Overcoming barriers to agroecological practices: Assessing the role of financial incentive programs in facilitating cover crop adoption

by

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ABSTRACT

Industrial agriculture presents tremendous environmental challenges, and more sustainable management practices are needed to reduce negative environmental consequences. Increasing plant diversity in agroecosystems with cover crops is a promising solution to these challenges because they can provide a host of ecosystem services, including reducing nutrient pollution in waterbodies and improving farmers' adaptive capacity in the face of climate change. Despite their benefits, however, farmers face a wide range of constraints across scales that limit the adoption of cover crops. Macro-level policies and economic pressures, in particular, strongly influence farmer agency. Thus, this study explored strategies used by cover crop farmers in the Great Lakes region to overcome barriers, with a particular focus on how financial incentive programs impact farmer decision making. In semi-structured interviews, we found that farmers overcame cognitive, economic and social constraints by experimenting with cover crops on their farms, adjusting their mindsets and expectations about agroecological practices, and seeking local knowledge from peers. In most cases, cover crops complemented the use of conservation tillage practices, and farmers participated in government financial incentive programs to lower their financial risk. Farmers indicated that financial incentive programs, while instrumental in encouraging cover crop adoption, may be limited in effectiveness if they fail to address other constraints related to knowledge and risk management. Decision makers can learn from these early cover crop

adopters to design policies that leverage existing resources and provide a clearer path for the adoption of agroecological practices.

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1 INTRODUCTION

Row crop farmers in the United States operate within a highly competitive system where, in order to maximize yield and profit, they are pressured to grow vast monocultures and specialize in few crops, all but eliminating other ecosystem functions (Buttel et al, 1990; Schulte et al, 2006; Nassauer et al, 2007). This intensification necessitates the heavy use of synthetic inputs, resulting in environmental externalities that include water pollution, soil loss, and greenhouse gas emissions (Matson et al, 1997; Tilman et al, 2002; Kremen and Miles, 2012; IPCC, 2007). Farmers themselves are also negatively impacted by this system: they are now taking on record levels of debt in the face of extremely narrow profits margins (CRS Report, 2018), while the number of farms continues to shrink (MacDonald et al, 2013) and rural communities experience a concomitant decline (Johnson and Lichter, 2019). Increasingly erratic weather events caused by climate change further exacerbate these challenges (IPCC, 2013; Trenberth, 2011).

To address problems posed by industrial agriculture, many have called for a shift toward management systems based on agroecological principles – defined here as practices that rely more on ecological processes (e.g. decomposition and nutrient cycling, predation) than synthetic inputs for key functions (IAASTD, 2008; De Schutter, 2010; FAO, 2014). Increasing crop diversity, for instance, can enhance ecosystem functions that moderate the use of fertilizers and chemicals, mitigate externalities, and improve resilience to global change (Davis et al, 2012; Isbell et al, 2017; Robertson et al, 2014). Cover cropping, or growing non-harvested plants in rotation with primary crops, is one such agroecological practice that increases crop diversity, with well-documented benefits like minimizing soil erosion and recycling and retaining nutrients in soil (Blanco-Canqui et al, 2015; Dabney et al, 2001).

However, given the broader context of agricultural industrialization, farmers face a multitude of constraints to adopting agroecological practices. A complex suite of ecological, social, economic, and political factors interact across scales to influence, and ultimately limit, farmers' decisions and their ability to adapt to environmental changes (Blesh and Wolf, 2014; Hendrickson and James, 2005). This web of constraints is shaped by overarching national and international policies that prioritize large-scale industrial agriculture (Stuart and Gillon, 2013; Capellesso et al, 2016), which helps to explain why a well-known agroecological practice like cover cropping is still only used on 3.8% of cropland in the United States (USDA, 2017).

This points to the need for a greater understanding of how farmers overcome barriers to adopt agroecological practices. While much existing research has focused on farmers' individual characteristics and motivations for adoption of conservation practices, less is known about the specific strategies and resources they use when transitioning to agroecological management (Blesh and Wolf, 2014). Furthermore, much of the adoption literature has focused on variables at the micro-scale (e.g. personal values) and the meso-scale (e.g. social networks), with less attention to variables at the macro-scale (e.g. Farm Bill policies), even though these factors have been shown to significantly influence farmer decision making (Stuart and Gillon, 2013; Wejnert, 2002; Lubell and Fulton, 2008).

Thus, this paper aims to contribute to a greater understanding of how farmers overcome barriers to adopt agroecological practices, with a particular focus on how policies impact farmer decision making related to management of cover crops. We further narrow our focus to financial incentive payments, a common policy instrument used to encourage and facilitate cover crop adoption. Specifically, we ask two key questions: 1) How have farmers overcome barriers to cover crop adoption? and 2) From farmers' perspectives, what changes to incentive payment programs are needed to support greater cover crop adoption?

