2004). The hillslope scenarios included an analysis of spatial (e.g. variable rate) and temporal (e.g. fall vs spring) distribution of fertilizer application, as well as the amount of fertilizer applied.

Whole-Watershed Simulations

We conducted four whole-watershed scenarios (two precipitation treatments and two fertilizer management treatments): 1) variable rate fertilizer application with 2013 precipitation *(roughly average precipitation year: 284mm from January 1st to August 1st)*; 2) uniformly high fertilizer application *(101 kg-N/ha fall application, 44 kg-N/ha spring top-dress)* under 2013 precipitation; 3) variable rate fertilizer application under 2011 precipitation *(high precipitation year, 457mm from January 1st to August 1st)*; and 4) uniformly high fertilizer application under 2011 precipitation. These scenarios were run using the same calibrated input parameters determined in Objective 1, except: the 2011 weather file was used for high precipitation scenarios, and the management file was changed to apply a uniformly high rate of fertilizer for the uniform scenarios.

Hillslope Simulations

We used the same calibrated input parameters as determined in Objective 1 for the hillslope scenarios, however the hillslope was steeper (maximum of 31% steepness) and was fixed with a soil saturated conductivity depth distribution similar to those observed by Brooks & Boll (2004). The lateral saturated conductivity (lateral K_{sat}) for soils 3R5, 4R, and 5RS (Appendix B) was adjusted according to Brooks and Boll (2004) to examine how the model simulates lateral redistribution on a hillslope (Table 7). Above the restrictive layer the lateral K_{sat} was calculated by multiplying the vertical K_{sat} by 10 in first foot of soil, by 5 in the second foot of soil, and by 2 in the third foot of soil. The hillslope scenarios consisted of 5- 10 m x 10 m cells. The elevations, soil files, and fertilizer rates used for each hillslope position and scenarios described below can be found in Table 8.

Table 7. Hillslope scenario soil lateral Ksat values.

Soil	Lateral Saturated Hydraulic Conductivity (kg·s/m^3)		
Layer	3R5	4R	5RS
1	0.028036	0.028035	0.028035
2	0.008036	0.018035	0.018035
3	0.008036	0.018035	0.018035
4	0.008036	0.016035	0.014035
5	0.004018	0.007018	0.007018
6	0.004018	0.007018	0.006018
7	0.004018	0.007018	0.002181
8	0.004018	0.001607	0.002181
9	0.001607	0.001607	0.002181
10	0.001607	0.001607	0.00109
11	1.02×10^{-6}	0.000804	0.00109
12	1.02×10^{-6}	0.000804	0.00109
13	1.02×10^{-6}	1.4×10^{-7}	2.1×10^{-7}
14	1.02×10^{-6}	1.4×10^{-7}	2.1×10^{-7}
15	1.02×10^{-6}	1.4×10^{-7}	2.1×10^{-7}

Table 8. Hillslope scenario cell elevation, soil, and fertilizer management.

			Fertilizer Management Scenario (kg-N/ha applied)			
Hillslope Position	Elevation (m)	Soil File	Uniform	Yield-based	CropSyst-based	Lateral
1 (top)	731.4	3R5	Fall: 10 Spring: 44	Fall: 56 Spring: 44	Fall: 20 Spring: 20	Fall: 20 Spring: 20
2	730.5	3R5	Fall: 101 Spring: 44	Fall: 79 Spring: 44	Fall: 20 Spring: 60	Fall: 20 Spring: 70
3	727.4	4R	Fall: 101 Spring: 44	Fall: 101 Spring: 44	Fall: 20 Spring: 100	Fall: 20 Spring: 140
4	725.9	4R	Fall: 101 Spring: 44	Fall: 101 Spring: 44	Fall: 20 Spring: 160	Fall: 20 Spring: 160
5 (bottom)	725.8	5RS	Fall: 101 Spring: 44	Fall: 101 Spring: 44	Fall: 20 Spring: 180	Fall: 20 Spring: 180

First, a *uniform* scenario was simulated using the rate and timing of the high fertilizer zone at the study site: 101 kg-N/ha in the fall and 44 kg-N/ha in the spring. Using the yield outputs from the *uniform* scenario, we generated a *yield-based* variable rate scenario to simulate the fertilizer management being based off of previous years' yield monitor data. For the *yield-based* scenario, three zones were created on the hillslope and application rates followed the low, medium, and high methods used on the study site.

We also conducted a series of *optimization* scenarios to determine the differences in optimal rates along a hillslope for a particular year. Optimal rates were determined by incrementally increasing fall and spring fertilizer rates by 20 kg-N/ha (applied uniformly across the hillslope) until the highest attainable returns to risk for each hillslope position was identified. We assessed the yield outputs to find the optimum fertilizer rate for each hillslope position to maximize "returns to risk" (described in Results section). Once we found the optimum fertilizer rate for each hillslope position, we ran a *CropSyst-based* scenario (Table 8) with fertilizer application directly informed by the *optimization* scenarios. Finally, because returns to risk for some hillslope positions in the variable rate *CropSyst-based* scenario did not reach the levels in the uniform *optimization* scenarios, we explored the importance of lateral redistribution of nitrogen on the distribution yields by comparing the effects of increasing fertilizer rates at upslope positions on downslope yields and returns to risk, see the *lateral* scenario in Table 8.

Statistical Analysis

The simulated data was assessed in comparison to the observed field data for whole-watershed simulations using:

Root Mean Square Error (RMSE): Standard deviation of the model prediction error. *n* is the number of paired values, *S* is the simulated value, *O* is the observed value. Lower values indicate better model fit.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{N}[S_i - O_i]^2}$$

Nash-Sutcliffe: A common method to assess the predictive power of hydrologic models. This will be used to assess how well the modeled surface runoff fits with field measured surface runoff (discharge at outlet) and how well the soil water content is simulated through time. It determines the magnitude of residual variance to observed data variance. A value of 1 indicates a perfect fit between simulated and observed values; a value of 0 indicates the simulated values are as accurate as the observed mean. Q_o is the observed value (discharge or soil water content) at time *t*; Q_s is the simulated value (discharge or soil water content) at time *t*.

$$NSE = 1 - \frac{\sum_{t=1}^{T}(Q_o^t - Q_s^t)^2}{\sum_{t=1}^{T}(Q_o^t + \overline{Q_o})^2}$$

Results

Objective 1: Model Assessment

The primary water components that were assessed for accuracy in comparison to observed data were surface runoff and spatial and temporal soil water content patterns. CropSyst-Microbasin predicted surface runoff from the outlet with a Nash-Sutcliffe efficiency (NSE) of 0.62, and a total simulated depth of 104 mm (113 observed) of water leaving the watershed (Figure 8). For all soil core measurements of water content at all sites and at all depths on 10/19/2011, 4/17/2012, 9/25/2012, 3/29/2013, 6/10/2013, and 9/10/2013 the predicted values fit the observed values with a RMSE of 0.037 m^3/m^3 (Figure 9). The predicted soil water content at the Site 5 0.3 m depth fit the observed soil moisture probe data with a NSE of 0.61 over the entire simulation period (October 2011 to October 2013), and a NSE of 0.89 during the winter wheat simulation period (October 2012 to October 2013) (Figure 10). The variation in soil water content profiles and drying patterns across soil types (and across the watershed), is illustrated in Figure 11: Site 2 (panel a) shows relatively faster drying patterns above the restrictive layer at 0.6 m of depth compared to the layers below 0.6 m; Site 7 (panel b) shows no change in water content in the restrictive layer below 0.6 m; Site 11 (panel c) shows greater water content changes through the entire profile, which does not have a restrictive layer.

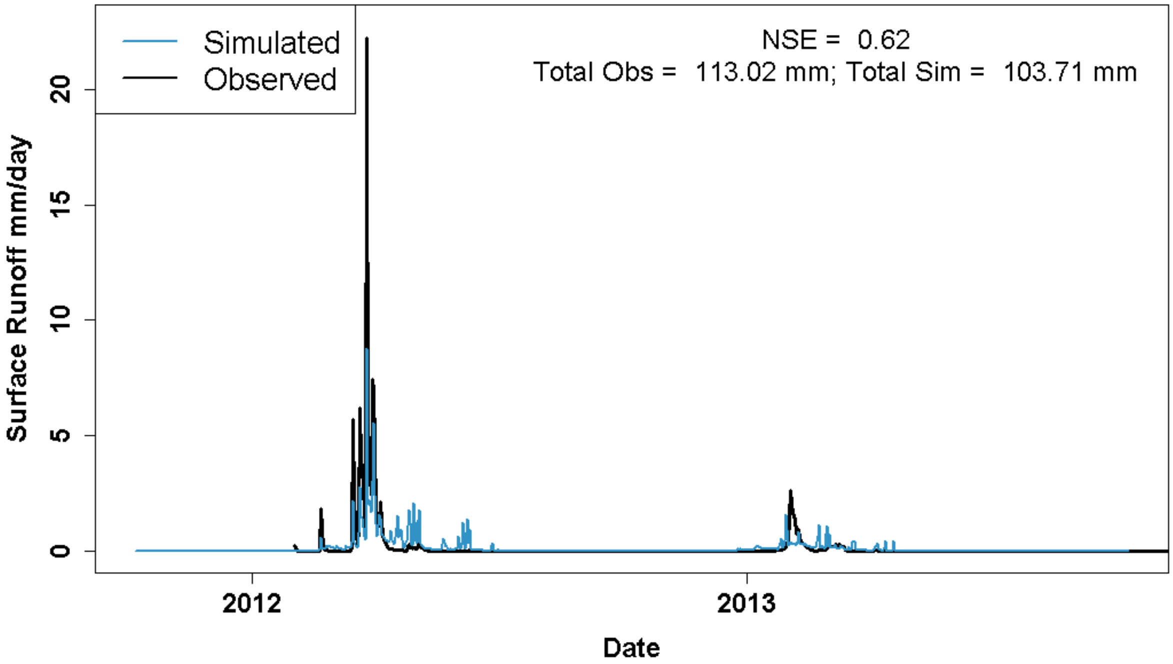


Figure 8. Simulated and observed surface runoff at site. Nash-Sutcliffe = 0.62.

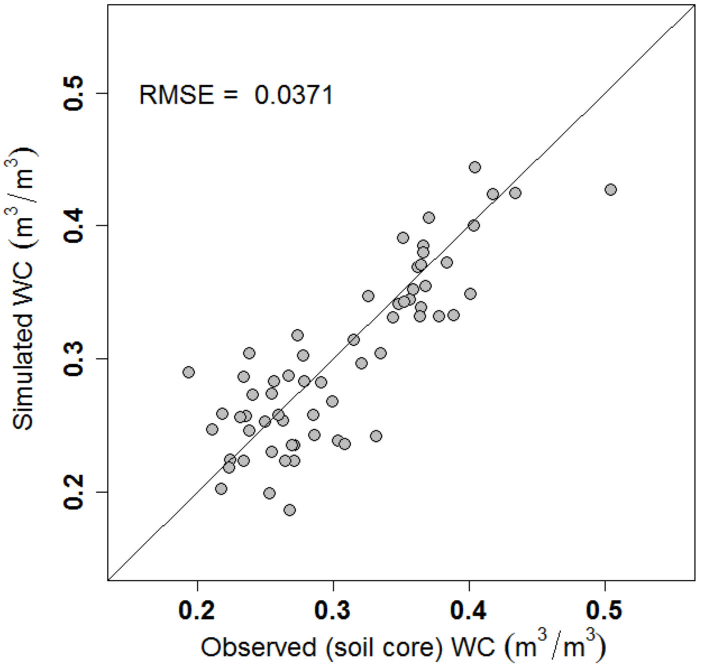


Figure 9. Simulated and observed volumetric water content.

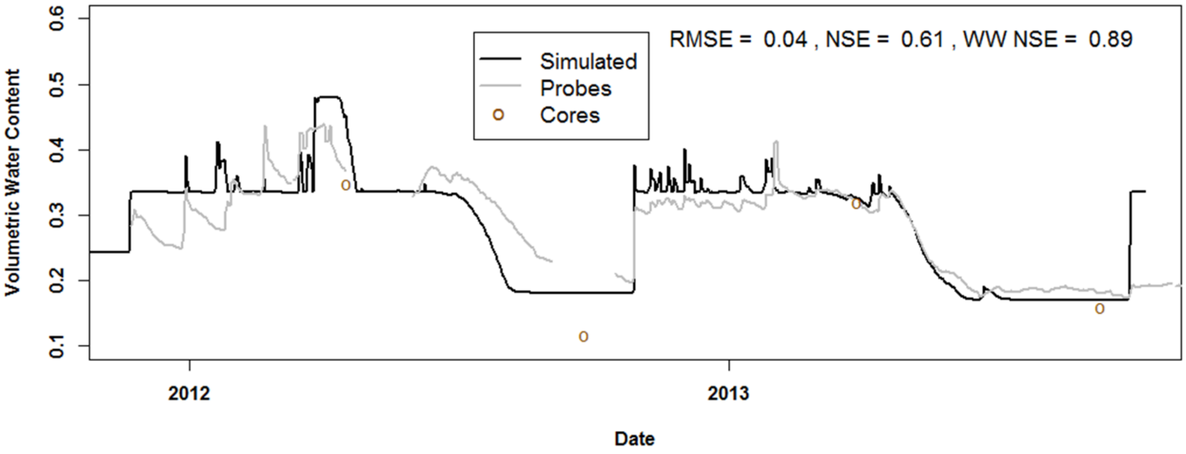


Figure 10. Site 5 (0.3m depth) simulated and observed soil moisture fall 2011 - fall 2013. WW NSE = NSE for the winter wheat production year.

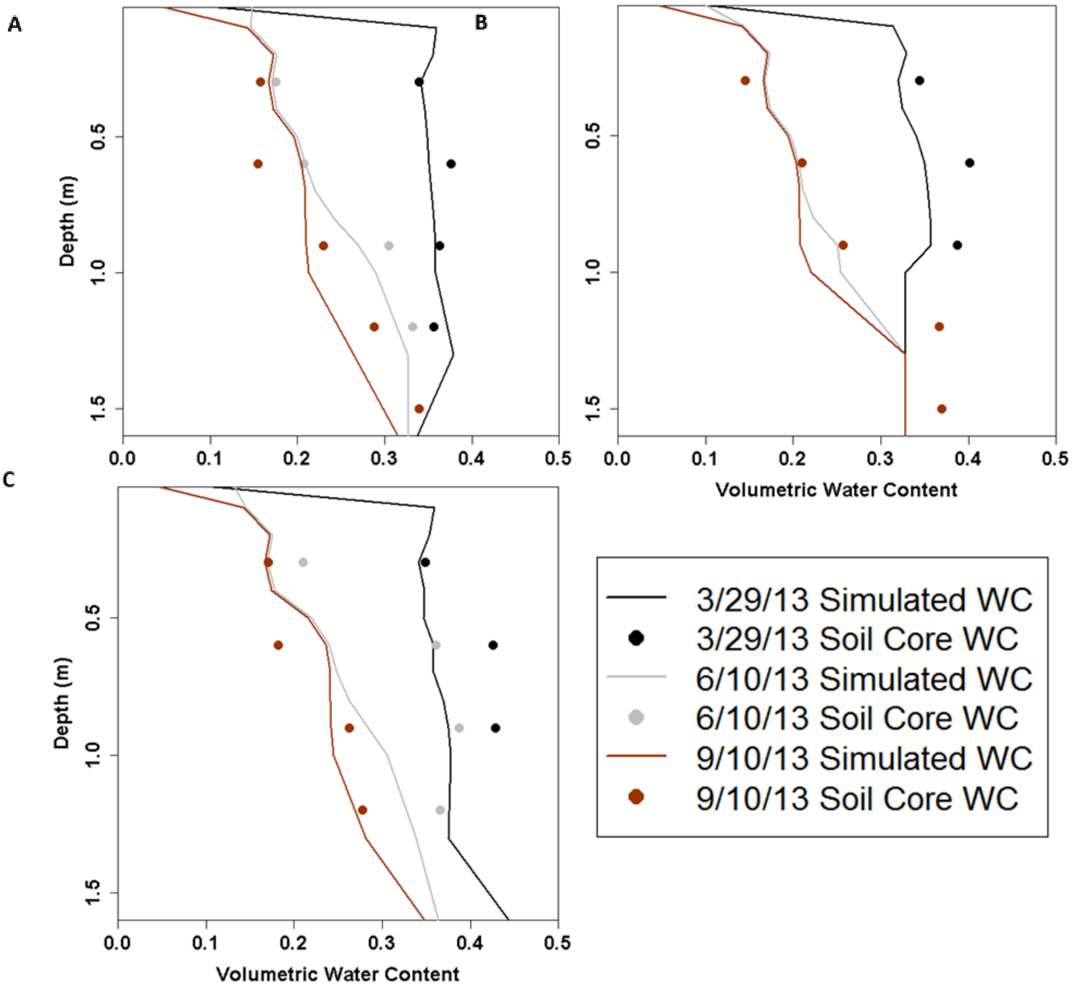


Figure 11. Simulated and observed soil moisture profiles in 2013. A = site 2; B = site 6; C = site 11.

The primary crop and nutrient components that were assessed for accuracy in comparison to observed data were yield, nitrogen uptake, soil nitrogen, and surface runoff nitrogen concentrations. The average observed yield on the field during the 2013 production year was 91 bushels per acre; the average simulated yield during the same time was 87 bushels per acre (Table 9). Observed yields from the grower's yield monitor ranged from 50 – 135 bushels per acre, and modeled yields ranged from 60 – 140 bushels per acre. Hand-harvest nitrogen uptake measurements at the 12 sites ranged from 80 to 145 kilograms per hectare, NDRE-based nitrogen uptake values range from roughly 80 to 190 kilograms per hectare, with an RMSE of 20 kilograms per hectare to directly measured data (Magney et al., unpublished data, see Appendix A).

The NDRE values have a higher upper limit than the hand-harvested samples because the highest producing area of the field is not captured within the 12 hand-harvest sites. The modeled nitrogen uptake values range from roughly 90 to 200 kilograms per hectare. The difference between simulated and NDRE-based nitrogen uptake values are spatially distributed across the watershed (Figure 12). Differences in nitrogen uptake values ranged from 60 kilograms per hectare greater in NDRE values to 100 kilograms per hectare greater in CropSyst-Microbasin values.

Table 9. Statistical evaluation of CropSyst-Microbasin yield and nitrogen uptake predictions.

	Observation type	P_{mean}	O_{mean}	*n*	RMSE	% Error
Yield *(bu/ac)*	Hand-harvest samples at 12 sites	87	84	12	19	22.6
	Yield monitor *(100m² resolution)*	87	91	1093	14	15.5
Nitrogen Uptake *(kg-N/ha)*	Hand-harvest samples at 12 sites	147	110	12	50	45.4
	NDRE *(100m² resolution)*	138	137	1093	28	20.4

P_{mean}: mean of predicted (simulated) value, O_{mean}: mean of observed value, *n*: number of observations, RMSE: root mean square error.

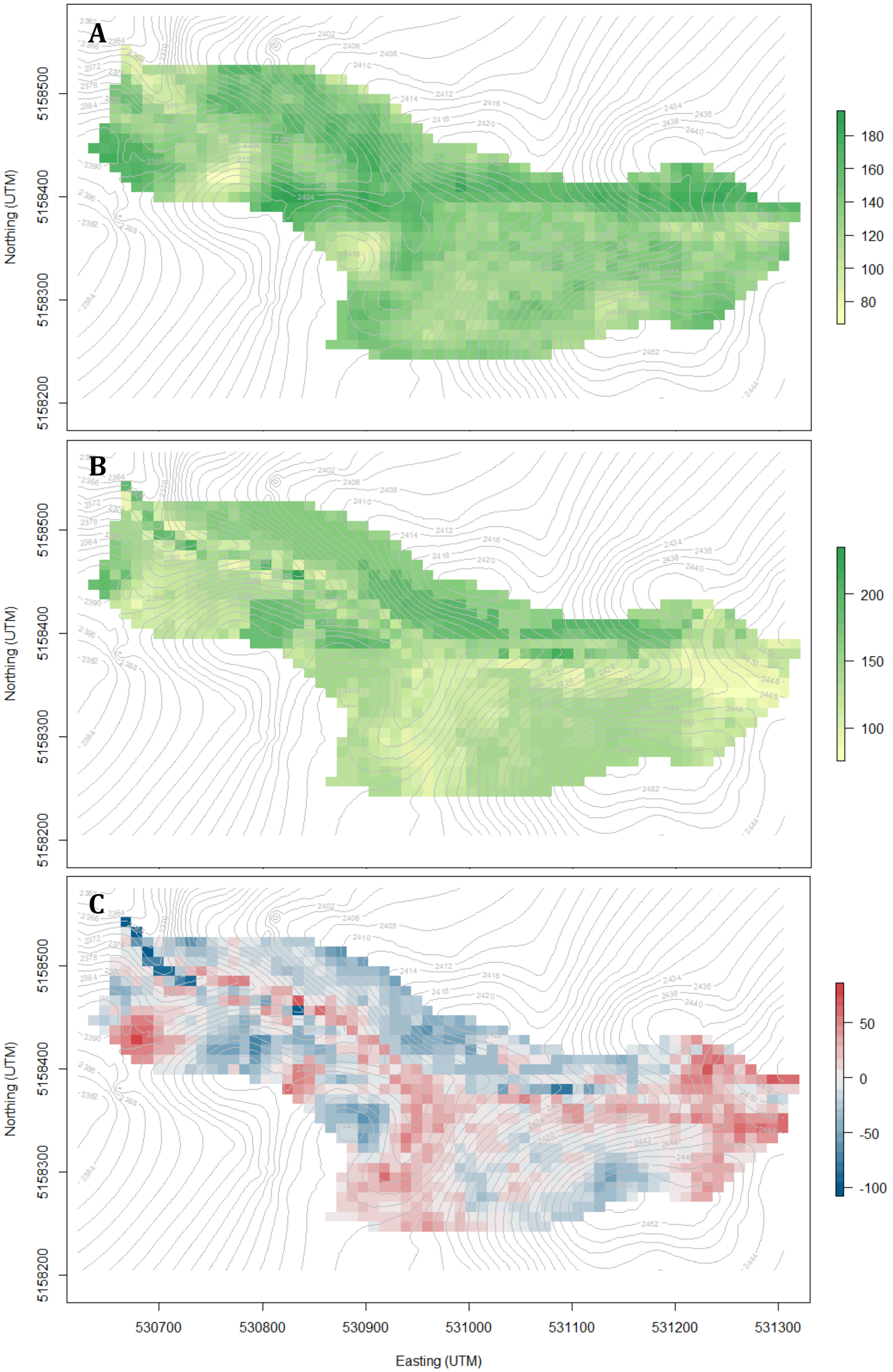


Figure 12. Predicted nitrogen uptake maps (kg-N/ha). A: NDRE-based nitrogen uptake values; B: CropSyst-Microbasin nitrogen uptake predictions; C: NDRE prediction minus CropSyst-Microbasin prediction of nitrogen uptake.

At site 11, with a restrictive layer at 5 feet of depth, simulated soil nitrate in the top 3 feet of soil is close to observed values in spring 2013, however simulated ammonium values are nearly 50 kilogram per hectare greater than observed soil ammonium (Figure 13). Simulated soil nitrate tends to strip out of the soil above the restrictive layer with the first major rain event. The simulated transfer of nitrate from the top two feet of soil into the top of the restrictive layer at 3 feet below the surface as site 7 is shown in Figure 14, this pattern is not seen in the observed data.

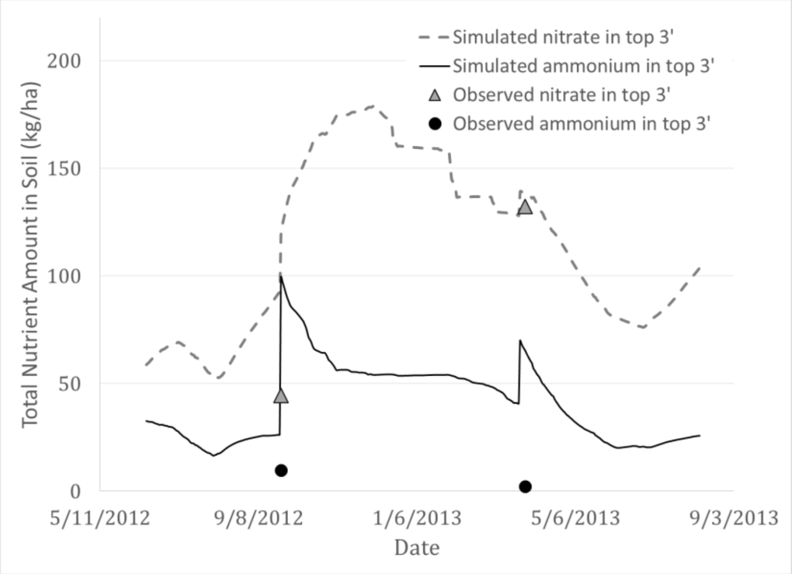


Figure 13. Site 11 (restrictive layer at 5') simulated and observed soil nitrate and ammonium.

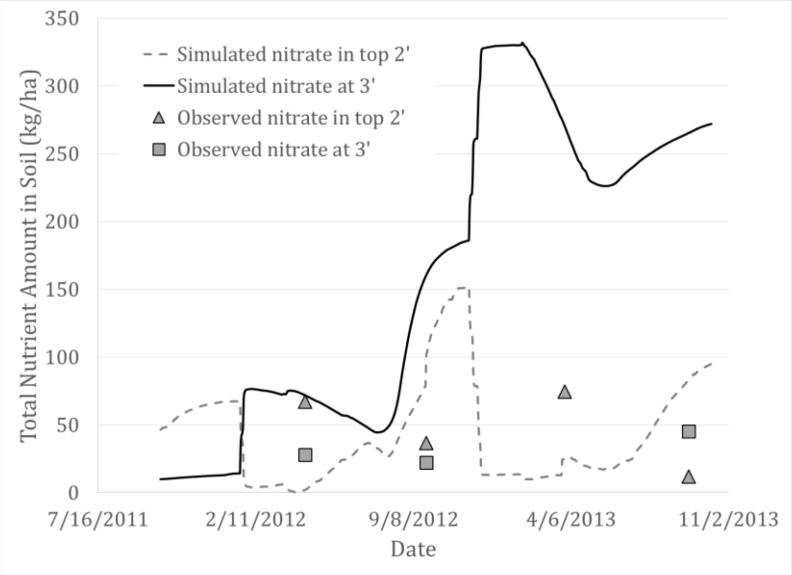


Figure 14. Site 7 (restrictive layer at 3 feet) simulated and observed soil nitrate.

Objective 2: Fertilizer Management Scenarios

Whole-watershed Fertilizer Management Scenarios

The main outputs that were assessed were nitrogen loss (including nitrate and ammonium leaching and nitrous oxide emissions) and crop yield. To incorporate the higher fertilizer cost in a uniformly high fertilizer application, the crop yields were assessed with regards to "returns to risk:"

$$\begin{gathered} Returns\ to\ Risk\ (\$/acre) = \\ \left[Crop\ Yield\ \left(\frac{bushels}{acre}\right) \times Crop\ Price\ \left(\frac{\$}{bushel}\right)\right] \\ - \left[Cost\ of\ Production\ \left(\frac{\$}{acre}\right) + \left(Fertilizer\ Price\ \left(\frac{\$}{pound}\right) \times Fertilizer\ Applied\ \left(\frac{pound}{acre}\right)\right)\right] \end{gathered}$$

Returns to risk is a useful metric to assess the different fertilizer management scenarios because the highest possible yield is not desirable if the costs to attain such a yield are greater than the revenue benefit of the yield. The 2013 price per bushel of soft white winter wheat of $6.75 was used, and the per acre costs of production apart from fertilizer costs was estimated at $363. The cost of production is highly variable from farm to farm, but this value is a sound estimation of costs for local growers producing soft white winter wheaunder variable or uniform application based on results from Chapter 4.

Under "average" (2013) precipitation, the variable rate fertilizer management resulted in an average yield of 88 bushels per acre and average returns to risk of $141 per acre, whereas the uniform fertilizer management resulted in an average of 90 bushels per acre and $147 per acre (Table 10). With 2013 precipitation, total nitrogen loss under variable rate management was 17 kg less than under uniform management. With 2011 precipitation, total nitrogen loss under variable rate management was 22 kg less than under uniform management (Table 10). Under "high" (2011) precipitation, the variable rate fertilizer management resulted in an average yield of 87 bushels per acre and average returns to risk of $136 per acre, whereas the uniform fertilizer management resulted in an average yield of 89 bushels per acre and average returns to risk of $139 per acre (Table 10).

Table 10. Average field yield and returns to risk, and total nitrogen leaching for whole-watershed fertilizer management scenarios.

Precipitation	Fertilizer Management *(total kg N applied)*	Average Yield (bu/ac)	Average Returns to Risk ($/ac)	Total N leaching (kg N from NO_3 & NH_4)
Average	Variable Rate *(1391 kg N)*	88	141	919
	Uniform *(1595 kg N)*	90	147	936
High	Variable Rate *(1391 kg N)*	87	136	1138
	Uniform *(1595 kg N)*	89	139	1160

Differences in yield between variable rate and uniform fertilizer management varied spatially across the field (Figure 15). When looking at individual cells in the watershed, the variable rate fertilizer management resulted in a maximum of 0.5 bushels per acre higher than uniform application, and uniform application resulted in a maximum of 8 bushels per acre higher than variable rate application. The greatest increases in yield under uniform application were in the low fertilizer application zones under variable rate management. Additionally, certain areas of the field saw greater returns to risk under variable rate and other areas saw greater returns to risk under uniform application (Figure 16). The areas that see the greatest increase in returns to risk under uniform application (red areas in Figure 16) are areas with moderately deep soils that are in the low variable rate zone. The areas that see the greatest increase in returns to risk under variable rate application (green areas in Figure 16) are areas with restrictive layers between 1 and 2 feet below the surface.

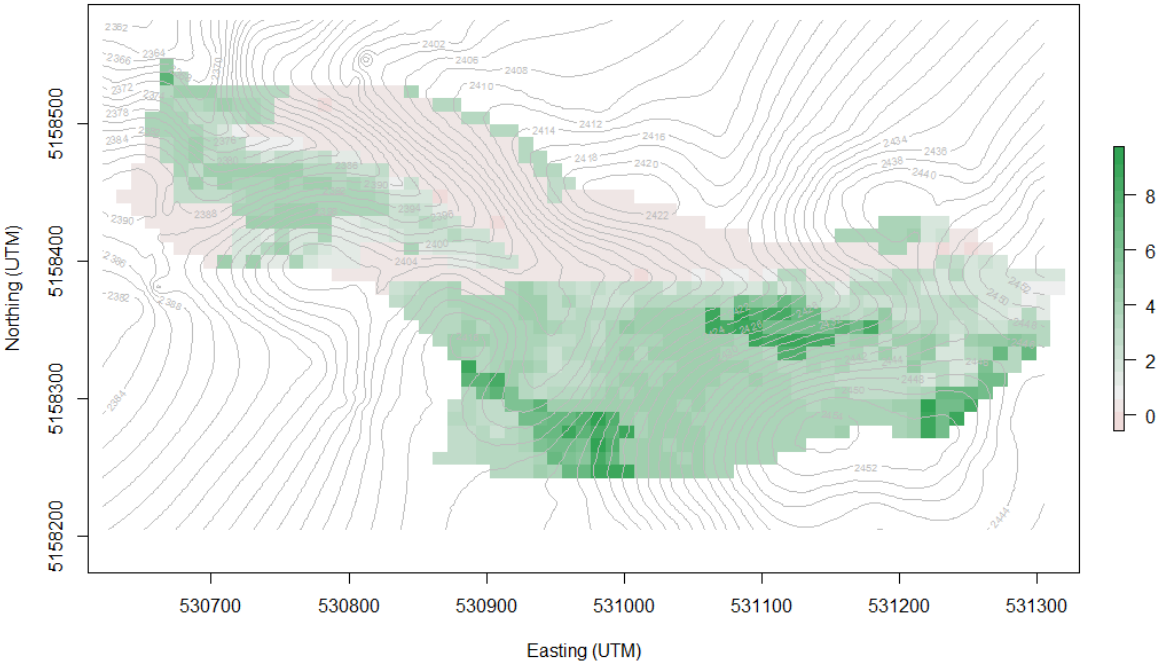


Figure 15. Uniform - variable rate yield (bu/ac) in an average precipitation year; green areas are locations uniform management out-yielded precision management.

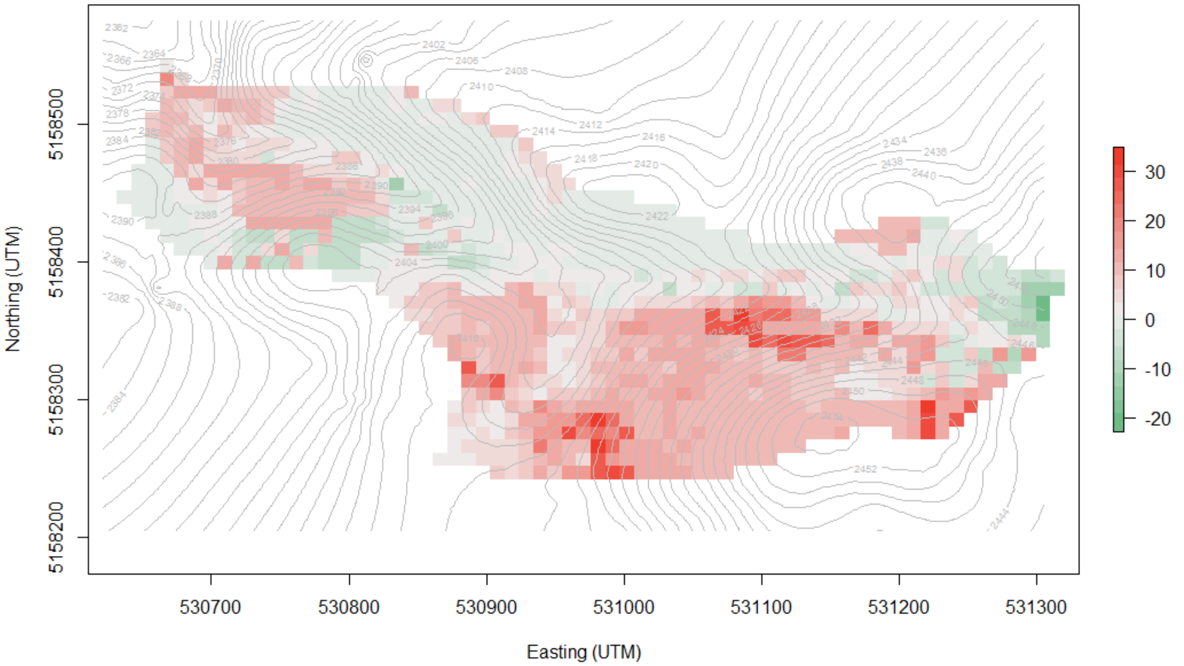


Figure 16. Uniform - variable rate returns to risk ($/ac) in an average precipitation year; green areas are locations that precision management out-profited uniform management; red areas are locations that uniform management out-profited precision management.

Under average precipitation, the variable rate fertilizer management resulted in a total of 981 kg-N loss from the watershed, whereas the uniform fertilizer management resulted in 1002 kg-N loss. Under high precipitation, the variable rate fertilizer management resulted in a total of 1214 kg-N loss, whereas the uniform fertilizer management resulted in 1240 kg-N loss (Table 11). The low and medium fertilizer zones saw an increase in final root zone nitrogen content under uniform application, with some cells resulting in as much as 35 kg-N per hectare higher than under variable rate application (Figure 17).

Table 11. Whole-watershed nitrogen loss under variable and uniform fertilizer application during an average and high precipitation year.

Precipitation	Fertilizer Management *(total kg N applied)*	Total N leaching (kg N from NO_3 & NH_4)	Nitrous Oxide-N loss (kg N)	Total N loss (kg N)
Average	Variable Rate *(1389 kg N)*	919	63	981
	Uniform *(1584 kg N)*	936	66	1002
High	Variable Rate *(1389 kg N)*	1138	76	1214
	Uniform *(1584 kg N)*	1160	80	1240

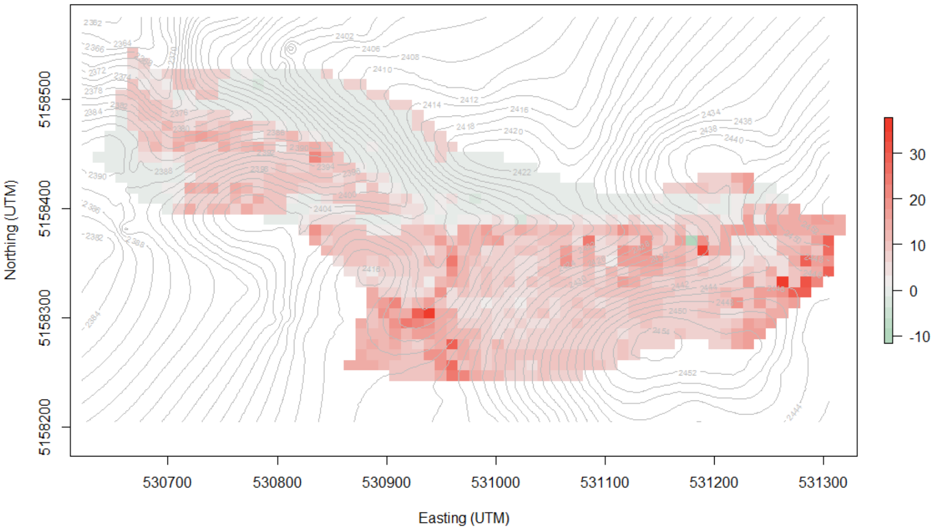


Figure 17. Difference between root zone nitrogen content (kg-N/ha) under uniform management and variable rate management (positive values indicate higher N under uniform scenario, negative values indicate higher N under variable rate scenario).

Hillslope Fertilizer Management Scenarios

A visual schematic of the *Uniform* scenario is provided in Figure 18 with hillslope position lateral transport, nitrogen loss, yield, and returns to risk. The first three hillslope (upslope) positions tended to experience a net loss of soil nitrogen due to lateral redistribution and the last two hillslope positions (bottom of hill) tended to experience a net gain of soil nitrogen due to lateral redistribution. The first two hillslope positions have a lower yield potential (68 and 75 bushels per acre) under high fertilizer application than the lower three hillslope positions (95, 94, and 80 bushels per acre). Greater than 50% of the total nitrogen loss occurs at the bottom hillslope position.

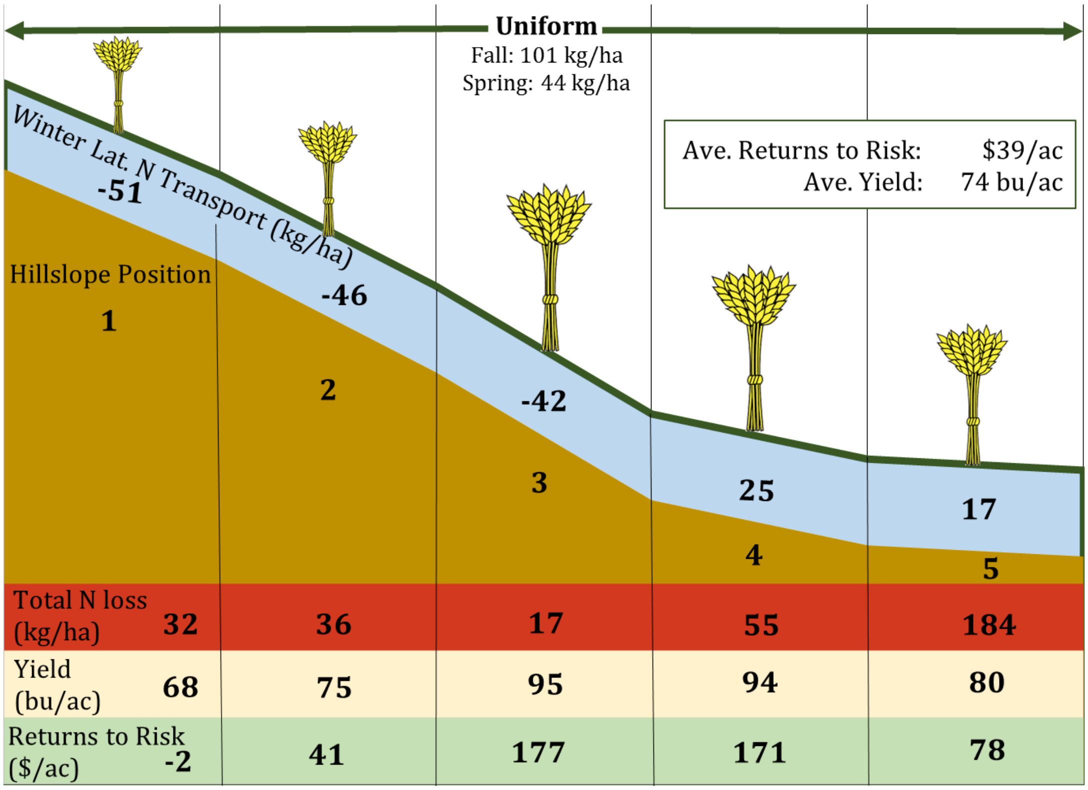


Figure 18. Uniform hillslope scenario results; negative lat. N transport means a net loss of soil nitrogen via lateral transport, positive lat. N transport means a net gain of soil nitrogen via lateral transport.

The *Uniform* scenario produced an average yield of 82 bushels per acre, average returns to risk of $93 per acre (Table 12), and an average hillslope nitrogen loss of 64 kg-N per hectare (Table 13). The *Yield-based* scenario (generated from the yield outputs of the *Uniform* scenario as if the grower had used a yield monitor to create 3 fertilizer zones) produced an average yield of 82 bushels per acre, average returns to risk of $99 per acre (Table 12), and an average hillslope nitrogen loss of 65 kg-N per hectare (Table 13). The *CropSyst-based* scenario (generated from using CropSyst-Microbasin to optimize returns to risk, further described below) produced an average yield of 85 bushels per acre, average returns to risk of $127 per acre (Table 12), and an average hillslope nitrogen loss of 57 kg-N per hectare (Table 13). The *Lateral* scenario (applying fertilizer with anticipation of lateral redistribution), produced an average yield of 86 bushels per acre, average returns to risk of $127 per acre (Table 12), and an average hillslope nitrogen loss of 58 kg-N per hectare (Table 13).

Table 12. Yield and returns to risk for each hillslope scenario.

	Yield (bu/ac)				**Returns to Risk ($/ac)**			
Hillslope position	Uniform	Yield-based	CropSyst-based	Lateral	Uniform	Yield-based	CropSyst-based	Lateral
1 (top)	68	68	63	63	-2	24	35	35
2	75	74	70	71	41	51	55	54
3	95	94	92	95	177	174	178	171
4	94	93	102	103	171	168	204	209
5 (bottom)	80	80	99	99	78	78	165	166
Average	82	82	85	86	93	99	127	127

Table 13. Fertilizer application rates and total nitrogen loss for each hillslope scenario.

	Fall/Spring Fertilizer Rate (kg-N/ha)				**N loss (kg-N/ha)**			
Hillslope position	Uniform	Yield-based	CropSyst-based	Lateral	Uniform	Yield-based	CropSyst-based	Lateral
1 (top)	101/44	56/44	20/20	20/20	32	32	31	31
2	101/44	79/44	20/60	20/70	36	35	35	35
3	101/44	101/44	20/100	20/140	17	16	16	17
4	101/44	101/44	20/160	20/160	55	55	53	53
5 (bottom)	101/44	101/44	20/180	20/180	184	189	152	152
Average	101/44	88/44	20/104	20/114	65	65	57	58

A selection of the fertilizer rates assessed in CropSyst-Microbasin to generate the *CropSyst-based* scenario are displayed in Table 14. By selecting for optimum returns to risk, the yield and cost of fertilizer are simultaneously incorporated, thus providing an optimum rate where per-unit yield fertilizer cost is maximized. The optimum returns to risk for hillslope position 1 were under the 20/20 fall/spring fertilizer application (kg-N/ha); for hillslope position 2 were under 20/60 fall/spring fertilizer application; for hillslope position 3 were under 20/100 fall/spring fertilizer application; for hillslope position 4 were under 20/160 fall/spring fertilizer application; and for hillslope position 5 were under 20/200 fall/spring fertilizer application.

Table 14. Returns to risk and nitrogen loss under fertilizer rates assessed to optimize returns to risk; bold values are greatest hillslope position returns to risk.

Fall/Spring Rate (kg-N/ha)	Hillslope position Returns to Risk ($/ac)						Hillslope position nitrogen loss (kg-N/ha)					
	1	2	3	4	5	Average	1	2	3	4	5	Average
0/0	22	29	96	-12	-73	12	29	33	13	47	143	53
20/20	**35**	52	142	66	-1	58.8	31	34	15	49	148	55
20/60	31	**58**	172	139	73	94.6	32	35	16	51	150	56.8
20/100	14	51	**183**	188	127	112.6	32	36	17	52	150	57.4
40/80*	14	52	**183**	179	109	107	32	36	17	53	163	**60.2**
20/160	-25	19	164	**214**	165	107.4	33	36	17	53	151	58
20/180	-39	5	152	210	**167**	99	33	36	18	53	152	58.4
20/200	-53	-8	138	204	166	89.4	33	37	18	53	152	58.6

*Simulation demonstrates 20 kg-N/ha in the fall is optimum: in comparison to the 20/100 (equal total amount of fertilizer applied) the returns to risk are not improved, while nitrogen losses increase. This pattern was observed when fall application was increased for each interval of increasing total nitrogen applied.

In all of the previous calculations of returns to risk, the wheat price was assumed to be $6.75 (2013 price for Soft White Winter Wheat) and the fertilizer cost was assumed to be $0.77 per pound of N (2013 cost). The fertilizer rates with optimum returns to risk for each hillslope position are dependent on these assumed prices. If the price of wheat goes up by 37% to $9.30 (and fertilizer cost remains the same) the optimum rate for hillslope position 1 is 20/60 kg-N/ha for fall/spring application; for hillslope position 2 and 3 is 20/100 kg-N/ha for fall/spring application; for hillslope position 4 is 20/160 kg-N for fall/spring application; and for hillslope position 5 is 20/200 (or greater) kg-N for fall/spring application (Table 15).

If the price of fertilizer goes up by 50% to $1.16 per pound of N (and the price of wheat remains the same) the optimum rate for hillslope position 1 is 0/0 kg-N/ha for fall/spring application; for hillslope position 2 is 20/20 kg-N/ha for fall/spring application; for hillslope position 3 is 20/60 kg-N/ha for fall/spring application; and for hillslope position 4 and 5 is 20/160 kg-N/ha for fall/spring application (Table 15).

Table 15. Optimum hillslope returns to risk if wheat price = $9.30 (37% increase) and if fertilizer cost = $1.16/lb-N (50% increase).

Fall/Spring Rate	Hillslope position Returns to Risk ($/ac) with *wheat price = $9.30*						Hillslope position Returns to Risk ($/ac) with *fertilizer cost = $1.16/lb-N*					
(kg-N/ha)	1	2	3	4	5	Average	1	2	3	4	5	Average
0/0	167	176	269	121	37	154	**22**	29	96	-12	-73	12
20/20	196	214	335	233	140	223	21	**34**	122	48	-20	41
20/60	**205**	242	391	354	261	291	6	33	**141**	114	47	69
20/100	187	**243**	**420**	429	345	325	-28	12	141	147	87	72
20/160	146	211	406	**481**	415	332	-90	-43	99	**153**	**106**	45
20/180	132	197	402	476	420	326	-132	-64	85	139	98	30
20/200	118	183	388	472	**425**	317	-132	-84	64	125	91	13

Discussion

CropSyst-Microbasin predictions of runoff, average field crop yield, and average field crop nitrogen uptake align well with observed data. The spatial patterns of soil water distribution also match observed variability well, with a watershed- and depth-wide RMSE of 0.03 m^3/m^3 (10% error). However, the spatial variability in crop nitrogen uptake and yield are less predictive of observed data (yield = 15 – 22% error; N-uptake = 20 – 45% error). The less accurate predictions of spatial variability in yield and nitrogen uptake may be due to model input errors. In particular the crop outputs are sensitive to plant available water and organic matter. It may also be due to difficulty in comparing to “observed” values. The hand harvest sample comparison have the highest percent error for yield and N uptake, this could be due to the fine-scale at which the samples were taken, a more accurate prediction may be found if a mean of nearby cell-outputs is used. The NDRE comparison has a 20% error, and the NDRE values themselves have a 14.5% error at the field site. There are difficulties in making direct comparisons between spatially detailed and approximated values, but they can provide insights into model processes and real-world applications.