Our study focused on the Lake Erie Watershed, where agricultural pollution has received widespread attention due to losses of nitrogen and phosphorus from fields that contribute to recurring algae blooms in Lake Erie (Michalak et al, 2013). We interviewed early adopters of cover crops in Michigan and Ohio, whose direct experience with the practice enabled them to reflect on their strategies for overcoming constraints, and address whether and how incentive payments influence cover crop adoption. Our approach was therefore intended to identify opportunities for policy change that support transitions to farm diversification through cover cropping.

2 BACKGROUND

2.1 Cover crops enhance ecosystem functions

Cover cropping is a key opportunity for diversifying grain rotations to achieve environmental objectives, both on and off farms. Cover crops, which include many varieties of grasses, legumes, and brassicas, are intentionally grown in periods between the cultivation of cash crops primarily to enhance ecosystem functions, such as building organic matter, suppressing weeds and pests, and supplying and retaining nutrients, among others (Snapp et al, 2005; Davis et al, 2012; King and Blesh, 2018; Schipanski et al, 2014). Cover crops are typically incorporated into the soil, therefore, rather than harvested. Prior to the Green Revolution, cover cropping was a common practice, although it largely disappeared from agricultural landscapes with the advent of synthetic inputs (Groff, 2015).

Some common examples of cover crops include crimson clover and hairy vetch – legumes that fix atmospheric nitrogen in the soil. They are grown after harvest in late summer, become dormant over the winter, and then continue growing and accumulating nitrogen in the spring. Before or shortly after spring planting, farmers terminate these cover crops either with herbicide or mechanical tillage methods. Other cover crops, like oats and rye, are cereals that can scavenge excess nutrients, therefore preventing nutrient losses that contribute to water pollution (SARE, 2012). These nutrients are utilized by and cycled through plants and microorganisms, instead of washing off fields (McSwiney et al, 2010). Through their impacts on agroecosystem carbon and nutrient cycling processes, cover crops can be an ecologically-based tool for nutrient management (Drinkwater and Snapp, 2007). While cover crops may be grown as a single species or as a mixture, a growing body of research suggests that mixing cover crop species based on functional trait diversity may optimize these ecosystem services (Blesh, 2018; Finney and Kaye, 2017; Storkey et al, 2015).

Cover crops may also help farmers adapt to both intense rainfall and drought caused by climate change. For instance, cover crops, whether as living biomass or residue, can shield soil from erosion during extreme rain events; at the same time, their living root systems in the soil can reduce nutrient leaching. In regions experiencing drought, cover crops may be managed to create a mulch that covers the ground to maintain moisture beneath. Cover crops are also an important tool in climate change mitigation: they sequester atmospheric carbon and store it in the soil, and they attenuate the use of fossil-fuel based inputs, particularly synthetic nitrogen fertilizer (Kaye and Quemada, 2017).

2.2 Policy context

Agriculture in the United States, including the use of cover crops, is largely driven by top-down policies in the Farm Bill. Dating to the Great Depression, this legislation was part of President Franklin Roosevelt's New Deal, designed to support farmers after a set of economic and ecological shocks devastated farming and rural communities. The first

Farm Bill stabilized farm prices by setting production limits and price supports; it also developed conservation programs to address deteriorating environmental conditions created by the Dust Bowl (Barnett, 2014).

Successive Farm Bills have since evolved in significant ways, responding to shifting needs, priorities, and global influence. At the same time, technological advancements and industrialization have caused the perennial problem of overproduction – where the supply of commodities exceeds demand, resulting in low farm prices. Numerous policy approaches have attempted to address this issue, and today, they primarily rest upon expanding global trade and subsidizing the incomes of commodity growers (Barnett, 2014).

The confluence of technological advancements, expanded markets, and complex political objectives transformed the agricultural landscape dramatically throughout the 20th century: many small, diversified farms were largely replaced by much larger farms specializing in either crops or livestock (Hoppe and Korb, 2005). This has manifested in agricultural landscapes with vast, uniform monocultures and concentrated livestock operations. Government subsidies and trade encourage the production of a select number of commodities, while persistently low prices and market instability pressure farmers to maximize yield and expand to take advantage of economies of scale. To fund their operations, many farmers take on tremendous levels of debt (CRS Report, 2019; USDA, 2020).

This system of agriculture has contributed greatly to environmental degradation. Industrial agriculture is a driver of biodiversity loss (Mattison and Norris, 2005) and species endangerment (Kerr and Deguise, 2004). Perhaps its most widely recognized environmental consequence, however, is the impairment of rivers and lakes: agriculture is the largest contributor of nonpoint source water pollution in the United States (EPA, 2020). In systems with low crop diversity and simple crop rotations, carbon and nitrogen cycles are “uncoupled” and require extensive fertilizer application, which causes these systems to be inherently “leaky” due to nutrient saturation (Drinkwater and Snapp, 2007). Erosion and surface runoff are the largest pathways of phosphorus loss from fields, while nitrogen is typically lost via nitrate leaching through the soil profile. These nutrients enter water bodies and create algae blooms and hypoxic “dead” zones around the globe (Diaz and Rosenberg, 2008). Despite this, environmental regulations are lax, and the Clean Water Act has virtually no regulations for nonpoint source pollution (Montpetit, 2002).