In assessing CropSyst-Microbasin predictions of observed field data, two model process limitations were identified. The first involved the transport of soil nitrate through the soil profile. The models tends to strip soil nitrate from the upper layers of the soil profile and accumulate nitrate in the restrictive layer, a process not supported by the observed field data. This process issue has since been resolved and updated model simulations and data analysis are being conducted.

Through the model assessment we noticed two key limitations of the model that may affect the ability of the model to simulate spatial yield and nitrogen uptake patterns in the Palouse region. One of the limitations was an inability to capture the effect of soil saturation on crop growth and nitrogen uptake by plants. The model does not limit crop growth or reduce yields under saturated conditions (Malik et al., 2002). The yellow of crops in saturated or waterlogged areas is prevalent in the high precipitation zone of the Palouse. Secondly, the model does not account for decreased yield due to excess soil nitrogen. Under high soil nitrogen concentrations, through "lodging," wheat stalks fall over, resulting in lower yields. The model should incorporate an excessive nitrogen yield limitation according to documented excessive nitrogen concentration thresholds (Gardner & Jackson, 1976; Knowles et al., 1991).

Another phenomenon observed by the grower in this field and document in literature but not captured by the Cropsyst-Microbasin is complex interaction between nitrogen and water uptake rates called 'haying-off' (Herwaarden et al., 1998a, 1998b; 1998c). The grower at the field site observed that his yields have increased with variable rate application; because he has actually seen an *increase* in yields in the areas he now applies a low rate of fertilizer. However, in comparing the whole-watershed uniform and variable rate simulation, CropSyst-Microbasin predicts a *decrease* in low-zone yields under variable rate application. This grower-observed phenomenon may be the documented "haying-off" response of wheat under excess nitrogen and limited water conditions (Herwaarden et al., 1998a, 1998b; 1998c). For the model to more accurately simulate areas of the field that may see decreases in yield under higher nitrogen applications, this "haying-off" response should be incorporated. In order for the "haying-off" response to work, the model should also incorporate crop water uptake as a function of nitrogen availability and use (Brown, 1971). In the current version of the model crop water uptake rates do not vary with crop nitrogen uptake. In actuality, the increased early season water use is what drives the late-season water-limited “haying-off” response in the low-yielding areas of the study site. These limitations should be addressed in future versions of CropSyst-Microbasin in order for the model to be able to capture some of the key interactions and feedback mechanisms observed in the region that can have a great impact on the amount of nitrogen fertilizer needed to optimize crop yield.

These model process limitations must be considered when interpreting the outputs for watershed and hillslope simulations. However, even with these known limitations, there are some interesting insights to be gleaned from the hillslope scenarios. The hillslope scenarios provide a basis to build future fertilizer management scenarios. Future scenarios should examine the effect of slope, soil type, and weather on the efficiency of different fertilizer management techniques. The hillslope scenarios indicate spring application of fertilizer will likely result in higher fertilizer efficiency.

Outputs from the hillslope scenarios demonstrate the ability of CropSyst-Microbasin to model the impact that lateral redistribution of nitrogen may have on yield (and therefore returns to risk). When the optimum fertilizer rates were applied to each hillslope position under the *CropSyst-based* scenario (Table 12), the yield outputs (and returns to risk) were lower than each hillslope maximum returns to risk in the optimization trials (Table 14). We hypothesized that the higher yield and returns to risk in the series of optimization rates were due increased lateral redistribution of nitrogen. In the optimization rate simulations, a uniform rate was applied across the entire hillslope. Therefore, when the fertilizer rates on upslope positions were lowered in the *CropSyst-based* simulation, less nitrogen was available to move laterally and contribute to down-slope yield increases. This provided the impetus to run the *Lateral* scenario, which further proved that the lateral redistribution of nitrogen contributes to slight increases in downslope yields. On certain landscapes where lateral redistribution of nitrogen may be a key process, CropSyst-Microbasin will be a useful tool to assess fertilizer management options.

The hillslope results must be taken in consideration with the real-world limitation of the growers. Especially on the eastern edge of the Palouse, which is where the study site is located, growers struggle with overly wet soils in the spring, limiting their ability to drive on their fields and may limit the feasibility of spring application. Additionally, applying a variable rate of fertilizer in the spring will likely require additional start-up machinery costs as spring application is generally broadcast rather than incorporated into the soil as in the fall. The hillslope scenarios provide a window into the significance of lateral redistribution of nitrogen in Palouse fields.

A more detailed look at the spatially explicit areas of the watershed where CropSyst-Microbasin over- or under-predict nitrogen uptake in comparison to NDRE-based values may provide a more thorough understanding of the drivers of crop nitrogen uptake. This could include an analysis of soil field capacity, in-season water content, plant available water, and soil organic matter. This analysis could be especially fruitful if other field sites across the Palouse are incorporated.

Conclusion

This study provides a first-look at the utility of CropSyst-Microbasin in assessing optimum fertilizer management practices on variable landscapes such as on the Palouse. We identified shortcomings that should be addressed to make the model more robust for real-world application: nitrate stripping in the top layers of soil and the maintenance of high yields under excess nitrogen and water conditions. CropSyst-Microbasin accurately predicted field observations of spatial and temporal changes in soil water content (simulated v. observed RMSE = 0.03 m^3/m^3), total surface runoff (NSE = 0.62), and average crop yield (observed = 92 bu/ac, simulated = 89 bu/ac). In the 2013 winter wheat production year, variable rate fertilizer application decreased overall nitrogen losses by 21 kg-N in a 10.9 ha field. Hillslope simulations demonstrated no decrease in N loss under a yield-based variable rate fertilizer application and a 12.3% reduction in N loss under a CropSyst optimum fertilizer scenario, highlighting a potential use of the model to inform fertilizer management. The whole-watershed predictions should be analyzed in conjunction with other metrics (such as NDRE) to explore spatial drivers of variability, including a comparison with other field sites on the Palouse. Future whole-watershed simulations should be run for more years, with an adjustment of applied nitrogen according to the differences in end-of-season soil N content (Figure 17) to explore the long-term effect of each fertilizer management type. The hillslope simulations should examine the effect of slope, soil, and weather on fertilizer efficiency. CropSyst-Microbasin should be used as a tool alongside field observations and the practical knowledge of growers, researchers, and agency personnel. To highlight the importance of this, the shortcoming mentioned previously would not have been identified without assessing model outputs alongside observed field data and practical knowledge.

Chapter 4. Starting to Address Barriers to Adoption of Precision Agriculture on the Palouse

Abstract

Precision fertilizer management has promise for addressing nitrogen loss issues on the Palouse while lowering fertilizer costs for growers. However, even with government financial incentives programs (Nutrient Management Plans, or "NMPs") that are targeted to overcome start-up costs and increase adoption, precision fertilizer practices are not commonly used. This study increases understanding of financial and non-financial barriers to adoption of precision practices. We conducted a budget analysis and found that farms using precision practices are profitable in the region (average yield 92 bushels per acre, average returns to risk $157 per acre). We assessed participation in government incentive programs and adoption of improved nutrient management practices through an exploratory mixed-methods social study (survey and interviews) of growers. Forty-two percent of growers surveyed have participated in precision fertilizer NMPs. From the survey, the most commonly identified reasons for not participating in NMPs were insufficient financial incentives and too much paperwork involved in participation; one of the least common barriers was too much time involved in implementation. Interviewed growers commented that successful implementation of precision practices is highly profitable and productive but time consuming. To increase adoption of precision fertilizer practices, information obtained from grower interviews and their economic analyses should be disseminated in a way that fosters grower-to-grower connections and education.

Introduction

Precision fertilizer application is a promising management strategy to improve nitrogen fertilizer efficiency by applying a variable rate of fertilizer to match field-scale variability in crop nutrient needs (Huggins, 2010). It is particularly well suited to highly heterogeneous landscapes like the Palouse. Under precision fertilizer management, fewer fertilizer inputs are needed to maintain or even increase average yields. This is a win-win situation: growers lower fertilizer costs and maintain yields and less nitrogen is added to the fields, which lowers the risk of nitrogen loss to the surrounding environment.

Precision fertilizer application requires specialized equipment, thus it can have high start-up costs. However, there are government conservation incentives programs (Nutrient Management Plans, or "NMPs") that work to overcome the initial financial barrier. Even though precision practices are promising for the environment it is not a commonly used method on the Palouse. These incentives programs were developed to help growers get started.

Adoption of new farming practices is generally fairly slow; there are many likely barriers to adoption. A meta-analysis of U.S. adoption studies found that common indicators of likely adopters are: capital, education, income, farm size, access to information, positive environmental attitudes, environmental awareness, and use of social networks (Prokopy et al., 2008). Another meta-analysis concluded that the indicators with the most impact on adoption include: access to and quality of information, financial capacity, and use of agency or local networks such as farmer or watershed groups (Baumgart-Getz et al., 2012). Meta-analyses of U.S. adoption of farm conservation practices highlight that results can be variable and given the wide political and cultural differences across the United States, localized studies may be much more informative than generalized conclusions (Baumgart-Getz et al., 2012; Knowler & Bradshaw, 2007; Prokopy et al., 2008).

Studies focused on precision agriculture adoption have found that access to information about precision technology is not limiting adoption (Daberkow & McBride, 2003). Likely barriers are uncertainty in profitability and a lack of demonstrated effects on yield, input use, and environmental outcome (Khanna et al., 1999). If new practices are profitable in the long term, they may be more likely to be adopted (Prokopy et al., 2008). Government incentives programs only provide financial assistance for the first three years of implementation. Therefore, communicating the potential for long-term profitability of precision fertilizer practices to growers may be essential to increase adoption.

Results from a long-term research project focused around the Palouse Region, Solutions to Environmental and Economic Problems (STEEP), found that expense in adopting new tillage practices is a common barrier (Kane et al., 2012). In addition, it was found that peer conservation leaders (other local growers) may be the most influential in grower conservation tillage decisions (Kane et al., 2012). Boie (2013) found that common barriers to adoption for Palouse growers (in Whitman County) are: profitability, lack of understanding, lack of trust, grower resistance to toothless mandates, and concerns over the local applicability of the practice. Common reasons for Palouse growers to adopt conservation practices included: sense of stewardship, generational change, public demands for conservation, profitability, trusted education & outreach, and local influence. An important theme that was repeatedly observed by Boie (2013) was the need for outreach and communication of conservation practices from those with deep-rooted local understanding. If the communicator is perceived as a local, with understanding and appreciation of what is in the grower's best interest, the information is much more likely to be internalized.

Boie (2013) also examined the cultural worldview of growers and "information sources" in Whitman County. The information sources included people from universities, government agencies, and farm business professionals. She found that growers tend to fall into the "hierarchical individualist" worldview, and Whitman County information sources are more likely to fall into the "egalitarian communitarians" worldview. This has practical implications because people tend to only trust information from those that share the same worldview (Kahan et al., 2011). To address this disconnect between Palouse information sources and growers, Boie (2013) calls for increased peer-to-peer outreach and for the establishment of strong partnerships. Professionals will have greater success if they have practical local farming knowledge, display a vested interest in the grower's operation, and share a cultural worldview with the grower (Boie, 2013; Genskow & Wood, 2011).

The present study aimed to *begin* overcoming barriers to adoption of precision practices on the Palouse by delving into the needs that have been outlined above. The objectives for this study were to 1) assess the profitability of precision fertilizer practices once they have been implemented on the farm and government financial incentives have ceased; 2) understand and quantify local participation in government incentives programs, adoption of new nutrient management practices apart from incentives program, and reasons for non-adoption through a concurrent mixed-methods social study (survey and interviews); and 3) from the interviews in Objective 2, provide the groundwork for localized peer-to-peer outreach efforts by displaying how four Palouse growers have successfully adopted precision fertilizer practices and made use of government incentives programs.

Methods

Study Location

This study was conducted in the cereal grain-producing region of the inland Pacific Northwest. A large portion of this area is known as "The Palouse." The region was broken up into agro-ecological classes according to distinct production practices and environmental conditions, primarily driven by a precipitation gradient across the region with low annual precipitation in the west (~15 cm/yr) and higher annual precipitation in the east (~75 cm/yr) (Figure 19) (Huggins et al., 2014). This study assessed the long-term profitability of precision fertilizer practices for growers located in the annual cropping zone (Objective 1). The annual cropping zone is located on the wetter, eastern side of the Palouse and receives higher annual precipitation than the rest of the region, which typically has sufficient rainfall to produce a crop every year without the risk of excessive crop water stress. Feedback from a longitudinal survey across the entire grain production region (Figure 19) was synthesized to quantify participation in incentives programs, examine adoption behavior, and to identify reasons for not adopting management practices (Objective 2). Lastly we provide a summary of the experiences from four growers in the Palouse who successfully adopted precision fertilizer practices and took advantage of government incentives programs as an initial step in providing the groundwork for localized peer-to-peer outreach efforts (Objective 3). For a detailed description of the environmental conditions and farming practices in the region, see Chapter 1. Introduction.

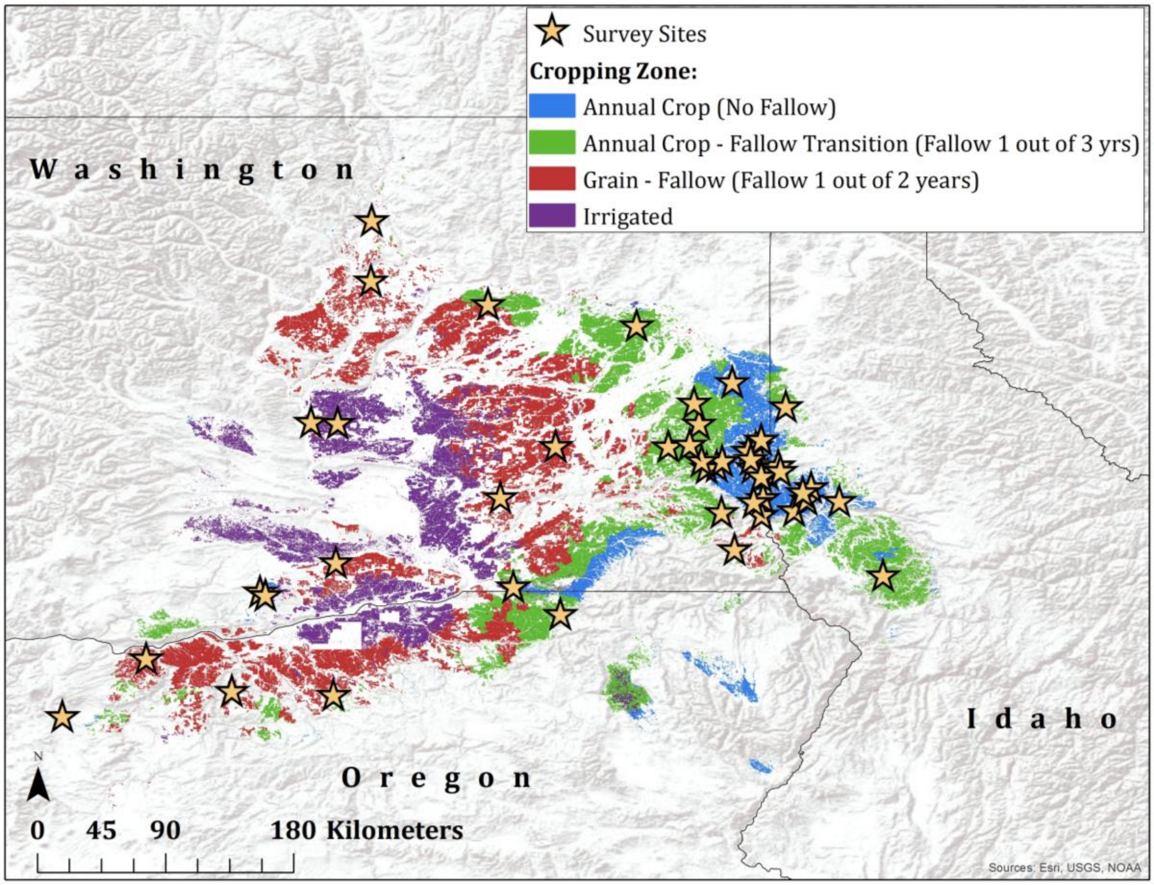


Figure 19. Agroecological classes of the Inland Pacific Northwest cereal grain-producing region and locations of longitudinal surveys (Huggins et al., 2014).

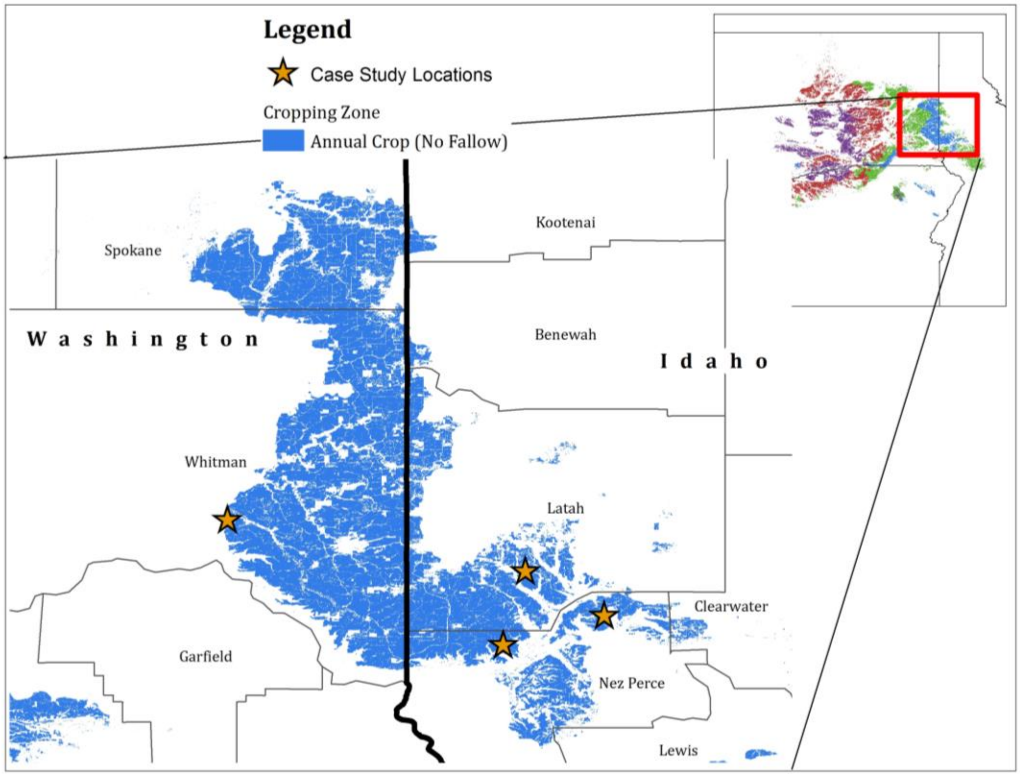


Figure 20. Grower interview locations in the annual cropping zone of the Inland Pacific Northwest cereal grain-producing region.

Objective 1: Budget Analysis

We compared annual farm enterprise budgets of three production techniques: precision fertilizer application with conservation tillage "precision," uniform fertilizer application with conservation tillage "uniform," and uniform fertilizer application with conventional tillage "conventional." The uniform and precision budget information for the 2011-2014 growing seasons was obtained from Davis (2014), whereas the conventional budget information was obtained from Idaho Extension budgets (Painter, 2014). The Davis (2014) budgets consist of early adopters with regard to conservation practices, and therefore are not representative of all growers in the region.

The Davis (2014) budgets were generated with growers providing specific farm management practices (seeding rate, fertilizers, pesticides, equipment usage, etc.) and average farm yields from 2011 through 2014. Each year of the survey, growers described their farming practices in detail, including timing, inputs, and machinery. This information was used to classify the grower as "precision" or "uniform," create an enterprise budget, a schedule of operations, and a list of machinery for each grower every year. Examples of the growers' worksheets that describe their farming operations and machinery complement can be found in Appendices C & D.

In the Idaho Extension budgets "conventional," assumptions include: 1) crop prices are typically based on 5-year average prices; 2) a 2500-acre farm is assumed; and in both the Idaho Extension budgets and the Davis budgets, it was assumed that: 3) input prices, such as fertilizer, are based on a survey of input suppliers for the region; and 4) land costs are based on a typical lease agreement for the area, where one-third of the fertilizer, chemical, and crop insurance costs are covered by the land owner and two-thirds are covered by the tenant. In each detailed budget table for precision, uniform, and conventional production (in Appendix E), the operating interest was calculated as 5.75% on operating capital for 9 months, the overhead costs cover legal, accounting, and utility fees, calculated as 2.5% of operating expenses, and the management fee as 5% of gross revenue.

The primary metric used to compare production types was "returns to risk:"

$$Returns\ to\ Risk\ (\$/acre) = (Crop\ Yield\ \times\ Crop\ Price) - Total\ Cost\ of\ Production$$

Objectives 2 & 3: Mixed Methods Social Study

We used a concurrent mixed methods study approach to explore and quantify local participation in government incentives programs, adoption of new nutrient management practices apart from incentives program, and identify reasons for non-adoption. A survey of early adoption growers was used to quantify participation in NMPs and overall adoption of best nutrient management practices regardless of whether the grower participated in a government incentive program. We also conducted semi-structured interviews with four precision growers in the annual cropping zone of the Palouse.

The survey quantified the percentage of growers participating in NMPs and identified the primary reasons growers have not participated in NMPs across the greater inland Pacific Northwest grain-producing region. The survey is part of the Regional Approaches to Climate Change (REACCH) – Pacific Northwest Agriculture project (USDA-AFRI project 2011-68002-30191). It included 48 wheat growers across the region, 22 of which are located in the annual cropping zone. The longitudinal survey was conducted once per year and collected detailed social, economic, agronomic, biotic, and climatic issues on the farm (Painter et al., 2014). Each year the growers answered standard, fixed questions along with new questions generated by regional scientists to better inform interdisciplinary agricultural research. In order to keep the length of the interview process within a reasonable amount of time we were limited to just three questions regarding the adoption of NMPs. In addition, the survey participants had been predetermined and were primarily growers considered early adopters of new farming practices.

The following three questions were added to the 2015 version of the REACCH survey:

1. The NRCS facilitates the Environmental Quality Incentives Program (EQIP) and the Conservation Stewards Program (CSP) to address environmental concerns. A component of some agreements are **Nutrient Management Plans.** Using the following responses**, please indicate your level of involvement in Nutrient Management Plans**:
   (Circle all that apply)
   a. Basic Nutrient Management Plan *(source, time, rate, method & buffers, etc)*
   b. Enhanced Nutrient Management Plan *(split application, stabilizers, tissue tests, post-harvest soil test, etc)*
   c. Adaptive Nutrient Management Plan *(evaluate & adjust application over multiple seasons)*
   d. Precision Nutrient Management Plan *(use of precision techniques and tools)*
   e. Other (list):____
   f. I have never included a Nutrient Management Plan in a CSP or EQIP agreement
   g. I have never participated in CSP or EQIP
2. If you **have not** participated in a Nutrient Management Plan, why not (please mark all that apply)?
   a. ___ Equipment and/or software needed to implement a *Precision* Nutrient Management Plan is too expensive
   b. ___ It is risky to decrease overall fertilizer inputs
   c. ___ Too time-consuming to implement and maintain new practices
   d. ___ The management practices promoted in Nutrient Managements Plans are not compatible for my farm
   e. ___ Too much paperwork involved
   f. ___ Financial incentive is too small
   g. ___ I need technical support or training from agency or extension professionals
   h. ___ I need technical support or training from other growers
   i. ___ I need technical support or training from other agri-business professionals
   j. ___ I don't want to work with the NRCS
   k. ___ Other (specify)
3. Which of the following nutrient management practices would you do on your farm in the absence of any government financial incentives or eligibility requirements (please mark all that apply)?
   a. ___ Pre-plant soil test to determine fertilizer rate
   b. ___ Pre-plant AND post-harvest soil test to determine appropriate fertilizer rate
   c. ___ Buffer strips near streams, ditches, etc.
   d. ___ Split application of fertilizer (multiple applications on one crop)
   e. ___ Variable rate fertilizer
   f. ___ Follow recommended "4 R's" –**R**ight source of nutrients, **R**ight time of application, **R**ight fertilizer rate, and **R**ight method of application
   g. ___ Other (specify)

For the four in-person semi-structured interviews, we used the following open-ended questions:

1. What are the overall costs and benefits of adopting variable rate fertilizer practices on your farm?
2. What has been your experience with programs such as EQIP (or others) that provide financial incentives for adopting variable rate fertilizer practices?

Results

Objective 1: Budget Analysis

Precision farms averaged 92 bushels per acre of Soft White Winter Wheat (SWWW) from 2011 through 2014. During the same time period, conventional farms (uniform fertilizer application and conventional tillage) averaged 80 bushels per acre and uniform farms (uniform fertilizer application and conservation tillage) averaged 90 bushels per acre (Figure 21). Precision farmers averaged $157 per acre in returns to risk for SWWW from 2011 through 2014. During the same time period, conventional farms averaged $66 per acre in returns to risk and uniform farms averaged $191 per acre in returns to risk (Figure 22).

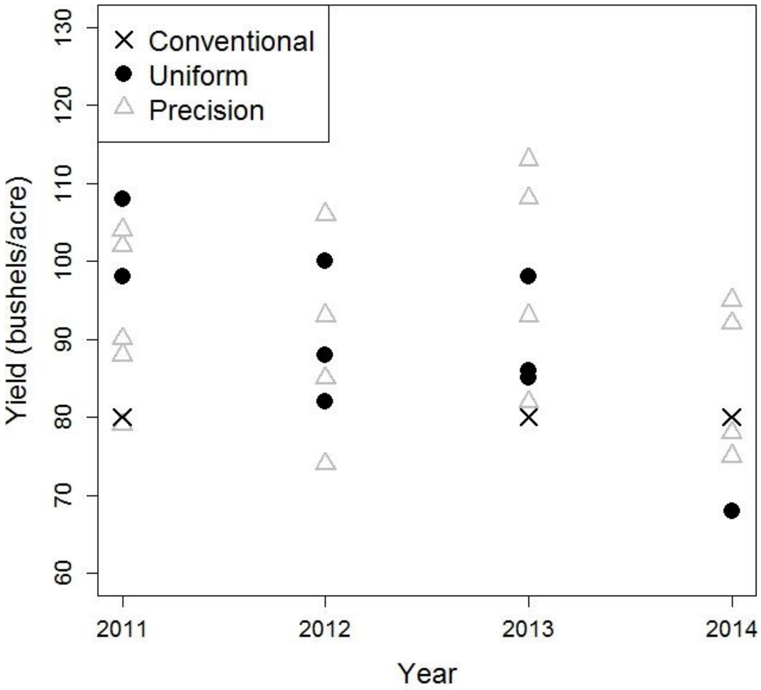


Figure 21. Soft white winter wheat yields 2011 - 2014 on conventional, uniform, and precision farms.

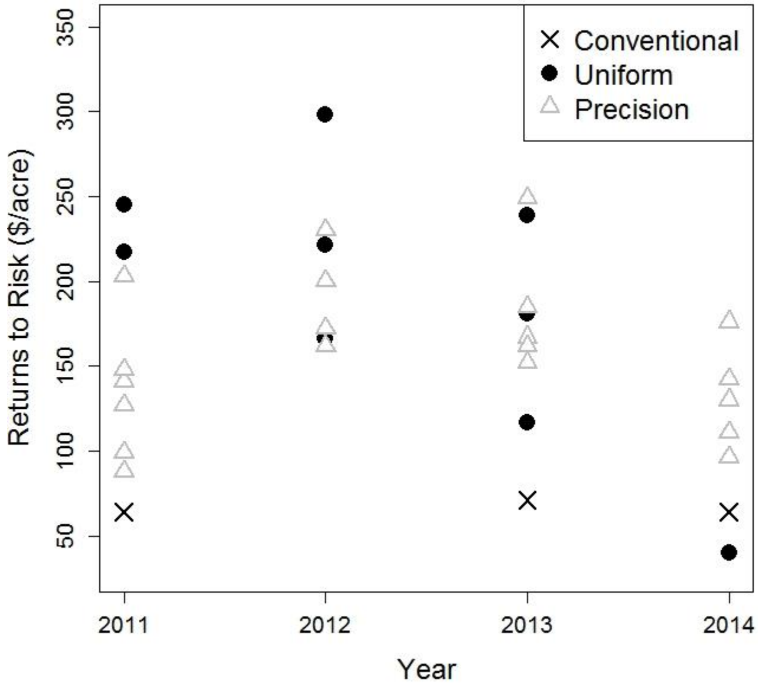


Figure 22. Soft white winter wheat returns to risk 2011 - 2014 on conventional, uniform, and precision farms.

The conventional production results in minimal variability between years because it is an average regional budget, not based on specific, individual farm budgets as the precision and uniform values. Annual yield, wheat price, revenue, and total cost of production can be found in Table 16.

Table 16. Comparison of Soft White Winter Wheat budgets under precision fertilizer management with conservation tillage ("Precision"), uniform fertilizer management with conservation tillage ("Uniform"), and uniform fertilizer management with conventional tillage ("Conventional").

Year	Production Type	Yield (bu/ac)	Price per bushel	Total Cost (TC) of Operation	Returns over TC ($/ac)
2014	Conventional	80	$6.70	$472	**$64**
	Uniform 2	68		$419	**$36**
	Precision 1	75		$406	**$96**
	Precision 2	92		$505	**$111**
	Precision 3	78		$380	**$143**
	Precision 4	92		$486	**$130**
	Precision 5	95		$461	**$176**
2013	Conventional	80	$6.75	$469	**$71**
	Uniform 1	86		$400	**$181**
	Uniform 2	85		$456	**$117**
	Uniform 3	98		$422	**$240**
	Precision 1	93		$442	**$186**
	Precision 2	108		$576	**$153**
	Precision 3	82		$386	**$168**
	Precision 4	93		$466	**$162**
	Precision 5	113		$514	**$249**
2012	Uniform 1	88	$7.50	$439	**$221**
	Uniform 2	82		$449	**$166**
	Uniform 3	100		$452	**$298**
	Precision 1	85		$437	**$201**
	Precision 2	106		$564	**$231**
	Precision 3	74		$392	**$163**
	Precision 4	93		$526	**$171**
2011	Conventional	80	$6.50	$456	**$64**
	Uniform 1	98		$420	**$217**
	Uniform 2	108		$457	**$245**
	Precision 1	90		$443	**$142**
	Precision 2	90		$485	**$100**
	Precision 3	79		$366	**$148**
	Precision 4	102		$536	**$127**
	Precision 5	104		$473	**$203**
	Precision 6	88		$484	**$88**

Detailed annual budgets for precision, conventional, and uniform farms can be found in Appendix E.

Objectives 2 & 3: Mixed Methods Social Study

Survey

Due to time constraints, 33 of the 49 in-person REACCH surveys were completed for the 2015 survey (Figure 23). A total of 16 (48%) have participated in a Basic NMP, ten (30%) have participated in an Enhanced NMP, 12 (36%) have participated in an Adaptive NMP, and 14 (42%) have participated in a Precision NMP (Figure 24). Five growers (15%) have never participated in EQIP or CSP and an additional five have never included a NMP as a part of any EQIP or CSP contract. The two most common responses for reasons for not participating in a NMP were that there is too much paperwork involved and that the financial incentives are too small (four responses each). The least common reasons were: it takes too much time to implement, need support from other growers, and don't want to work with NRCS (one response each). Nearly all of the growers (32 of 33) indicated they conduct pre-plant soil tests to determine fertilizer rates without financial incentives to do so. Twenty-two growers (67%) indicated they practice variable rate and split application without financial incentives. Seven respondents indicated they install buffers without financial incentives.

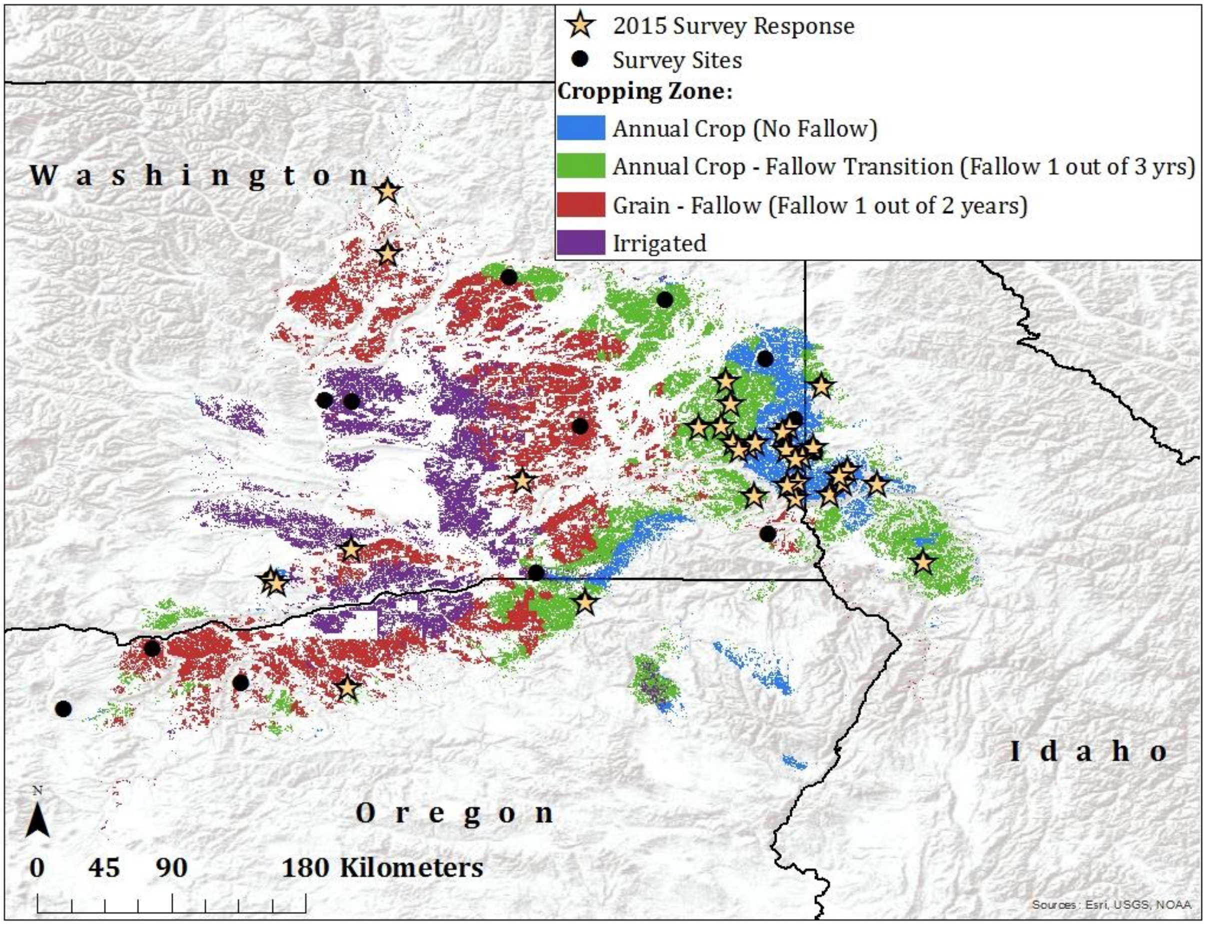


Figure 23. Map of 2015 completed in-person longitudinal surveys.

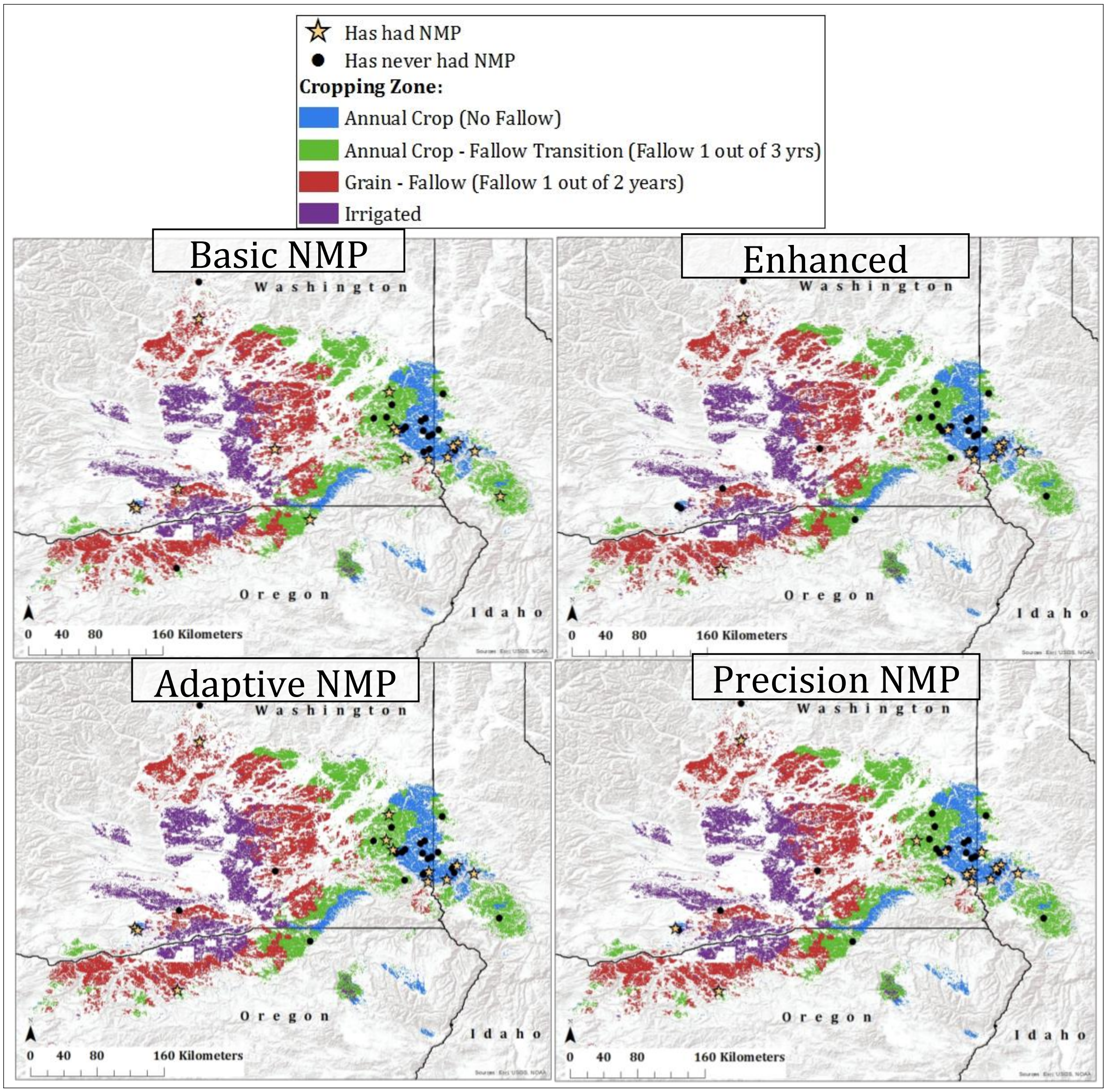


Figure 24. Map of growers that have adopted Basic, Enhanced, Adaptive, and Precision NMPs.

Interviews

The interviews with the growers showed that all four have found precision practices to be profitable and beneficial to their overall farm production. All four growers made use of various government incentives programs when they first adopted precision practices. Two of the growers reflected on the significant amount of time it took to successfully implement these practices on their farm. Each grower took a slightly different path to implementing precision practices and they each have unique approaches to applying the practices on their land. Each grower interview is described below with summary farm information and take-home messages from the grower followed by a more in-depth discussion of the interview. See Table 17 for a summary comparison of the four farms and grower interview results.

Table 17. Summary of grower farm conditions and take home messages.

	Annual Precip. (mm)	Ave. Winter Wheat yield 2011 – 2014 (bu/ac)	Ave. Returns to Risk ($/ac)	Take Home Messages
Grower 1	750	95	147	EQIP was essential; no set formulas to adopt precision
Grower 2	600	105	239	EQIP & CSP was essential
Grower 3	650	91	147	Precision gave a yield increase and more consistent protein quality; biggest cost is time
Grower 4	500	77	124	Precision is worth it; big cost is time

Grower 1

Quick farm facts:

-Roughly 750 mm of annual precipitation
-Average winter wheat yield 2011-2014 of 95 bushels per acre
  -Average returns to risk for winter wheat production of $147 per acre
  (See Table 18 and Table 19 for budget summaries)

Take home messages from the grower:

-I couldn't have started 7 years ago without the financial assistance from EQIP
-There are no set formulas for adopting precision fertilizer practices
-If I were to start today, I wouldn't be able to meet the current EQIP standards

Grower 1 started using precision fertilizer practices 7 years ago with financial assistance from the EQIP program and technical assistance from Trimble®. Without the EQIP program, his investment in new equipment would have had to be spread out over 5 years, and he likely would not have gone through the transition. He was the first to adopt variable rate fertilizer practices in his county, so with no one to provide advice or to give an example he was left to pave his own path.

Grower 1 estimated that his return on investment was seen within a couple of years. His estimate of the overall input costs for new equipment was $16,000 - $20,000 and he received $15,000 in financial assistance spread over three years. His start up equipment costs included purchasing a monitor ($4,000), a controller ($2,000), auto steering and auto shutoff, and building a backpacker applicator ($10,000). He also noted the non-financial "cost" embedded in adopting variable rate practices—it was fairly time consuming to learn and growers must have the mindset going in that they *want* to learn. Now that he has established methods for variable rate application on his land, he sees his biggest benefit as cost savings through using less fertilizer. He has decreased his overall fertilizer use by a third, which is 3-4 semi loads (~6,000 gallons) totaling $16,000 - $24,000 in savings per year. The investment in auto shutoff was the quickest to pay itself off because it lowers the total fertilizer needed and the total amount of chemicals applied. He said the trick with successfully implementing variable rate practices and quickly gaining the return on investment is to decrease the overall fertilizer use while maintaining yields, which can take some time to perfect.

This grower based his fertilizer zones on the previous yield maps, with adjustments according to his experience and knowledge of the land. With the Farm Works Software® he uploads the yield monitor data and the program delineates his fields into three zones: high, medium, and low fertilizer application rates. Occasionally, he will adjust certain zones and has the ability to convert an area of "low" application to "medium," but the program will not allow an area to go from "low" to "high." An example is when an area comes up as a "low" yielding area, but he knows from experience that it yielded low because that area of the field was too wet. Then in a drier year that portion of the field may be able to yield higher, so he will adjust it to a "medium" level.

According to grower 1, the *key* to raising overall farm yields with precision fertilizer application is to target the low zones. On his farm, a lot of the low yielding areas have thin soils (shallow restrictive layers and shallow rocky/compacted soil). These areas will actually yield *higher* with *less* fertilizer, because with a greater amount of initial N in the soil the crop will grows quickly in the early part of the season. However, the thin soil runs out of water much earlier in the season than areas with deeper soils, leaving the crop suddenly out of resources to fully mature, resulting in a lower yield.

Since he adopted precision fertilizer practices with financial assistance from EQIP, there have been important changes in the qualification requirements of EQIP (see note below this paragraph).** Seven years ago, the grower was able to enroll and receive financial incentives for precision fertilizer practices without needing to convert to no-till, though he was required to drop three tractor passes, considered conservation tillage. He farms on the far eastern side of the annual cropping zone, which has the highest annual precipitation in the region. No-till practices exacerbate his common problem of dealing with *too much* water. A field being managed without tillage holds in more moisture, a small amount of tillage breaks up the soil surface allowing more moisture to escape, a necessary process nearly every year in this zone. However, to join EQIP now and receive financial assistance for adopting precision fertilizer practices, growers are essentially required to adopt no-till, which is problematic for two reasons.

First of all, growers in this zone are highly unlikely to adopt no-till because of the excess water issues. Secondly, he said if a grower is required to adopt no-till in order to receive financial assistance for new precision fertilizer practices, the initial investment costs quickly skyrocket, becoming prohibitively expensive. The grower explained that if he had been required to purchase no-till equipment, the start-up cost would have been closer to $500,000, rather than the much easier to swallow $16,000 - $20,000. In that case he would not have adopted precision fertilizer practices, which would mean an additional 6,000 gallons of fertilizer being placed on his fields every year. He described the EQIP program as working exactly like it should when he started seven years ago. However, he is dismayed at how ineffective it has become with essentially a no-till requirement in an area where no-till is not viable because of excess water. He also exhibited frustration with the CSP program because of the huge amounts of paperwork required to participate in it.

**After asking the local NRCS staff about any changes to the tillage requirements, it became clear the grower description of tillage requirements is likely a mis-understanding of the policies. However the policies as explained by the NRCS may pose similar problems. When a grower wants to sign up for a nutrient management plan, they must also make improvements to soil conservation. Therefore, if a grower has already adopted aggressive conservation tillage, the only next step for improving the soil conservation score is to adopt no-till. Without making this improvement in tillage operations, the grower would be ineligible for nutrient management plans. Thus, the grower would deal with the problems described above. However, if a grower were currently using conventional tillage, adopting conservation tillage practices would allow them to be eligible for nutrient management plans.

Table 18. Summary of annual wheat production costs for Farm 1.

Year and Crop	**Yield (bu/ac)**	**Price**	**Revenue ($/ac)**	**Total Cost of Operation**	**Returns to Risk ($/ac)**
2011 Soft White Winter Wheat	102	$6.50	$663	$536	**$127**
2012 Soft White Winter Wheat	92	$7.50	$694	$526	**$167**
2013 Soft White Winter Wheat	93	$6.75	$628	$466	**$162**
2014 Soft White Winter Wheat	92	$6.70	$616	$486	**$130**
2011 Dark Northern Spring Wheat	42	$8.00	$336	$394	**-$58**
2012 Dark Northern Spring Wheat	45	$8.50	$383	$402	**-$19**
2013 Spring Wheat	50	$7.15	$358	$396	**-$38**
2014 Spring Wheat	40	$7.10	$284	$343	**-$59**

Table 19. Farm 1 Soft White Winter Wheat 2014 breakeven analysis.

	-10%	**Base Yield**	**+10%**
Price	82.80	92	101.20
Operating Cost Breakeven	$3.40	$3.06	$2.78
Ownership Cost Breakeven	$2.47	$2.22	$2.02
Total Cost Breakeven	$5.87	$5.29	$4.81
	10%	**Base Price**	**10%**
Yield	$6.03	$6.70	$7.37
Operating Cost Breakeven	46.7	42.1	38.2
Ownership Cost Breakeven	33.9	30.5	27.8
Total Cost Breakeven	80.7	72.6	66.0

Grower 2

Quick farm facts:

-Roughly 600 mm of annual precipitation
-Average winter wheat yield 2011-2014 of 105 bushels per acre
-Average returns to risk for winter wheat production of $239 per acre
(See Table 20 and Table 21 for budget summaries)

Take home messages from the grower:

-In regards to EQIP & CSP programs: "I can't say enough good things about them"
-"You don't know until you try [something new], EQIP & CSP take the risk out of it."

Grower 2 started his path toward precision nitrogen application by first adopting direct seeding. After observing a couple of serious erosion events on his fields, he knew he had to change the way he was managing the land. So he purchased new direct seeding/no-till equipment with financial assistance from the EQIP program to establish new management practices to reduce erosion. In 2005, he purchased an Exactrix® for his no-till drill to improve the evenness of his fertilizer applications and reduce gaseous losses of the anhydrous ammonia fertilizer he uses. The cost of an Exactrix® system has nearly tripled since he purchased his rig, making it financially unfeasible for most individual growers today. He later purchased a yield monitor with CSP "enhancement" funds and started experimenting with precision fertilizer application—something the Exactrix® can do well with a variable rate application controller. As a result of the currently high Exactrix® cost, he recognizes that this is an unlikely path for an individual grower to take today. However, he recommended using the conservation programs such as EQIP and CSP to assist in purchasing new equipment to improve management practices, whether it is to address soil erosion, nitrogen loss, or other land management issues.

Grower 2 has modified his precision fertilizer techniques with experience and as new information arises. When he first started precision fertilizer application, his zones were based on outputs from the yield monitor. Working with his consultant, they delineated four zones: low, medium 1, medium 2, and high. He has found it useful to establish the overall rate of fertilizer for a field based on pre-plant soil N testing, but notes that zone-specific soil testing has not been useful on his farm. Recently, he and his consultant have started basing the prescription fertilizer maps on infrared images of the field. These maps align very closely with the zones based on yield monitor data.

Grower 2 spoke very highly of how EQIP and CSP have worked exactly as they were intended. With the financial assistance, he has been able to continually improve his management practices and address soil erosion and excess nitrogen problems. He is always striving to improve and said, “You don’t know until you try, EQIP and CSP take the risk out of it.” He just started a new EQIP contract to test out the use of cover crops. He planted 50 acres with a cover crop this past year and has areas where it has worked well, but also areas where it has not worked well. It is a learning process, and he will continue to learn and modify his land management.

Table 20. Summary of annual wheat production costs for Farm 2.

Year and Crop	**Yield (bu/ac)**	**Price**	**Revenue ($/ac)**	**Total Cost of Operation**	**Returns to Risk ($/ac)**
2011 Soft White Winter Wheat	104	$6.50	$676	$473	**$203**
2012 Hard Red Winter Wheat	106	$8.50	$899	$570	**$329**
2012 Dark Northern Spring Wheat	66	$8.50	$565	$414	**$151**
2013 Soft White Winter Wheat	113	$6.75	$763	$514	**$249**
2013 Hard Red Spring Wheat	75	$7.15	$536	$412	**$124**
2014 Soft White Winter Wheat	95	$6.70	$638	$461	**$176**
2014 Hard Red Spring Wheat	73	$7.10	$515	$414	**$101**

Table 21. Farm 2 Soft White Winter Wheat 2014 breakeven analysis.

	-10%	**Base Yield**	**+10%**
Price	85.67	95.19	104.71
Operating Cost Breakeven	$2.83	$2.55	$2.32
Ownership Cost Breakeven	$2.56	$2.30	$2.09
Total Cost Breakeven	$5.39	$4.85	$4.41
	10%	**Base Price**	**10%**
Yield	$6.03	$6.70	$7.37
Operating Cost Breakeven	40.2	36.2	32.9
Ownership Cost Breakeven	36.3	32.7	29.7
Total Cost Breakeven	76.5	68.9	62.6

Grower 3

Quick farm facts:

-Roughly 650 mm of annual precipitation
-Average winter wheat yield 2011-2014 of 91 bushels per acre
 -Average returns to risk for winter wheat production of $147 per acre (see Table 22 and Table 23 for budget summaries)

Take home messages from the grower:
-You can get into precision agriculture with $0 if you fully utilize EQIP & CSP
-Has seen a 10% increase in overall yield and more consistent protein content with precision quality
-Biggest cost is time

Grower 3 started using precision agriculture practices in 2005, with financial assistance from the EQIP program. He said that if you can fully utilize the EQIP and CSP programs, you can get into precision agriculture with $0, saying, “That’s how I did it.” In 2005, he was considered an early adopter, which surprised him. He was even more amazed at how slowly the practice has spread in the last ten years. He thought that it was a result of high wheat prices, which enable growers to become complacent. The lack of precision agriculture adoption surprised him so much because over 90% of the equipment driven on the fields around the Palouse are not being fully utilized with regards to precision capabilities. He saw the problem as more related to growers lacking the know-how of going from precision concepts and outputs of a yield monitor to actually creating a prescription map, rather than as an equipment purchase barrier.

He has been able to adopt precision nutrient management with minimal large equipment purchases. He recently built a fertilizer backpacker/applicator (with financial assistance from EQIP/CSP), which is controlled with a Trimble CFX-750 GPS (Figure 25). The fertilizer applicator is connected to a 38’ cultivator. There are three separate nozzle controls for each 12.6-foot section of the cultivator, each section may be separately shut off or adjusted to avoid double application on overlapping sections or corners (Figure 26).

He noted numerous costs and benefits for adopting variable rate. He saw the biggest savings through a lower cost per unit bushel produced and estimates an overall increase in yield of 10%, primarily in his Hard Red Winter Wheat. Another benefit is more consistent protein quality. The biggest cost is time, he usually spends about four days just taking soil samples, and then it takes a long time to organize all of the data and files needed to eventually make the prescription maps. He estimated that he usually spends roughly 60-100 hours per year preparing his prescription maps.

He suggests that the EQIP/CSP programs could be improved by placing more emphasis on providing training for growers who are interested in learning to apply precision fertilizer techniques on their own land. He did not think a grower should have to pay a crop or technology consultant to make the fertilizer maps. He thinks growers would be more successful in making fertilizer maps because each individual grower knows more about their own fields than anyone else ever can.

Table 22. Summary of annual wheat production costs for Farm 3.

Year and Crop	**Yield (bu/ac)**	**Price**	**Revenue ($/ac)**	**Total Cost of Operation**	**Returns to Risk ($/ac)**
2011 Soft White Winter Wheat	88	$6.50	$572	$484	**$88**
2012 Hard Red Winter Wheat	98	$8.50	$832	$604	**$227**
2013 Hard Red Winter Wheat	95	$7.38	$704	$545	**$159**
2014 Hard Red Winter Wheat	82	$7.10	$582	$412	**$170**
2011 Dark Northern Spring Wheat	50	$8.00	$403	$407	**-$4**
2012 Dark Northern Spring Wheat	51	$8.50	$434	$399	**$35**
2013 Dark Northern Spring Wheat	64	$7.15	$455	$330	**$125**

Table 23. Farm 3 Hard Red Winter Wheat 2014 breakeven analysis.

	-10%	**Base Yield**	**+10%**
Price	73.80	82	90.20
Operating Cost Breakeven	$2.79	$2.51	$2.28
Ownership Cost Breakeven	$2.79	$2.51	$2.29
Total Cost Breakeven	$5.58	$5.02	$4.57

	-10%	Base Price	+10%
Yield	$6.39	$7.10	$7.81
Operating Cost Breakeven	32.2	29.0	26.3
Ownership Cost Breakeven	32.3	29.0	26.4
Total Cost Breakeven	64.5	58.0	52.8

Figure 25. Fertilizer backpacker built by Grower 3.

Figure 26. Three valve system to vary application rate in three sections of the cultivator.

Grower 4

Quick farm facts:

-*Roughly 500 mm of annual precipitation*
-*Average winter wheat yield 2011-2014 of 77 bushels per acre*
-*Average returns to risk for winter wheat production of $124 per acre (see Table 24 and Table 25 for budget summaries)*

Take home messages from the grower:
-*"Just about all of it [precision agriculture] is worth it"*
-*A major cost is time troubleshooting the technology*
-*The best progress is made when the government, researchers <u>and</u> growers are working together and innovating*

Grower 4 first started with precision agriculture practices roughly 15 years ago. To first get started in precision agriculture, this grower worked with USDA/WSU researcher Dave Huggins on an NRCS "Conservation Innovation Grant" (CIG). He purchased his first Mid-Tech yield monitor set-up for $22,000 with $6,000 of financial support from the CIG. The rest of his precision agriculture purchases have been without financial assistance of any kind. He has never participated in a precision nitrogen contract with NRCS through EQIP or CSP, but in the 1990's he participated in a basic NMP for three years. The basic level requires grid soil sampling to establish overall fertilizer rates and pays a maximum of $10,000 each year for three years.

The precision agriculture equipment that Grower 4 uses includes a hoppered tank and an autoboom with deflectors. The hoppered tank is essential for the steep slopes this grower farms (up to a 45% grade). The autoboom is capable of changing the rate of application along seven sections of the boom. This is highly efficient for going around corners, when the outside of the boom may be going close to 30 miles per hour, while the inside of the boom is going less than five miles per hour. The boom automatically corrects for the different speeds, changing the rate of application accordingly such that the same amount of input (fertilizer, chemical, etc.) is applied per unit area. The autoboom will also shut off any portions of the boom that overlap with previous passes, providing significant savings. This grower recommends the autoboom only for large-scale operations because of its high price tag of $20,000.

To accomplish variable nitrogen fertilizer application, Grower 4 manually changes the rate as he drives around the field. He said, “We know the land, we know where it is good and where it is bad.” He felt better using a manually adjusted variable fertilizer because he felt he is better able to react to the landscape he knows so well. He said that you cannot trust the precision fertilizer application to be fully robotic yet, “you have to have a brain out there.” They based the overall fertilizer rates on soil samples, previous N applications and crop yields.

When discussing the overall costs and benefits of precision agriculture, he said, “just about all of it is worth it.” He went on to say that the precision sprayer is a “no-brainer” because he has seen huge savings through a reduction of total chemicals applied to his fields. The biggest cost he had, other than the initial equipment purchase costs, was the time spent troubleshooting computers and technology.

Grower 4 also discussed precision spraying for pests, concluding that it is difficult to utilize precision spraying because there is such a short window to spray in and if the technology fails, the window is missed. He has spent a lot of time troubleshooting the computer programs and discussed the frustration of the technology not working when you need it to. He has a family member who has been trained in computer programming, which makes it more feasible for his operation to troubleshoot programing/computer issues.

Another major struggle with precision agriculture highlighted by Grower 4 is decision-making with respect to equipment and technology purchases. Precision agriculture equipment and technology are expensive yet become obsolete fast. Therefore, the grower discussed the difficulty in deciding when to wait and when to purchase. He stressed the importance of being smart about when to purchase, recognizing the need to make an investment in the face of rapidly changing technology.

Grower 4 took a lot of pride in being ahead of the curve, even ahead of the NRCS conservation programs, with regard to conservation practices on his farm. He has found that he has been ineligible for the vast majority, if not all, of the EQIP and CSP financial incentives. He expressed frustration with the programs as being set up for growers with little or no conservation practices in place, and that once you are doing things well on the farm, you are no longer eligible.

When reflecting on the current and future status of conservation techniques, and specifically precision agriculture practices, he thought that innovative growers were the cornerstones to progress. It is the innovative grower that tries something new on their land and then when they find something that works, he said, "Well, then we go ask Huggins [the USDA researcher] why it worked." He expressed a positive partnership between innovative growers and agricultural research, and recognized the solutions and understanding will not come from just growers and will not come from just researchers. He felt that progress is made when the government, researchers *and* the growers are working together and innovating.

Table 24. Summary costs of production for Farm 4.

Year and Crop	**Yield (bu/ac)**	**Price**	**Revenue ($/ac)**	**Total Cost of Operation**	**Returns to Risk ($/ac)**
2011 Soft White Winter Wheat	100	$6.50	$650	$489	**$161**
2012 Hard Red Winter Wheat	75	$8.50	$638	$474	**$163**
2013 Hard Red Winter Wheat	68	$7.38	$502	$390	**$111**
2014 Hard Red Winter Wheat	66.5	$7.10	$472	$404	**$69**
2011 Soft White Spring Wheat	90	$6.50	$585	$510	**$75**
2011 Dark Northern Spring Wheat	90	$8.00	$720	$555	**$165**
2012 Dark Northern Spring Wheat	50	$8.50	$425	$405	**$20**
2013 Dark Northern Spring Wheat	45	$7.15	$322	$359	**-$37**
2014 Hard Red Spring Wheat	40	$7.10	$284	$355	**-$71**

Table 25. Farm 4 Hard Red Winter Wheat Production in 2014 breakeven analysis.

	-10%	**Base Yield**	+10%
Price	59.85	66.5	73.15
Operating Cost Breakeven	$3.46	$3.11	$2.83
Ownership Cost Breakeven	$3.39	$3.05	$2.78
Total Cost Breakeven	$6.85	$6.17	$5.60

	-10%	**Base Price**	**+10%**
Yield	$6.39	$7.10	$7.81
Operating Cost Breakeven	32.4	29.1	26.5
Ownership Cost Breakeven	31.8	28.6	26.0
Total Cost Breakeven	64.2	57.7	52.5

Discussion

NMPs to overcome start-up costs

All four growers that were interviewed recognized the start-up equipment costs for precision nitrogen management as a barrier to adoption. Each grower used government incentive programs to subsidize expenses related to adoption of precision practices. Three of farms worked directly with their local NRCS office to obtain financial help through the Environmental Quality Incentives Program and/or the Conservation Stewards Program. The fourth farm worked with a USDA researcher to obtain the funds through an NRCS Farm Innovation Grant. Each grower took a unique approach to adopting precision practices, with farm-specific choices of machinery and technology, farm-specific use of government programs, and farm-specific implementation on the field. One of the top responses in the survey for reasons to not adopt precision practices was "financial incentives are too small." Disseminating information on how the four growers made good use of the incentives available with respect to the specific needs of their farm may show other growers how the incentives can work on their own farm.

Long-term profitability

In assessing the profitability of precision practices after they have been fully implemented on the farm and government incentives have ceased, the precision and uniform farms produced similar yields from 2011-2014. The average returns to risk was higher for uniform farms over the same time period. To fully assess the profitability of precision practices, each year should be analyzed individually. However, due to the small sample size in this study, further budget comparisons should be conducted before drawing conclusions. This initial comparison does show the promise for precision practices to be profitable in the region.

Characteristics of the Precision Growers Interviewed

The precision growers tend to be "early adopters" in terms of new management practices. Through the interviews, it became apparent that they are very interested in learning about and trying new methods, including soil erosion, nutrient, and pest related practices. These growers are relatively tech savvy and work to incorporate new technologies such as GPS guidance for their tractors and advanced mapping techniques to improve the management of their farms. These growers are all “super” managers, putting a large amount of time and resources into managing their land in the best way they can. With the highly specialized tools they use to manage their farms, they end up with higher than average yields and larger profit margins than other farms in the region.

Increasing adoption on the Palouse

Precision fertilizer practices are a promising strategy for improving nitrogen management in the annual cropping zone of the inland Pacific Northwest. This zone has higher profit margins than the drier areas to the west (Davis 2014), providing greater financial capacity to bear the start-up costs. However, the start-up costs are often still a significant barrier to adoption, creating a perfect niche for the financial incentives to work effectively. The interviews illustrate the capacity for the financial incentives to work exactly as intended. Then the budget analysis demonstrates that once the start-up costs are overcome, precision farms tend to out-profit uniform farms.

Through the interviews and longitudinal survey, a key issue with the effectiveness of the NMP policy is the strict eligibility requirements. Often, to be eligible for the program, a grower must adopt no-till, which can greatly increase the start-up costs by necessitating the purchase of a no-till drill in addition to precision fertilizer application equipment. No-till is an unfeasible practice on the eastern edge of the annual cropping zone where growers are more commonly dealing with too much water. If this makes a grower ineligible, they end up maintaining current practices and adopting no new conservation methods. If nutrient management is a priority conservation practice on the Palouse, this barrier to eligibility should be overcome through policy implementation changes.

In the interviews, a common theme was that a major “cost” to implementing precision practices is time. However, this was one of the least common survey responses for a reason to not adopt. Also, a common theme in the interviews was that the government incentives programs worked exactly as they should, but in the survey “financial incentives are too small” was among the most common reasons for not adopting. These anomalies may be due to survey limitations (described in the next section), misperceptions among non-adopters, or unique farm circumstances.

The four semi-structured interviews provide tangible examples of how different growers in the annual cropping zone have profitably transitioned to precision fertilizer practices, providing excellent outreach material to increase adoption. As described in the introduction, growers on the Palouse tend to be of the "hierarchical individualist" worldview, whereas information sources (university researchers and agency personnel) tend to be "egalitarian communitarians" (Boie, 2013). This is problematic because people tend to only internalize information when it is coming from someone with a shared worldview. This is where the interview information may be highly useful: if we incorporate the grower interviews into extension materials or programs and let the examples speak for themselves the material may be more impactful to local growers than if it were presented in a classic scientific outreach format. An example of this already working locally is the REACCH Case-Study of Eric Odberg (Yorgey, Kantor, Painter, Davis, & Bernacchi, 2014). This approach may also help to foster grower-to-grower connections and mentorship within the region.

Limitations of Survey Data

The longitudinal survey questions showed a high participation rate in NMPs, with only 10 of the 33 respondents having never participated in a NMP contract. This was surprising given the low participation rate provided by the Latah NRCS office of ~20% of EQIP contracts containing a NMP. However, the question did not get at annual participation rate, but rather asked if the grower *had ever* participated in a NMP. Therefore, it may be a limitation of the questions, making it difficult to draw conclusions. Additionally, the survey is primarily of growers that are considered to be "early adopters" when it comes to conservation practices, so the high participation rates are likely un-representative of the general farm population.

Another potential problem with the survey questions is a misunderstanding of what we meant by "Nutrient Management Plan." This is because a couple of growers responded that they had participated in NMPs, but never in EQIP or CSP. However, the intent was to only consider a NMP official if it had been a part of an EQIP or CSP contract, potentially compromising the results. We intended to quantify how many growers were adopting these practices separate from NMP incentives versus how many were adopting the practices with the financial incentives. This information would inform how effectively the policy is actually promoting adoption.

There were also issues with the answers to question 3 about what the growers would do on their farm in the absence of financial incentives. Growers 1-3 indicated in interviews that the financial incentives were integral in their ability to adopt precision fertilizer practices in the first place; however, in answering question 3, they indicated they would do it without financial incentives.

These issues arose from the need to keep the number of questions to three, since this was tacked on to a much larger survey and we needed to work within the confines of that study. If future studies seek to conduct a similar survey, we recommend that the questions parse out current versus past participation and fully define the difference between adopting best nutrient practices as a part of an NMP contract versus adopting the practices alone.

Conclusion

When growers are eligible for NMPs, the policy works as it should by overcoming the initial financial barrier to adopting precision practices. Strict tillage eligibility requirements may decrease the number of farmers able to adopt precision practices. Once the financial incentives cease and precision practices have been fully implemented, precision farms are profitable on the Palouse, though a larger sample size is needed to fully assess precision in comparison to uniform practices. Four interviews in this study provide tangible examples of how growers can profitably adopt precision practices on the Palouse and make use of available incentives programs. To increase adoption of precision practices, the budget analysis and information from the interviews should be incorporated into extension materials to increase peer-to-peer connections and outreach, as recommended by Boie (2013).

Chapter 5. Synthesis: A Path Forward

Precision fertilizer management has promise for decreasing agricultural nitrogen loss while increasing long-term profitability for growers in the Palouse Region (Chapter 3 & 4). The Nutrient Management Plan (NMP) financial incentive program works well to help interested and eligible growers overcome high start-up costs (Chapter 4). However, even with the available NMPs, precision fertilizer practices are not a common practice on the Palouse. There are several likely barriers to adoption in the Palouse including the time and cost of adoption and credibility of information sources. For precision practices to become commonplace on the Palouse, NMPs need to be reprioritized and supplemented with complimentary approaches. Reprioritization will increase eligibility by separating NMPs from strict soil erosion conservation tillage requirements. The complimentary approaches needed include: 1) providing growers with tools rather than directives; and 2) fostering peer-to-peer mentorships. Through these efforts, information source credibility issues can be addressed throughout the region. The following is derived from insights gleaned during this thesis research on policy implementation, hydrology, economics, and social science. It proposes a path forward for NMPs in order to effectively increase adoption of precision fertilizer practices on the Palouse.

First, NMPs need to be reprioritized to increase grower eligibility. Since NMPs are a supplementary conservation practice, they fall secondary to soil conservation measures. If a grower is interested in adopting a NMP they must also improve their soil conservation practices, which often means reducing tillage. If the field is managed under conventional tillage it can be relatively easy and inexpensive to improve soil conservation by reducing the number of passes or making minor equipment changes. However, if the field is already managed under conservation tillage, adopting no-till may be the only option for a grower to maintain eligibility. No-till has much higher start-up costs and is not practical for the far eastern edge of the Palouse Region (Chapter 4). With these strict eligibility requirements, a grower interested in receiving support to adopt precision practices may end up simply not adopting any new conservation practice (Grower Interview). If we, as a society, want increased adoption of precision practices, we need to separate eligibility for NMPs from the strict tillage requirements. An example of how this could work is if a grower demonstrated that the adoption of no-till is not feasible given the farm's situation and that the best practical soil conservation measures are in place, the grower would still be eligible for NMP assistance to adopt precision practices. By reprioritizing fertilizer management as equal to, rather than secondary to soil erosion abatement, NMPs will be more effective in increasing adoption across the Palouse.

There are two complimentary approaches needed to increase the efficacy of NMPs and overcome non-financial barriers to adoption. The first is an emphasis on providing growers with tools to make management decisions rather than giving growers management directives. This need became apparent when growers would repeatedly ask to see our hydrology, nutrient, and crop data during the project. Nearly every grower in the study expressed that they know their own land better than any scientist or crop consultant ever could. The grower simply needs tools from researchers to make the best management decisions on their farm. "Tools" could range from a simple presentation of data or status of scientific knowledge, to a fully interactive decision making interface (such as a GIS-based decision support tool). Researchers should provide open access to easily digestible data, with summary information and take home messages embedded. The important data for growers to understand related to precision practices is the inherent spatial variability of Palouse fields. The SCF project has data from four field sites that clearly demonstrate spatial variability in soil moisture, runoff, soil properties, crop yield, nitrogen uptake, and nutrient cycling. These data, along with profitability metrics (see Chapter 3 "Results" & Chapter 4) could go a long way in simply engaging more growers in precision fertilizer discussions. In addition to providing baseline-understanding data, researchers should provide more complex tools to interested growers, such as CropSyst-Microbasin (Chapter 3) or a GIS-based tool. As Grower 4 stated, "innovative growers are the cornerstone to progress… progress is made when the government, researchers, and growers are working *together* (Chapter 4)." Therefore, to supplement NMPs and increase adoption of precision practices, researchers and agency personnel need to emphasize providing tools for decision making to growers rather than providing management directives. If researchers provide information, growers can use it within the context of their unique farm needs.

The second complimentary approach to increase the efficacy of NMPs and overcome non-financial barriers to adoption is to foster peer-to-peer relationships in the region, including grower-to-grower connections and generating peer relationships between agency personnel and growers. First, grower-to-grower relationships may be fostered by extension employees through grower example-cases and grower partnerships. People tend to not internalize information when it is coming from someone with a different worldview (Boie, 2013; Kahan et al., 2011, Chapter 4). This is of particular importance in the Palouse, where it has been documented that growers tend to be of a different worldview than researchers and extension and agency employees. Peer-to-peer education partners those with the same worldview together, increasing educator credibility and learner absorption of information. The significant potential of using example-cases is demonstrated in the success of the REACCH Farmer-to-Farmer Case Study Series (Yorgey, n.d.). By placing information about precision practices within written and video interviews with growers, the information source becomes much more credible (as a peer) to other growers. Example-case outreach efforts may also increase actual grower-to-grower interaction and mentorship as interested growers have a known peer to ask for information from. Additionally, a mentorship program such as the successful direct seed program (Snouwaert, 2014) could be successful for precision nitrogen management. Example-cases and grower partnerships would increase local understanding of precision practices and available financial incentives programs, while overcoming embedded credibility problems.

The second method to increase “peer-to-peer” mentorship is to change the personal approach for university and agency employees in interacting with growers. University and agency employees should view interactions with growers as a peer partnership (Nowak, 2011). Nowak (2011) calls for conservationists to go on a “conservation journey” and learn with growers, rather than thinking of it as a top-down flow of information. Second, university and agency employees that are interacting with growers should be friendly, positive, and helpful. Each employee should be a "people-person." While this is seemingly simple, it is surprisingly not always the case, as was made clear when some growers expressed less-than-positive opinions about participating in government programs. Significant differences in participation between counties has already been identified, but only grower perceptions of practices have been assessed to explain the differences without any look at the agency personnel – grower relationships (Kane et al., 2012). A study on grower perceptions of working with local conservationists, participation rates, and friendliness or helpfulness of local staff could provide insights into the importance of this approach. If the local implementation agencies were full of incredibly friendly and helpful employees, and if growers were treated as peers rather than subordinates to conservationists, growers may be clamoring at the door to participate in these programs.

In summary, by reprioritizing nutrient management as equal to, rather than secondary to soil erosion abatement, and by supplementing NMPs with complimentary approaches of providing tools to growers and fostering peer-to-peer partnerships, we may see precision fertilizer management become common practice on the Palouse. Reprioritization will increase eligibility by separating NMPs from strict and sometimes unfeasible soil erosion conservation tillage requirements. Of course, this reprioritization must be done with consideration of limited budgets and resources. However, if we as a society value improved nitrogen management, a reprioritization will be critical to successfully improving how we apply and manage nitrogen. The recommended complimentary approaches will additionally serve to overcome local information source credibility problems and improve relationships between growers, agencies, and researchers. A reprioritized and supplemented NMP program will bring growers, researchers, and government workers together as peers, fostering idea sharing, innovation, and improved nitrogen fertilizer management in the Palouse Region.

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Appendix A

Soil Calibration Steps

1. Create soil files based on observed data at the 12 intensive sampling locations. Soil core samples were collected at 0.3 m depth increments to 1.5 m providing observations of clay content, bulk density, nitrogen concentration, and organic matter content.
    a. Calculate saturation (m^3/m^3) from bulk density (assuming particle density of 2.65 g/cm^3):

    $$Saturation = 1 - \frac{bulk\ density}{particle\ density}$$

    b. Calculate field capacity using a relationship to bulk density based on locally collected soil samples (Holtan et al., 1968):

    $Field\ Capacity = minimum\ value\ of$:
    $Porosity - 0.03, or$
    $0.1372 \times bulk\ density + 0.1454$

    c. Calculate wilting point using a relationship to bulk density based on locally collected soil samples (Holtan et al., 1968):

    $Wilting\ Point = bulk\ density\ \times 0.2285 - 0.157$

    d. Calculate air entry potential and Campbell B values based on Holtan (1968).
    e. Using only well-calibrated, continuous data from Decagon Devices soil moisture probes (probe data that agrees with soil core water content values), adjust field capacity and permanent wilting point (See Figure 26 for non-well-calibrated data, see Figure 27 for well calibrated data). At some sites and some depths we were unable to attain well-calibrated data due to equipment malfunction, improper installation, and/or dense soil limitations.

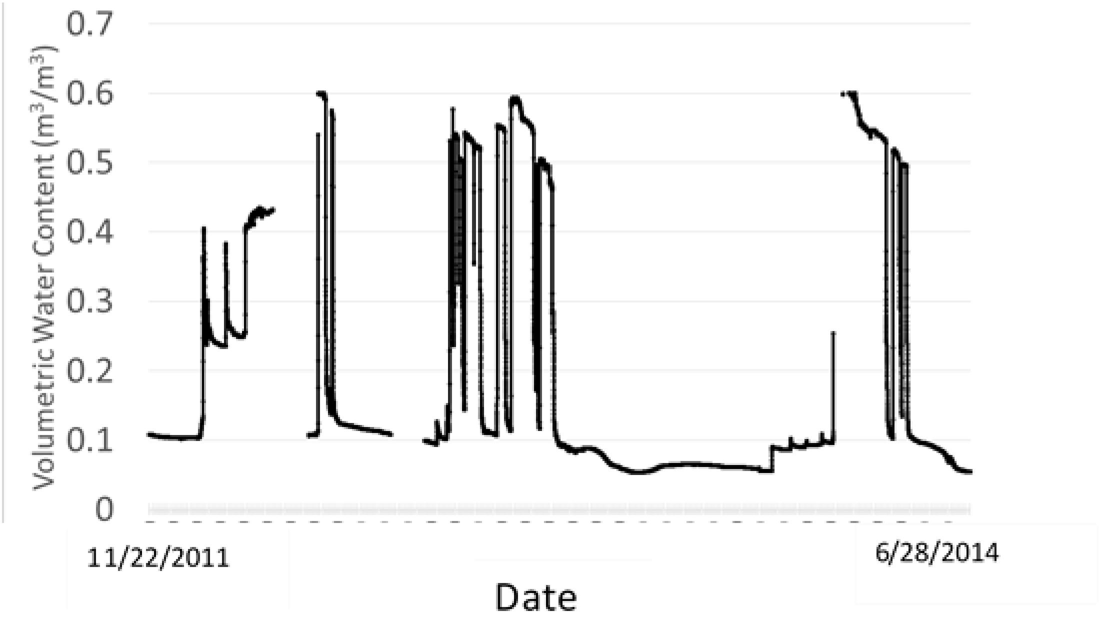


Figure 27. Decagon Devices soil moisture probe data, Site 10 depth 0.6m.

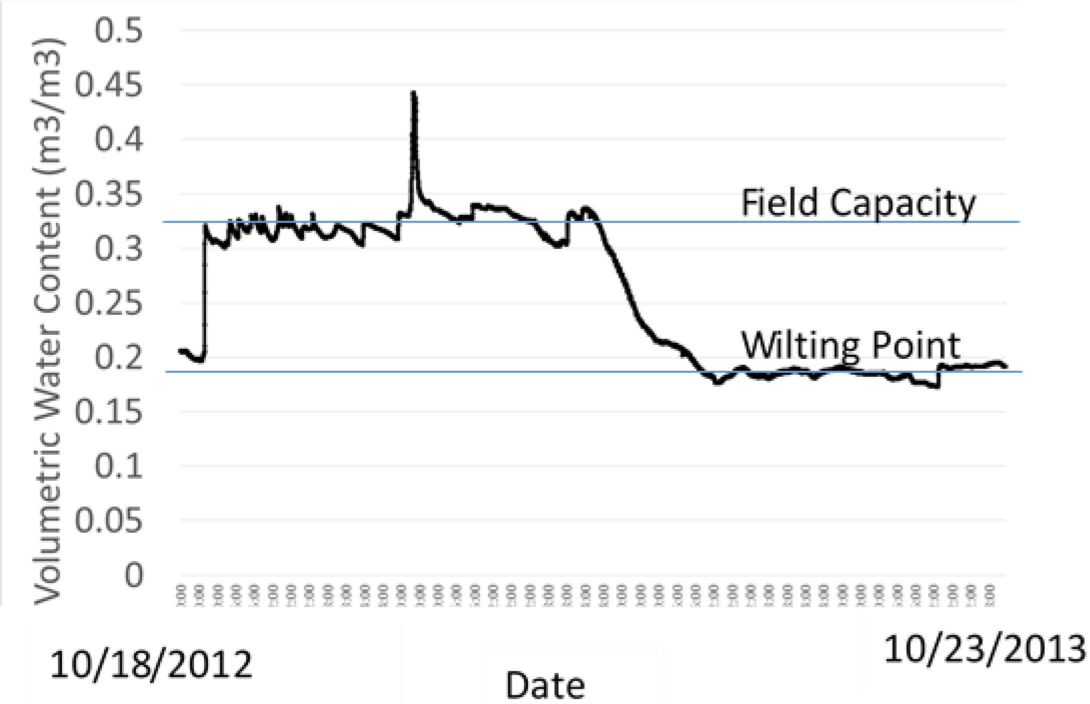


Figure 28. Decagon Devices soil moisture probe data, Site 5 depth 0.3m.

2. Using bulk density measurements from the 36 soil sampling locations, collaborators Dr. Caley Gasch and Matteo Poggio generated bulk density maps of the field for each 0.3m increment to 1.5m of depth with a 10m by 10m grid resolution. The maps were generated using automated 3D regression-kriging, based on Hengl et al. 2014. The bulk density maps

provided a basis for the spatial distribution of soil types in the watershed. An important factor in soil type at the site is depth to restrictive layer. We classified the restrictive layer as any soil depth with a bulk density above 1.65 g/cm^3. The depth of possible root growth was limited to no deeper than the top layer of the restrictive soil depths. Saturated soil hydraulic conductivity was first calculated based on locally collected soil water retention samples (Figure 28; Holtan et al., 1968).

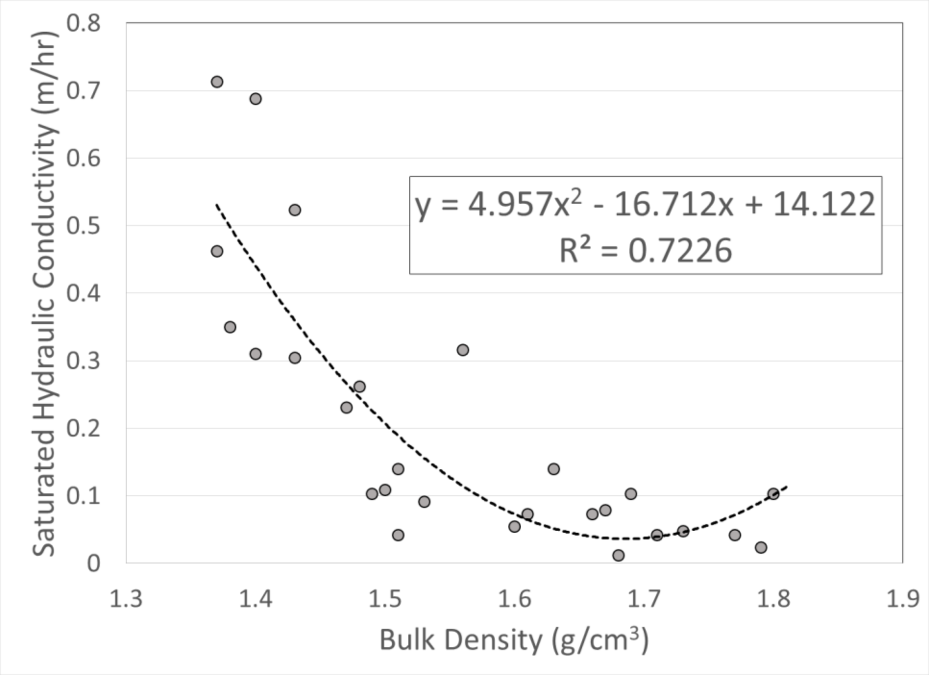
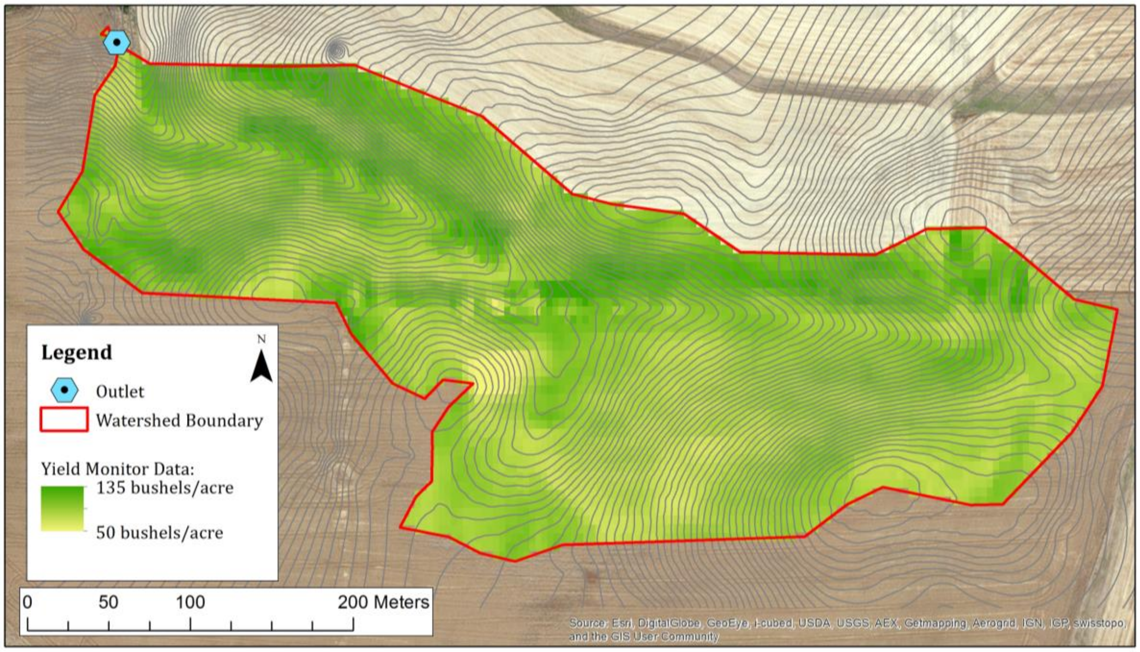


Figure 29. Soil bulk density and saturated hydraulic conductivity relationship.

3. Since the soil input data was extrapolated from a course resolution of 36 sample sites in the 109,300 m^2 (10.9 hectare) watershed and conductivity values were calculated using bulk density relationships (such as in Figure 28) with associated error, we further calibrated Ksat, first using observed watershed discharge to calibrate the restrictive horizon layers, then using soil moisture probes to calibrate the layers above the restrictive horizon.
    a. The total observed depth of water discharge from February 2nd 2012 through October 1st, 2013 was 113.02mm. This total amount of runoff provided a basin wide measure to calibrate K_{sat}. Based on field observations, we assumed a maximum depth to restrictive layer of 1.5m. Since the restrictive layer K_{sat} value controls the amount of water leaving the watershed as surface runoff versus percolation, this value was adjusted to a value resulting in the proper amount of discharge. The values were only adjusted within the margin of error in the original calculations based on bulk density, so we are confident in the values as a best-estimate.
    b. To calibrate the K_{sat} above the restrictive horizon, we compared soil water holding patterns above the restrictive layer between simulated and well-calibrated Decagon Devices soil moisture probes. If the water was leaving a layer faster than observed,

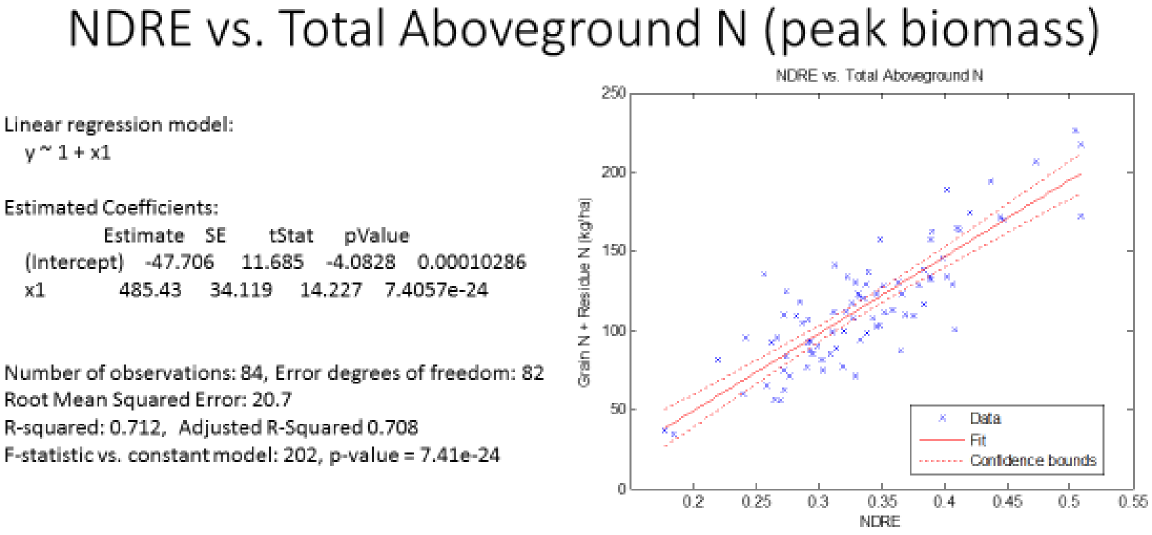
we lowered the Ksat (within the margin of error of the original calculation in Figure 28), and vice versa.

4. At this point in the calibration process, the water parameters (continuous soil moisture at the 12 sites, instantaneous soil moisture at 36 sites, and surface runoff) fit observed data well (see Chapter 3 Results). Next, the crop outputs were examined and due to discrepancies in the simulated and observed yield (Figure 29) and nitrogen uptake (Figure 30 & 31), we further calibrated organic matter. From the remote sensing data, an interesting line of high nitrogen uptake was identified through the field site, which did not correspond to topographic changes. The grower indicated it was an old fence line that has only been farmed for about ten years, as opposed to 60+ years on the rest of the field. We expect that the area in this old fence line has higher soil organic matter than the rest of the field. Further contributing to this hypothesis is that simulated yield is sensitive to soil organic matter and the first simulations resulted in an under-prediction of yield along the fence line. Using a delineation of the fence line from RapidEye NDRE N predictions (Magney, unpublished data, Figure 30 & 31), we increased soil organic matter to the upper end of observations for each depth (any soil file with “O” in the name corresponds to a cell on the fence line with higher organic matter). None of the sampling locations for organic matter fall in the fence line, but we are confident in assuming the organic matter content on the fence line is at least not less than the highest observed values in the watershed.
5. Finally, the south facing slope in the “high” fertilizer zone resulted in a significant under prediction of yield and nitrogen uptake. To increase yields and nitrogen uptake to within the range of observed values, we increased field capacity by 0.01 to 0.04 m^3/m^3 on this slope. This stage of the calibration, we have the least confidence in and hope to further explore the role of field capacity on yield and nitrogen uptake, and investigate other potential parameters or processes that may be resulting in an underprediction of yield on this slope without increasing field capacity.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 30. Yield monitor data, Winter Wheat harvested August 2013.



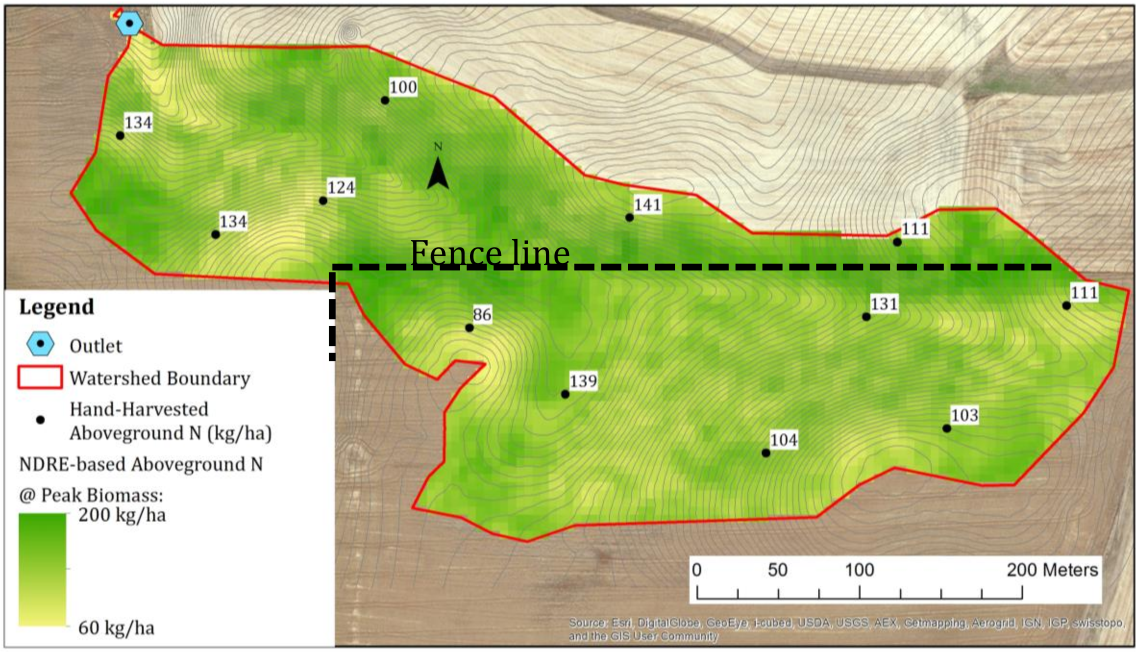
NDRE vs. Total Aboveground N (peak biomass)

```
Linear regression model:
   y ~ 1 + x1

Estimated Coefficients:
                  Estimate     SE       tStat      pValue
   (Intercept)    -47.706    11.685    -4.0828    0.00010286
   x1              485.43    34.119     14.227    7.4057e-24


Number of observations: 84, Error degrees of freedom: 82
Root Mean Squared Error: 20.7
R-squared: 0.712,  Adjusted R-Squared 0.708
F-statistic vs. constant model: 202, p-value = 7.41e-24
```

Figure 31. NDRE N prediction linear regression model.

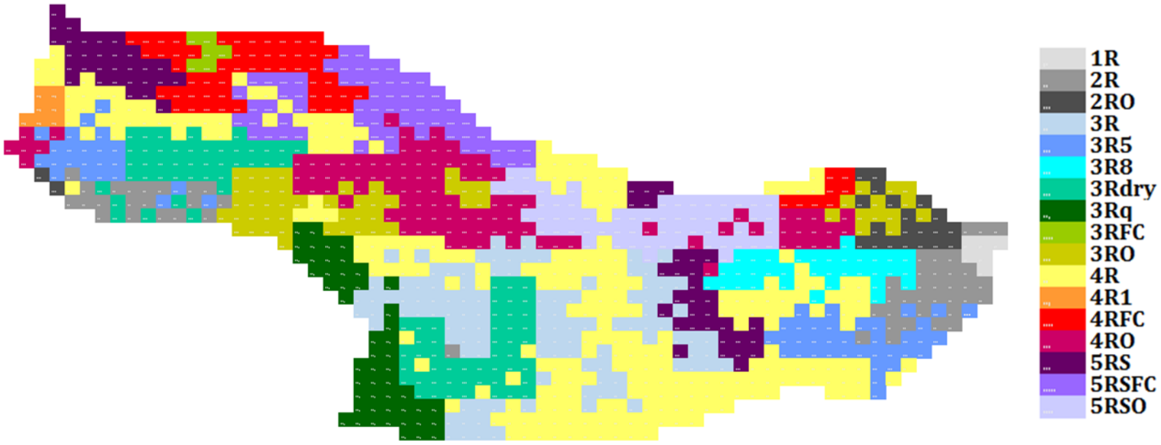


Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 32. NDRE-based aboveground N at peak biomass and hand-sampled aboveground N at harvest.

Appendix B

Soil Map of Study Site:



Soil 1R

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	4.0	2.3	0.4	1.30	2.37	0.32	0.14	2.37
2	0.075	29.3	3.8	6.7	1.1	1.30	2.37	0.32	0.14	2.37
3	0.1	32.2	3.0	9.0	1.5	1.40	2.37	0.34	0.16	2.37
4	0.1	31.6	2.5	9.0	1.5	1.38	2.37	0.33	0.16	2.37
5	0.1	40.8	2.0	5.0	0.8	1.70	0.0002	0.33	0.23	0.0002
6	0.1	40.8	1.8	3.7	0.8	1.70	0.0002	0.33	0.23	0.0002
7	0.1	40.8	1.3	3.7	0.0	1.70	0.0002	0.33	0.23	0.0002
8	0.1	40.8	0.6	3.7	0.0	1.70	0.0002	0.33	0.23	0.0002
9	0.1	40.8	0.6	3.7	0.0	1.70	0.0002	0.33	0.23	0.0002
10	0.1	40.8	0.5	3.7	0.0	1.70	0.0002	0.33	0.23	0.0002
11	0.1	40.8	0.4	3.7	0.0	1.70	0.0002	0.33	0.23	0.0002
12	0.3	40.8	0.4	11	0.1	1.70	0.0002	0.33	0.23	0.0002
13	0.3	40.8	0.4	11	0.1	1.70	0.0002	0.33	0.23	0.0002
14	0.3	40.8	0.2	11	0.1	1.70	0.0002	0.33	0.23	0.0002
15	0.3	40.8	0.2	11	0.1	1.70	0.0002	0.33	0.23	0.0002

Soil 2R

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	4.5	2.2	0.4	1.30	2.37	0.32	0.14	1.72
2	0.075	29.3	4.5	6.4	1.2	1.30	1.27	0.32	0.14	1.53
3	0.1	32.2	4.0	8.7	1.7	1.40	1.27	0.34	0.16	1.53
4	0.1	31.6	3.4	8.7	1.7	1.38	1.27	0.33	0.16	1.53
5	0.1	32.2	2.8	5.0	1.0	1.40	1.27	0.34	0.16	1.53
6	0.1	35.0	2.3	1.3	0.7	1.50	1.27	0.35	0.19	1.53
7	0.1	36.5	2.0	1.3	0.7	1.55	1.27	0.36	0.20	1.53
8	0.1	40.8	0.8	1.3	0.0	1.70	0.0001	0.33	0.23	0.0001
9	0.1	40.8	0.8	1.8	0.0	1.70	0.0001	0.33	0.23	0.0001
10	0.1	40.8	0.5	1.8	0.0	1.70	0.0001	0.33	0.23	0.0001
11	0.1	40.8	0.4	1.8	0.0	1.70	0.0001	0.33	0.23	0.0001
12	0.3	40.8	0.4	8.0	0.1	1.70	0.0001	0.33	0.23	0.0001
13	0.3	40.8	0.4	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001
14	0.3	40.8	0.2	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001
15	0.3	40.8	0.2	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001

Soil 2RO

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	4.5	3.1	0.6	1.30	2.37	0.34	0.14	1.72
2	0.075	29.3	4.5	9.1	1.7	1.30	1.27	0.37	0.14	1.53
3	0.1	32.2	4.0	12.3	2.3	1.40	1.27	0.37	0.15	1.53
4	0.1	31.6	3.4	12.3	2.3	1.38	1.27	0.35	0.15	1.53
5	0.1	32.2	2.8	5.0	1.7	1.40	1.27	0.35	0.15	1.53
6	0.1	35.0	2.6	2.0	1.9	1.50	1.27	0.35	0.15	1.53
7	0.1	36.5	2.4	2.0	1.9	1.55	1.27	0.36	0.20	1.53
8	0.1	40.8	2.4	2.0	1.7	1.70	0.0001	0.33	0.23	0.0001
9	0.1	40.8	2.3	4.0	1.7	1.70	0.0001	0.33	0.23	0.0001
10	0.1	40.8	2.2	4.0	1.7	1.70	0.0001	0.33	0.23	0.0001
11	0.1	40.8	0.6	4.0	1.3	1.70	0.0001	0.33	0.23	0.0001
12	0.3	40.8	0.5	15.0	4.0	1.70	0.0001	0.33	0.23	0.0001
13	0.3	40.8	0.4	17.0	4.0	1.70	0.0001	0.33	0.23	0.0001
14	0.3	40.8	0.2	17.0	4.0	1.70	0.0001	0.33	0.23	0.0001
15	0.3	40.8	0.2	17.0	4.0	1.70	0.0001	0.33	0.23	0.0001

Soil 3R

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	3.6	2.3	0.4	1.30	2.37	0.32	0.14	2.37
2	0.075	29.3	3.4	6.7	1.2	1.30	1.55	0.32	0.14	1.55
3	0.1	32.2	3.0	9.0	1.0	1.40	1.22	0.34	0.16	1.55
4	0.1	31.6	2.7	9.0	1.0	1.38	1.22	0.33	0.16	1.55
5	0.1	32.2	1.5	5.0	1.0	1.40	1.22	0.34	0.16	1.22
6	0.1	35.0	1.4	1.3	0.7	1.50	0.85	0.35	0.16	0.85
7	0.1	36.5	1.3	1.3	0.6	1.55	0.77	0.36	0.16	0.77
8	0.1	36.5	1.0	1.3	0.6	1.55	0.77	0.36	0.16	0.77
9	0.1	36.5	0.9	1.8	0.6	1.55	0.77	0.36	0.16	0.77
10	0.1	36.5	0.8	1.7	0.6	1.55	0.77	0.36	0.16	0.77
11	0.1	40.8	0.8	1.7	0.6	1.70	0.0002	0.33	0.23	0.0228
12	0.3	40.8	0.4	8.0	0.1	1.70	0.0002	0.33	0.23	0.0228
13	0.3	40.8	0.4	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001
14	0.3	40.8	0.2	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001
15	0.3	40.8	0.2	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001

Soil 3R5

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	3.6	2.2	1.5	1.30	2.37	0.32	0.14	1.72
2	0.075	29.3	3.4	6.5	4.5	1.30	0.68	0.32	0.14	1.53
3	0.1	32.2	3.0	8.7	6.0	1.40	0.68	0.34	0.16	1.53
4	0.1	31.6	2.7	8.7	6.0	1.38	0.68	0.33	0.16	1.53
5	0.1	32.2	1.5	5.0	0.9	1.40	0.68	0.34	0.16	1.53
6	0.1	35.0	1.4	1.3	0.9	1.50	0.68	0.35	0.16	1.53
7	0.1	36.5	1.3	1.3	0.9	1.55	0.68	0.36	0.16	1.53
8	0.1	36.5	1.0	1.3	0.9	1.55	0.68	0.36	0.16	1.53
9	0.1	36.5	0.9	1.8	0.9	1.55	0.68	0.36	0.16	1.53
10	0.1	36.5	0.8	1.8	0.9	1.55	0.68	0.36	0.16	1.53
11	0.1	40.8	0.8	1.8	0.9	1.70	0.0009	0.33	0.23	0.0009
12	0.3	40.8	0.4	8.0	0.1	1.70	0.0009	0.33	0.23	0.0009
13	0.3	40.8	0.4	11.0	0.1	1.70	0.0009	0.33	0.23	0.0009
14	0.3	40.8	0.2	11.0	0.1	1.70	0.0009	0.33	0.23	0.0009
15	0.3	40.8	0.2	11.0	0.1	1.70	0.0009	0.33	0.23	0.0009

Soil 3R8

Layer	Thickness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	3.6	2.3	0.4	1.30	2.37	0.32	0.14	2.4
2	0.075	29.3	3.4	6.7	0.4	1.30	1.70	0.32	0.14	1.7
3	0.1	32.2	3.0	9.0	1.7	1.40	1.70	0.34	0.16	1.7
4	0.1	31.6	2.7	9.0	1.7	1.38	1.53	0.33	0.16	1.53
5	0.1	32.2	1.5	5.0	0.8	1.40	0.68	0.34	0.16	1.53
6	0.1	35.0	1.4	1.3	0.8	1.50	0.68	0.35	0.16	1.53
7	0.1	36.5	1.3	1.3	0.8	1.55	0.68	0.36	0.16	1.53
8	0.1	36.5	1.0	1.3	0.6	1.55	0.68	0.36	0.16	1.53
9	0.1	36.5	0.9	1.8	0.6	1.55	0.68	0.36	0.16	1.53
10	0.1	37.9	0.8	1.7	0.6	1.60	0.0005	0.36	0.21	0.0005
11	0.1	40.8	0.8	1.7	0.6	1.70	0.0005	0.33	0.23	0.0005
12	0.3	40.8	0.4	8.0	0.1	1.70	0.0005	0.33	0.23	0.0005
13	0.3	40.8	0.4	11.0	0.1	1.70	0.0005	0.33	0.23	0.0005
14	0.3	40.8	0.2	11.0	0.1	1.70	0.0005	0.33	0.23	0.0005
15	0.3	40.8	0.2	11.0	0.1	1.70	0.0005	0.33	0.23	0.0005

Soil 3Rdry

Layer	Thickness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	3.6	2.3	0.4	1.30	2.37	0.32	0.14	2.37
2	0.075	29.3	3.4	6.7	0.4	1.30	1.72	0.32	0.14	1.72
3	0.1	32.2	3.0	9.0	1.7	1.40	1.72	0.34	0.16	1.72
4	0.1	31.6	2.7	9.0	1.7	1.38	1.72	0.33	0.16	1.72
5	0.1	32.2	1.5	5.0	0.8	1.40	1.57	0.34	0.16	1.57
6	0.1	35.0	1.4	1.3	0.8	1.50	1.23	0.35	0.16	1.23
7	0.1	36.5	1.3	1.3	0.8	1.55	1.23	0.36	0.16	1.23
8	0.1	36.5	1.0	1.3	0.6	1.55	0.89	0.36	0.16	0.89
9	0.1	36.5	0.9	1.8	0.6	1.55	0.72	0.36	0.16	0.72
10	0.1	36.5	0.8	1.7	0.6	1.55	0.72	0.36	0.20	0.72
11	0.1	40.8	0.8	1.7	0.6	1.70	0.003	0.33	0.23	0.003
12	0.3	40.8	0.4	8.0	0.1	1.70	0.003	0.33	0.23	0.003
13	0.3	40.8	0.4	11.0	0.1	1.70	0.003	0.33	0.23	0.003
14	0.3	40.8	0.2	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001
15	0.3	40.8	0.2	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001

Soil 3RFC

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	3.6	2.3	0.4	1.30	2.37	0.35	0.14	2.37
2	0.075	29.3	3.4	6.7	0.4	1.30	1.55	0.37	0.14	1.55
3	0.1	32.2	3.0	9.0	1.7	1.40	1.22	0.37	0.15	1.55
4	0.1	31.6	2.7	9.0	1.7	1.38	1.22	0.36	0.15	1.55
5	0.1	32.2	1.5	5.0	0.8	1.40	1.22	0.36	0.16	1.22
6	0.1	35.0	1.4	1.3	0.8	1.50	0.85	0.35	0.16	0.85
7	0.1	36.5	1.3	1.3	0.8	1.55	0.77	0.36	0.16	0.77
8	0.1	36.5	1.0	1.3	0.6	1.55	0.77	0.36	0.16	0.77
9	0.1	36.5	0.9	1.8	0.6	1.55	0.77	0.36	0.16	0.77
10	0.1	36.5	0.8	1.7	0.6	1.55	0.77	0.36	0.16	0.77
11	0.1	40.8	0.8	1.7	0.6	1.70	0.0002	0.33	0.23	0.0228
12	0.3	40.8	0.6	8.0	0.1	1.70	0.0002	0.33	0.23	0.0228
13	0.3	40.8	0.5	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001
14	0.3	40.8	0.2	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001
15	0.3	40.8	0.2	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001

Soil 3RO

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	4.5	3.1	0.6	1.30	2.37	0.35	0.14	2.37
2	0.075	29.3	4.5	9.1	1.7	1.30	1.55	0.37	0.14	1.55
3	0.1	32.2	4.0	12.3	2.3	1.40	1.22	0.37	0.16	1.55
4	0.1	31.6	3.4	12.3	2.3	1.38	1.22	0.36	0.15	1.55
5	0.1	32.2	2.8	5.0	1.5	1.40	1.22	0.36	0.15	1.22
6	0.1	35.0	2.6	2.0	1.7	1.50	0.85	0.36	0.15	0.85
7	0.1	36.5	2.4	2.0	1.7	1.55	0.77	0.36	0.15	0.77
8	0.1	36.5	2.4	2.0	1.5	1.55	0.77	0.36	0.15	0.77
9	0.1	36.5	2.3	3.6	1.5	1.55	0.77	0.36	0.15	0.77
10	0.1	36.5	2.2	3.6	1.5	1.55	0.77	0.36	0.15	0.77
11	0.1	40.8	1.0	3.6	1.2	1.70	0.0002	0.33	0.23	0.0228
12	0.3	40.8	0.9	15.0	4.0	1.70	0.0002	0.33	0.23	0.0228
13	0.3	40.8	0.5	17.0	4.0	1.70	0.0001	0.33	0.23	0.0001
14	0.3	40.8	0.2	17.0	4.0	1.70	0.0001	0.33	0.23	0.0001
15	0.3	40.8	0.2	17.0	4.0	1.70	0.0001	0.33	0.23	0.0001

Soil 3Rq

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	4.0	2.3	0.4	1.30	2.37	0.32	0.14	2.37
2	0.075	29.3	3.5	6.7	0.4	1.30	1.55	0.32	0.14	1.55
3	0.1	32.2	3.0	9.0	1.7	1.40	1.22	0.34	0.16	1.22
4	0.1	31.6	2.8	9.0	1.7	1.38	1.22	0.33	0.16	1.22
5	0.1	32.2	2.5	5.0	0.8	1.40	1.22	0.34	0.16	1.22
6	0.1	35.0	1.8	1.3	0.8	1.50	0.85	0.35	0.16	0.85
7	0.1	36.5	1.7	1.3	0.8	1.55	0.77	0.36	0.16	0.77
8	0.1	36.5	1.5	1.3	0.6	1.55	0.77	0.36	0.16	0.77
9	0.1	36.5	0.8	1.8	0.6	1.55	0.77	0.36	0.16	0.77
10	0.1	36.5	0.7	1.7	0.6	1.55	0.77	0.36	0.16	0.77
11	0.1	40.8	0.5	1.7	0.6	1.70	0.00	0.33	0.23	0.23
12	0.3	40.8	0.5	8.0	0.1	1.70	0.002	0.33	0.23	0.0002
13	0.3	40.8	0.5	11.0	0.1	1.70	0.002	0.33	0.23	0.0002
14	0.3	40.8	0.2	11.0	0.1	1.70	0.002	0.33	0.23	0.0002
15	0.3	40.8	0.2	11.0	0.1	1.70	0.002	0.33	0.23	0.0002

Soil 4R

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	3.6	2.3	0.4	1.30	2.37	0.32	0.14	1.72
2	0.075	29.3	3.4	6.7	0.4	1.30	1.53	0.32	0.14	1.53
3	0.1	32.2	3.0	9.0	1.7	1.40	1.53	0.34	0.16	1.53
4	0.1	31.6	2.7	9.0	1.7	1.38	1.36	0.33	0.15	1.36
5	0.1	32.2	1.5	5.0	0.8	1.40	1.19	0.34	0.15	1.53
6	0.1	35.0	1.4	1.3	0.8	1.50	1.19	0.35	0.15	1.53
7	0.1	36.5	1.3	1.3	0.8	1.55	1.19	0.36	0.15	1.53
8	0.1	36.5	1.0	1.3	0.6	1.55	0.68	0.36	0.15	1.53
9	0.1	36.5	0.9	1.8	0.6	1.55	0.68	0.36	0.15	1.53
10	0.1	36.5	0.8	1.7	0.6	1.55	0.68	0.36	0.15	1.53
11	0.1	36.5	0.8	1.7	0.6	1.55	0.68	0.36	0.15	1.53
12	0.3	36.5	0.7	8.0	0.1	1.55	0.68	0.36	0.15	1.53
13	0.3	40.8	0.5	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001
14	0.3	40.8	0.2	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001
15	0.3	40.8	0.2	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001

Soil 4R1

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	3.6	2.3	0.4	1.30	2.37	0.33	0.14	1.72
2	0.075	29.3	3.4	6.7	0.4	1.30	1.53	0.33	0.14	1.53
3	0.1	32.2	3.0	9.0	1.7	1.40	1.53	0.36	0.16	1.53
4	0.1	31.6	2.7	9.0	1.7	1.38	1.53	0.36	0.15	1.53
5	0.1	32.2	1.5	5.0	0.8	1.40	0.68	0.34	0.15	1.53
6	0.1	35.0	1.4	1.3	0.8	1.50	0.68	0.35	0.15	1.53
7	0.1	36.5	1.3	1.3	0.8	1.55	0.68	0.36	0.15	1.53
8	0.1	36.5	1.0	1.3	0.6	1.55	0.68	0.36	0.15	1.53
9	0.1	36.5	0.9	1.8	0.6	1.55	0.68	0.36	0.15	1.53
10	0.1	36.5	0.8	1.7	0.6	1.55	0.68	0.36	0.15	1.53
11	0.1	36.5	0.8	1.7	0.6	1.55	0.68	0.36	0.15	1.53
12	0.3	37.9	0.7	8.0	0.1	1.60	0.07	0.36	0.15	0.07
13	0.3	37.9	0.5	11.0	0.1	1.60	0.07	0.36	0.21	0.07
14	0.3	40.8	0.2	11.0	0.1	1.70	0.0005	0.33	0.23	0.0005
15	0.3	40.8	0.2	11.0	0.1	1.70	0.0005	0.33	0.23	0.0005

Soil 4RFC

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	3.6	2.3	0.4	1.30	2.37	0.35	0.14	1.72
2	0.075	29.3	3.4	6.7	0.4	1.30	1.53	0.37	0.14	1.53
3	0.1	32.2	3.0	9.0	1.7	1.40	1.53	0.37	0.15	1.53
4	0.1	31.6	2.7	9.0	1.7	1.38	1.36	0.36	0.15	1.36
5	0.1	32.2	1.5	5.0	0.8	1.40	1.19	0.36	0.15	1.53
6	0.1	35.0	1.4	1.3	0.8	1.50	1.19	0.35	0.15	1.53
7	0.1	36.5	1.3	1.3	0.8	1.55	1.19	0.36	0.15	1.53
8	0.1	36.5	1.0	1.3	0.6	1.55	0.68	0.36	0.15	1.53
9	0.1	36.5	0.9	1.8	0.6	1.55	0.68	0.36	0.15	1.53
10	0.1	36.5	0.8	1.7	0.6	1.55	0.68	0.36	0.15	1.53
11	0.1	36.5	0.8	1.7	0.6	1.55	0.68	0.36	0.15	1.53
12	0.3	36.5	0.7	8.0	0.1	1.55	0.68	0.36	0.15	1.53
13	0.3	40.8	0.5	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001
14	0.3	40.8	0.2	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001
15	0.3	40.8	0.2	11.0	0.1	1.70	0.0001	0.33	0.23	0.0001

Soil 4RO

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	3.8	3.1	0.6	1.30	2.37	0.35	0.14	1.72
2	0.075	29.3	4.0	9.1	1.7	1.30	1.53	0.37	0.14	1.53
3	0.1	32.2	3.7	12.3	2.3	1.40	1.53	0.37	0.16	1.53
4	0.1	31.6	3.0	12.2	2.3	1.38	1.36	0.36	0.15	1.36
5	0.1	32.2	2.4	4.5	1.5	1.40	1.19	0.36	0.15	1.53
6	0.1	35.0	1.8	1.8	1.7	1.50	1.19	0.36	0.15	1.53
7	0.1	36.5	1.7	1.8	1.7	1.55	1.19	0.36	0.15	1.53
8	0.1	36.5	1.6	1.8	1.5	1.55	0.68	0.36	0.15	1.53
9	0.1	36.5	1.6	3.6	1.5	1.55	0.68	0.36	0.15	1.53
10	0.1	36.5	1.6	3.6	1.5	1.55	0.68	0.36	0.15	1.53
11	0.1	36.5	1.0	3.6	1.2	1.55	0.68	0.36	0.15	1.53
12	0.3	36.5	0.9	15.0	4.0	1.55	0.68	0.36	0.15	1.53
13	0.3	40.8	0.5	17.0	4.0	1.70	0.0001	0.33	0.23	0.0001
14	0.3	40.8	0.2	17.0	4.0	1.70	0.0001	0.33	0.23	0.0001
15	0.3	40.8	0.2	17.0	4.0	1.70	0.0001	0.33	0.23	0.0001

Soil 5RS

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	3.6	2.3	0.4	1.30	2.37	0.33	0.14	2.37
2	0.075	29.3	3.4	6.7	0.4	1.30	1.53	0.33	0.14	1.53
3	0.1	32.2	3.0	9.0	1.7	1.40	1.53	0.34	0.16	1.53
4	0.1	31.6	2.7	9.0	1.7	1.38	1.19	0.34	0.15	1.19
5	0.1	32.2	1.5	5.0	0.8	1.40	1.19	0.34	0.15	1.19
6	0.1	35.0	1.4	1.3	0.8	1.50	1.02	0.35	0.15	1.02
7	0.1	36.5	1.3	1.3	0.8	1.55	1.02	0.36	0.15	1.02
8	0.1	36.5	1.0	1.3	0.6	1.55	0.92	0.36	0.15	0.92
9	0.1	36.5	0.9	1.7	0.6	1.55	0.92	0.36	0.15	0.92
10	0.1	36.5	0.8	1.7	0.6	1.55	0.92	0.36	0.15	0.92
11	0.1	36.5	0.8	1.7	0.6	1.55	0.92	0.36	0.15	0.92
12	0.3	36.5	0.7	8.0	0.1	1.55	0.92	0.36	0.15	0.92
13	0.3	36.5	0.5	11.0	0.1	1.55	0.92	0.36	0.20	0.92
14	0.3	40.8	0.2	11.0	0.1	1.70	0.0002	0.33	0.23	0.0002
15	0.3	40.8	0.2	11.0	0.1	1.70	0.0002	0.33	0.23	0.0002

Soil 5RSFC

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	3.6	2.3	0.4	1.30	2.37	0.35	0.14	2.37
2	0.075	29.3	3.4	6.7	0.4	1.30	1.53	0.37	0.14	1.53
3	0.1	32.2	3.0	9.0	1.7	1.40	1.53	0.37	0.15	1.53
4	0.1	31.6	2.7	9.0	1.7	1.38	1.19	0.36	0.15	1.19
5	0.1	32.2	1.5	5.0	0.8	1.40	1.19	0.36	0.15	1.19
6	0.1	35.0	1.4	1.3	0.8	1.50	1.02	0.35	0.15	1.02
7	0.1	36.5	1.3	1.3	0.8	1.55	1.02	0.36	0.15	1.02
8	0.1	36.5	1.0	1.3	0.6	1.55	0.92	0.36	0.15	0.92
9	0.1	36.5	0.9	1.8	0.6	1.55	0.92	0.36	0.15	0.92
10	0.1	36.5	0.8	1.7	0.6	1.55	0.92	0.36	0.15	0.92
11	0.1	36.5	0.8	1.7	0.6	1.55	0.92	0.36	0.15	0.92
12	0.3	36.5	0.6	8.0	0.1	1.55	0.92	0.36	0.15	0.92
13	0.3	36.5	0.5	11.0	0.1	1.55	0.92	0.36	0.20	0.92
14	0.3	40.8	0.2	11.0	0.1	1.70	0.0002	0.33	0.23	0.0002
15	0.3	40.8	0.2	11.0	0.1	1.70	0.0002	0.33	0.23	0.0002

Soil 5RSO

Layer	Thick-ness (m)	Clay (%)	Organic Matter (%)	Initial NO_3 (kg/ha)	Initial NH_4 (kg/ha)	Bulk Density (g/cm^3)	K_{sat} (m/day)	FC (m^3/m^3)	PWP (m^3/m^3)	Lateral K_{sat} (m/day)
1	0.025	29.3	4.3	3.1	0.6	1.30	2.37	0.35	0.14	1.53
2	0.075	29.3	4.1	9.9	1.7	1.30	1.53	0.37	0.14	1.53
3	0.1	32.2	3.8	12.2	2.3	1.40	1.53	0.37	0.16	1.53
4	0.1	31.6	3.2	11.1	2.1	1.38	1.19	0.36	0.15	1.19
5	0.1	32.2	2.4	4.5	1.5	1.40	1.19	0.36	0.15	1.19
6	0.1	35.0	2.0	1.8	1.7	1.50	1.02	0.36	0.15	1.02
7	0.1	36.5	1.8	1.8	1.7	1.55	1.02	0.36	0.15	1.02
8	0.1	36.5	1.6	1.8	1.5	1.55	0.92	0.36	0.15	0.92
9	0.1	36.5	1.6	3.6	1.5	1.55	0.92	0.36	0.15	0.92
10	0.1	36.5	1.6	3.6	1.5	1.55	0.92	0.36	0.15	0.92
11	0.1	36.5	0.8	3.6	1.2	1.55	0.92	0.36	0.15	0.92
12	0.3	36.5	0.8	15.0	4.0	1.55	0.92	0.36	0.15	0.92
13	0.3	36.5	0.7	17.0	4.0	1.55	0.92	0.36	0.20	0.92
14	0.3	40.8	0.2	17.0	4.0	1.70	0.0002	0.33	0.23	0.0002
15	0.3	40.8	0.2	17.0	4.0	1.70	0.0002	0.33	0.23	0.0002

Appendix C

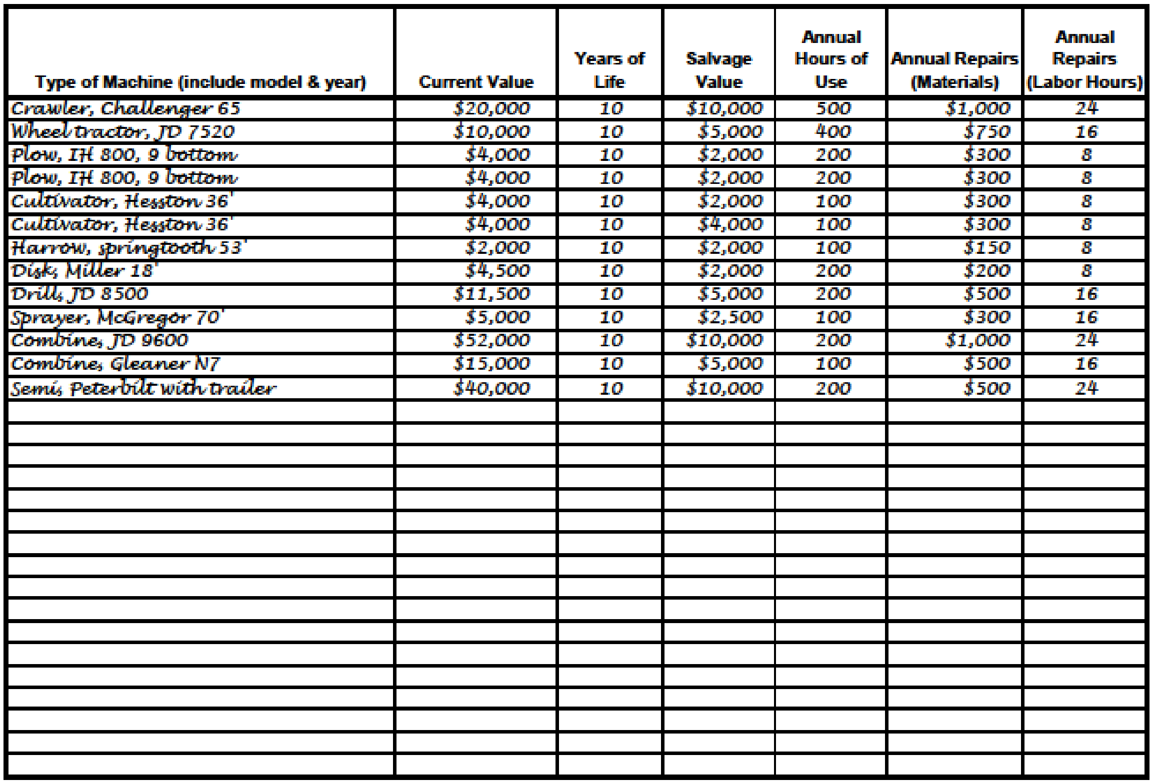
Example Schedule of Operations: No-Till Wheat Production

Crop (circle one): Spring Wheat [✓ Winter Wheat] Wheat Type (circle one): [✓ Soft White] Hard Red Club Year: 2011

			Equipment								Ac./Hr.			
Operation	Date	Times Over	Tooling	Owned	Rented	Custom Hire	Cost Per Unit if Rented		Cost Per Unit if Custom Hire		Machine	Labor	Fuel Consumption Per Machine Hour	Type, Cost, and Amount of Materials Used Along With Any General Comments
							$	Unit	$	Unit				
Spray Roundup	15-Oct	0.5	455HP tractor, 90' sprayer	x tractor	sprayer $5/ac		$5				40	44	0.4 gal/ac	12 oz Roundup
Spray Roundup	18-Apr	1	455HP tractor, 90' sprayer	x tractor	sprayer $5/ac						40	44	0.4 gal/ac	32 oz Roundup
Spray Roundup	3-Jun	1	455HP tractor, 90' sprayer	x tractor	sprayer $5/ac						40	44	0.4gal/ac	32 oz Roundup
Spray Roundup	24-Jul	1	455HP tractor, 90' sprayer	x tractor	sprayer $5/ac						40	40	0.4gal/ac	45 oz Roundup
Seed	15-Sep	1	455HP tractor, 35' no-till drill	x tractor							20	22	1 gal/ac	100# seed/ac plus 90-10-12 or 90-10-15 (N-P-S)
Spray weeds	8-Apr	1	455HP tractor, 90' sprayer	x tractor	sprayer $5/ac						40	44	0.4gal/ac	1 pt 2,4-D, 1/2 oz Amber, 4 oz Tilt
Harvest	30-Jul	1	combine, 30' header	x							10	12	1.3 gal/ac	
Hauling 500 bu per load	Aug		tandem axle truck	x									4miles/gal	10 miles roundtrip

Appendix D

Machinery Complement Example:



Type of Machine (include model & year)	Current Value	Years of Life	Salvage Value	Annual Hours of Use	Annual Repairs (Materials)	Annual Repairs (Labor Hours)
Crawler, Challenger 65	$20,000	10	$10,000	500	$1,000	24
Wheel tractor, JD 7520	$10,000	10	$5,000	400	$750	16
Plow, IH 800, 9 bottom	$4,000	10	$2,000	200	$300	8
Plow, IH 800, 9 bottom	$4,000	10	$2,000	200	$300	8
Cultivator, Hesston 36'	$4,000	10	$2,000	100	$300	8
Cultivator, Hesston 36'	$4,000	10	$4,000	100	$300	8
Harrow, springtooth 53'	$2,000	10	$2,000	100	$150	8
Disk; Miller 18'	$4,500	10	$2,000	200	$200	8
Drill; JD 8500	$11,500	10	$5,000	200	$500	16
Sprayer, McGregor 70'	$5,000	10	$2,500	100	$300	16
Combine; JD 9600	$52,000	10	$10,000	200	$1,000	24
Combine; Gleaner N7	$15,000	10	$5,000	100	$500	16
Semi; Peterbilt with trailer	$40,000	10	$10,000	200	$500	24

Appendix E

Precision FARM 1 Production Costs for Soft White Winter Wheat, 2014

Item	Quantity Per Acre	Unit	Price or Cost/Unit	Value or Cost/Acre
Gross Returns				
Wheat	75	bu	$6.50	$502.5
Variable Costs				
Seed:				**$24.00**
Wheat Seed	100	lb	$0.24	$24.00
Fertilizer:				**$92.60**
Nitrogen (Aqua)	85	lb	$0.52	$44.20
Sulfur (Thiosol)	17	lb	$0.41	$6.97
Nitrogen (Sol 32) side-dress	25	lb	$0.77	$19.25
1 gal 10-34				
Zinc	1	acre		$5.00
Boron	1	acre		$5.00
Huminc Acid	1	acre		$2.00
Molasses	1	Gal	$1.68	$1.68
Biologicals				$8.50
Pesticides:				**$33.55**
Roundup	16.0	oz	$0.18	$2.81
Surfactant	3.2	oz	$0.24	$0.75
Axiom 50%	6.0	oz	$2.14	$6.42
Powerflex	2	oz	$3.54	$7.09
Tilt	4.0	oz	$1.02	$4.06
Tilt	3	oz	$1.02	$3.05
Huskie	12.0	oz	$0.78	$9.37
Machinery:				**$29.69**
Fuel	2.44	gal	$3.50	$8.55
Lubricants	1	acre	$1.64	$1.64
Machinery Repairs	1	acre	$9.71	$9.71
Machinery Labor	0.51	acre	$20.00	$10.19
Other:				**$17.94**
Crop insurance	1	acre	$17.94	$17.94
Operating Interest				$10.01
Total Variable Costs				**$207.79**
Variable Costs per Unit				$2.77
Net Returns Above Variable Costs				**$294.71**

Precision FARM 1 Production Costs Continued

Ownership Costs:			
Machinery depreciation			$25.82
Machinery interest			$15.97
Machinery insurance, taxes, housing, licenses			$8.51
Land Cost*		1 acre:	$118.00
*Based on Share Rent Percentage:			
Landlord	33.00%		
Tenant	67.00%		
Overhead			$5.00
Management fee			$25.00
Total Fixed Costs			**$198.30**
Fixed Costs per Unit			$2.64
Total Costs per Acre			**$406.09**
Total Cost per Unit			$5.41
Net Returns over Total Costs, or Returns to Risk			**$96.41**

Precision FARM 2 Production Costs for SWWW 2014

Item	Quantity Per Acre	Unit	Price or Cost/Unit	Value or Cost/Acre
Gross Returns				
Wheat	92	bu	$6.70	$616.40
Variable Costs				
Seed:				**$28.80**
Wheat Seed	120	lb	$0.24	$28.80
Fertilizer:				**$120.16**
Nitrogen (liquid)	120	lb	$0.55	$66
Sulfur (Thiosul)	25	lb	$0.41	$10.25
Potash	35	lb	$0.75	$26.25
Phosphorous (11-37)	26	gal	$0.66	$17.16
Nitrogen (Urea)	1	lb	$0.50	$0.50
Pesticides:				**$64.36**
Roundup	32.0	oz	$0.18	$5.63
Surfactant	3.2	oz	$0.24	$0.75
Roundup (70% ground)	24.0	oz	$0.18	$2.95
Surfactant (70% ground)	3.2	oz	$0.24	$0.53
Axiom (70% ground)	8	oz	$2.14	$11.97
Widematch	24	oz	$0.57	$13.68
Twinline	6	oz	$1.93	$11.58
AllyExtra	0.5	oz	$7.85	$3.93
Powerflex	2	oz	$3.54	$7.08
Tilt	3	oz	$1.02	$3.05
Dimethoate	0.7	oz	$4.84	$3.23
Machinery:				**$25.35**
Fuel & Lubricants	2.83	gal	$3.50	$9.91
Lubricants	1	acre	$1.49	$1.49
Machinery Repairs	1	acre	$3.76	$3.76
Machinery Labor	0.51	acre	$20.00	$10.19
Custom & Consultants:				**$9.50**
Custom Aerial	1	acre	$9.50	$9.50
Other:				**$22.01**
Crop insurance	1	acre	$22.01	$22.01
Operating Interest				$13.68
Total Variable Costs				**$283.86**
Variable Costs per Unit				$3.09
Net Returns Above Variable Costs				**$332.54**
Ownership Costs:				
Machinery depreciation				$22.72
Machinery interest				$17.70
Machinery insurance, taxes, housing, licenses				$8.26
Land Cost			1 acre:	$135.26
Overhead				$7.00
Management fee				$31.00
Total Fixed Costs				**$221.94**
Total Costs per Acre				**$505.8**
Net Returns over Total Costs, or Returns to Risk				**$110.60**

Precision FARM 3 Production Costs for SWWW, 2013-2014

Item	Quantity Per Acre	Unit	Price or Cost/Unit	Value or Cost/Acre
Gross Returns				
Wheat	78	bu	$6.70	$522.60
Variable Costs				
Seed:				**$24.00**
Wheat Seed	100	lb	$0.24	$24.00
Fertilizer:				**$96.38**
Nitrogen (Aqua)	90	lb	$0.53	$47.70
Nitrogen (Uran)	5	lb	$0.77	$3.85
Nitrogen (Uran)	32	lb	$0.77	$24.26
Sulfur (Thiosul)	17	lb	$0.41	$6.97
Sulfur (Thiosul)	6	lb	$0.41	$2.35
Phosphorous (liquid)	15	gal	$0.75	$11.25
Pesticides:				**$26.43**
Osprey (50%)	4.75	oz	$3.53	$8.39
Dagger	12	oz	$0.26	$3.12
Widematch	20.8	oz	$0.57	$11.86
Tilt	3.0	oz	$1.02	$3.06
Machinery:				**$31.13**
Fuel	3.39	gal	$3.50	$11.86
Lubricants	1	acre	$1.51	$1.51
Machinery Repairs	1	acre	$8.53	$8.53
Machinery Labor	0.46	acre	$20.00	$9.23
Other:				**$18.66**
Crop insurance	1	acre	$18.66	$18.66
Operating Interest				$9.95
Ownership Costs:				
Machinery depreciation				$5.87
Machinery interest				$7.52
Machinery insurance, taxes, housing, licenses				$3.45
Land Cost			1 acre	$126.00
Overhead				$5.00
Management fee				$26.00
Total Costs per Acre				**$380.38**
Total Cost per Unit				$4.88
Net Returns over Total Costs, or Returns to Risk				**$142.22**

Precision FARM 4 Production Costs for SWWW 2014

Item	Quantity Per Acre	Unit	Price or Cost/Unit	Value or Cost/Acre
Gross Returns				
Wheat	92	bu	$6.70	$616.40
Variable Costs				
Seed:				**$28.00**
Wheat Seed	100	lb	$0.28	$28.00
Fertilizer:				**$126.67**
Nitrogen (liquid)	90	lb	$0.65	$58.50
Sulfur (Thiosul)	10	lb	$0.67	$6.70
Potash	20	lb	$0.30	$6.01
Phosphorous (11-37)	35	lb	$0.66	$23.10
Nitrogen (Urea)	40	lb	$0.65	$26.00
Sulfur (Thiosul)	5	gal	$0.67	$3.35
Potash	10	lb	$0.30	$3.01
Pesticides:				**$52.57**
Amber	0.56	oz	$11.95	$6.69
Widematch	20.00	oz	$0.61	$12.20
Express	0.30	oz	$17.20	$5.16
Everest 2.0	1.00	oz	$19.25	$19.25
Headline	3.00	oz	$3.09	$9.27
Machinery:				**$40.21**
Fuel & Lubricants	3.66	gal	$3.40	$12.44
Lubricants	1	acre	$1.92	$1.92
Machinery Repairs	1	acre	$14.70	$14.70
Machinery Labor	0.56	acre	$20.00	$11.15
Custom & Consultants:				**$0.25**
Custom Aerial	0	acre	$7.50	$0.00
Tissue Sampling	1	acre	$0.25	$0.25
Other:				**$22.01**
Crop insurance	1	acre	$22.01	$22.01
Storage Facility & Equip. Repairs				$0.00
Other Labor				
Operating Interest				$12.14
Total Variable Costs				**$281.84**
Variable Costs per Unit				$3.06
Net Returns Above Variable Costs				**$334.56**
Ownership Costs:				
Machinery depreciation				$14.24
Machinery interest				$9.75
Machinery insurance, taxes, housing, licenses				$5.56
Land Cost			1 acre:	$137.00
Overhead				$7.00
Management fee				$31.00
Total Fixed Costs				**$204.55**
Fixed Costs per Unit				$2.22
Total Costs per Acre				**$486.39**
Total Cost per Unit				$5.29
Net Returns over Total Costs, or Returns to Risk				**$130.01**

Precision FARM 5 Production Costs for SWWW, 2013-2014

Item	Quantity Per Acre	Unit	Price or Cost/Unit	Value or Cost/Acre
Gross Returns				
Wheat	95	bu	$6.70	$637.77
Variable Costs				
Seed:				**$21.60**
Wheat Seed	90	lb	$0.24	$21.60
Fertilizer:				**$118.08**
Nitrogen - NH3	110.0	lb	$0.55	$60.50
Nitrogen - Solution 32	29.5	lb	$0.77	$22.72
Phosphorous	20.7	lb	$0.75	$15.53
Potassium	6.7	lb	$0.57	$3.81
Sulfur	15.1	lb	$0.41	$6.20
High Yield	2.0	gal	$2.00	$4.00
N-Demand	1.0	gal	$2.00	$2.00
Sol 32	1.0	gal	$3.33	$3.33
Pesticides:				**$22.41**
Curtail	1.5	pt	$7.50	$11.25
Powerflex	2.00	oz	$3.54	$7.08
Tilt	4.0	oz	$1.02	$4.08
Machinery:				**$45.18**
Fuel	5.62	gal	$3.50	$19.66
Lubricants	1	acre	$2.97	$2.97
Machinery Repairs	1	acre	$6.88	$6.88
Machinery Labor	0.78	acre	$20.00	$15.67
Other:				**$23.52**
Crop insurance	1	acre	$22.77	$22.77
Soil Sampling	1	acre	$0.75	$0.75
Operating Interest				$11.68
Total Variable Costs				**$242.47**
Variable Costs per Unit				$2.55
Net Returns Above Variable Costs				**$395.30**
Ownership Costs:				
Machinery depreciation				$10.83
Machinery interest				$8.65
Machinery insurance, taxes, housing, licenses				$4.92
Land Cost			1 acre	$156.59
Overhead				$6.00
Management fee				$32.00
Total Fixed Costs				**$218.98**
Fixed Costs per Unit				$2.30
Total Costs per Acre				**$461.45**
Total Cost per Unit				$4.85
Net Returns over Total Costs, or Returns to Risk				**$176.32**

Conventional Production Costs for Soft White Winter Wheat, District 1 2014

Item	Quantity Per Acre	Unit	Price or Cost/Unit	Value or Cost/Acre
Gross Returns				
Wheat	80	bu	$6.70	$536.00
Variable Costs				
Seed:				**$24.30**
Wheat Seed	90	lb	$0.27	$24.30
Fertilizer:				**$81.30**
Nitrogen	90	lb	$0.63	$56.70
Phosphorous	30	lb	$0.72	$21.60
Sulfur	10	lb	$0.30	$3.00
Pesticides:				**$32.38**
Osprey	4.75	oz	$3.72	$17.67
Starane Flex	22.00	oz	$0.62	$13.64
Surfactant	3.20	oz	$0.20	$0.64
Brox M	1.60	oz	$0.27	$0.43
Fungicides:				**$23.85**
Quilt	14.00	oz	$1.48	$20.72
Syltac Sticker	0.50	pt	$6.25	$3.13
Machinery:				**$54.32**
Fuel	6.55	gal	$3.40	$22.28
Lubricants	1	acre	$3.35	$3.35
Machinery Repairs	1	acre	$9.31	$9.31
Machinery Labor	1.07	hour	$18.10	$19.39
Custom & Consultants:				**$11.40**
Custom Aerial	1	acre	$8.90	$8.90
Rental Sprayer	0	acre	$2.00	$0.00
Rental Ripper Shooter	1	acre	$2.50	$2.50
Other:				**$23.00**
Crop insurance	1	acre	$23.00	$23.00
Operating Interest				$10.20
Total Variable Costs				**$260.75**
Variable Costs per Unit				$3.26
Net Returns Above Variable Costs				**$275.25**
Ownership Costs:				
Capital recovery (includes depreciation & interest)		acre	$39.13	$39.13
Land Cost		acre	$132.00	$132.00
Overhead				$13.00
Management fee				$27.00
Total Fixed Costs				**$211.13**
Fixed Costs per Unit				$2.64
Total Costs per Acre				**$471.88**
Total Cost per Unit				$5.90
Net Returns over Total Costs, or Returns to Risk				**$64.12**

Uniform 1 Production Costs for Soft White Winter Wheat 2013

Item	Quantity Per Acre	Unit	Price or Cost/Unit	Value or Cost/Acre
Gross Returns				
Wheat	86	bu	$6.75	$580.5
Variable Costs				
Seed:				**$21.60**
Wheat Seed	90	lb	$0.24	$21.60
Fertilizer:				**$94.13**
Nitrogen - NH3	110	lb	$0.55	$60.50
Chlorine	8	lb	$0.90	$7.23
Potassium	20	lb	$0.57	$11.4
Phosphate (10-34)	20	lb	$0.75	$15.00
Pesticides:				**$27.81**
Orion	20.8	pt	$0.57	$11.81
Huskie	0.7	oz	$10.8	$7.56
Osprey (on 50%)	4.75	oz	$3.53	$8.39
Machinery:				**$30.72**
Fuel & Lubricants	2.9	gal	$3.50	$10.36
Lubricants	1	acre	$2.40	$2.40
Machinery Repairs	1	acre	$6.61	$6.61
Machinery Labor	0.56	acre	$20.00	$11.34
Custom & Consultants:				**$10.00**
Custom Aerial	1	acre	$8.75	$8.75
Rental Ripper Shooter	1	acre	$1.25	$1.25
Other:				**$20.72**
Crop insurance	1	acre	$22.21	$20.72
Operating Interest1				$10.37
Ownership Costs:				
Machinery depreciation				$3.78
Machinery interest				$2.04
Machinery insurance, taxes, housing, licenses				$0.69
Land Cost	1	acre	$147.00	$144.00
Overhead				$5.00
Management fee				$29.00
Total Costs per Acre				**$399.87**
Total Cost per Unit				$4.64
Net Returns over Total Costs, or Returns to Risk				**$180.62**

Uniform 2 Production Costs for Soft White Winter Wheat 2014

Item	Quantity Per Acre	Unit	Price or Cost/Unit	Value or Cost/Acre
Gross Returns				
Wheat	68	bu	$6.70	$456.00
Variable Costs				
Seed:				**$26.40**
Wheat Seed	110	lb	$0.24	$26.40
Fertilizer:				**$130.80**
Nitrogen	100	lb	$0.77	$77.00
Phosphorous	30	lb	$0.75	$22.50
Sulfur	20	lb	$0.41	$8.20
Nitrogen	30	lb	$0.77	$23.10
Pesticides:				**$47.03**
Roundup	46	oz	$0.18	$4.04
Crop oil	6.4	oz	$1.51	$4.84
R-11	3.2	oz	$0.21	$0.34
Sharpen	1	oz		$0.00
Huskie	13	oz	$0.78	$10.15
Ally	0.5	oz	$12.26	$6.13
Osprey	4.75	oz	$3.53	$16.78
Tilt	4	oz	$1.02	$4.08
R-11	3.2	oz	$0.21	$0.67
Machinery:				**$26.78**
Fuel	4.17	gal	$3.50	$14.61
Lubricants	1	acre	$2.19	$2.19
Machinery Repairs	1	acre	$3.49	$3.49
Machinery Labor	0.32	acre	$20.00	$6.50
Custom & Consultants:				**$14.40**
Rental Combine	1	acre	$14.40	$14.40
Other:				**$16.39**
Crop insurance	1	acre	$16.39	$16.39
Operating Interest				$13.25
Total Variable Costs				**$275.05**
Variable Costs per Unit				$4.04
Net Returns Above Variable Costs				**$183.95**
Ownership Costs:				
Machinery depreciation			$11.34	$11.34
Machinery interest			$11.63	$11.63
Machinery insurance, taxes, housing, licenses			$3.72	$3.72
Land Cost	1	acre	$87.38	$87.38
Overhead				$7.00
Management fee				$23.00
Total Fixed Costs				**$144.07**
Fixed Costs per Unit				$2.12
Total Costs per Acre				**$419.13**
Total Cost per Unit				$6.16
Net Returns over Total Costs, or Returns to Risk				**$36**

Uniform 3 Production Costs for Soft White Winter Wheat 2013

Item	Quantity **Per Acre**	**Unit**	Price or **Cost/Unit**	Value or **Cost/Acre**
Gross Returns				
Wheat	98	bu	$6.75	$661.50
Variable Costs				
Seed:				**$26.40**
Wheat Seed	110	lb	$0.24	$26.40
Fertilizer:				**$83.10**
Nitrogen (NH3)	100	lb	$0.55	$55.00
Sulfur (Thiosul)	15	lb	$0.41	$6.15
Phosphorous (liquid)	15	lb	$0.75	$11.25
Nitrogen (liq)	10	lb	$0.77	$7.70
Micros	1	acre	$3.00	$3.00
Pesticides:				**$23.05**
Huskie	10	oz	$0.78	$7.80
Beyond	3	oz	$3.73	$11.18
Tilt	4	oz	$1.02	$4.06
Machinery:				**$27.54**
Fuel	3.12	gal	$3.50	$10.93
Lubricants	1	acre	$1.65	$1.65
Machinery Repairs	1	acre	$9.66	$9.66
Machinery Labor	0.27	acre	$20.00	$5.30
Custom & Consultants:				**$0.50**
Rental Sprayer	1	acre	$0.50	$0.50
Other:				**$23.62**
Crop insurance	1	acre	$23.62	$23.62
Operating Interest				$5.53
Ownership Costs:				
Machinery depreciation			$14.17	$14.56
Machinery interest			$12.37	$12.74
Machinery insurance, taxes, housing, licenses			$6.52	$6.30
Land Cost	1	acre	$84.19	$167.00
Overhead				$5.00
Management fee				$33.00
Total Costs per Acre				**$422.80**
Total Cost per Unit				$4.31
Net Returns over Total Costs, or Returns to Risk				**$238.70**