The Conservation Title in the Farm Bill was created in 1985 with the goal of addressing some of these problems. Administered by the U.S. Department of Agriculture (USDA) and the Natural Resource Conservation Service (NRCS), today it includes a combination of retirement programs (e.g. paying farmers not to plant on marginal or sensitive land) and working lands programs (e.g. providing financial support to implement conservation practices on cropland and grazing land). Hundreds of practices are supported by working lands programs, although they utilize different approaches (reactive or preventative) and have varying degrees of effectiveness, and financial support, for addressing nonpoint source water pollution. Practices to address agricultural nutrient pollution have been placed into three broad categories. For instance, buffer strips and wetlands are considered “end of pipe” practices that intercept, but do not actually reduce, nutrients leaving farm fields; precision or "site-specific crop management" practices use data and technology to apply nutrients at varying quantities and locations across fields to increase nutrient use efficiency, but do not address the inherent "leakiness" of industrial agricultural systems; while agroecological practices, like cover crops and diversified crop rotations, re-couple carbon and nutrient cycles in fields and enhance ecological processes that reduce nutrient inputs and losses, preventing pollution in the first place. In their study on federal agricultural investments, Hufnagl-Eichiner et al (2011) explain that diversified, ecological systems "reflect the logic of pollution prevention and fundamental system redesign." But, when analyzing research and development portfolios in the Corn Belt – the leading source of nonpoint source pollution in the Gulf of Mexico – these agroecological management practices received far less federal support than reactive approaches that largely maintain the status quo. These investment decisions appear to signal a lack of political will to seriously address the fundamental cause of nonpoint source water pollution created by industrial agriculture. Furthermore, regardless of which practices are prioritized politically, conservation funding as a whole is regularly threatened in the Farm Bill: in the 2014, for instance, $6 billion was cut from the Conservation Title, which the Farm Bill maintained in 2018 (NSAC, 2018).

Despite these limitations, working lands programs in the Farm Bill, including the Environmental Quality Incentive Program (EQIP) and the Conservation Stewardship Program (CSP), promote the voluntary adoption of conservation practices and support farmers as they transition to unfamiliar practices, using financial incentives as a primary instrument to encourage farmer participation (Claassen, 2008). To enroll in these programs, farmers submit proposals for conservation practices on their land, and if accepted, enter into a contract with the government in exchange for payment. Depending on the program, farmers can receive all or partial funding to cover the cost of implementation. Usually, program enrollment is competitive, and a ranking system is used so contracts that accomplish a greater number of environmental objectives are given greater priority. Most contracts last between one to three years, although some last as long as ten years. Although they are administered by a federal agency, individual states identify priority areas and decide how to allocate funds across conservation practices, which influences the degree to which "effective" practices are supported in different locations. Often, local county governments create additional incentive-based programs for environmental conservation modeled after EQIP and CSP.

Because environmental objectives in the Farm Bill rely almost entirely on voluntary commitments, numerous studies on adoption have focused on factors that contribute to farmer participation in conservation programs. These studies have found that many variables have an influence (e.g. age, education, social networks, and farm size), but due to the heterogeneity of farms and farmers, these results have been largely inconsistent in terms of predicting program participation (Reimer and Prokopy, 2013). Furthermore, there is comparatively little empirical research addressing how policy instruments, like incentive payments, function in real life after implementation. Instead, much of the literature uses theoretical models to assess these tools, and therefore offer little insight into how farmers themselves interact with or perceive them (Dowd et al, 2008). We aim to fill this gap by exploring farmers' experiences with incentive payment programs to understand whether and how they support cover crop adoption.

2.3 Linking constrained choice and adaptive capacity

Given the unsupportive context in which farmers operate, constrained choice theory helps explain why cover crop adoption still remains so low in the United States, despite their widely-acknowledged benefits. The theory recognizes that individuals operate within a complex system of factors that interact across multiple levels to confine and influence opportunities, agency, and decision making; it argues for an interdisciplinary approach to better understand how this interplay impacts processes and outcomes (Bird and Rieker, 2008; Vuolo, 2016). Social-ecological factors interact across the micro-level (e.g. individuals and relationships), meso-level (e.g. communities and organizations) and macro-level (e.g. legal systems and economies) that together shape management decisions on farms (Stuart and Gillon, 2013; Guerra et al, 2017).

Hendrickson and James (2005) emphasize the importance of previously described macro-level factors in constraining farmers' choices. Broadly speaking, the industrialization of agriculture has created a "technological treadmill" whereby "farmers must run faster just to stay in place" (Cochrane, 1958). Increasingly concentrated markets in seeds, chemicals, crops, and livestock have also significantly narrowed farmers' options, and major decisions are now in the hands of fewer corporate actors (Hendrickson and James, 2005). Such macro-level constraints can significantly alter farmers' priorities and ability to adopt agroecological practices. For instance, economic pressures lead farmers to prioritize high yields over soil health, preventing the adoption of agroecological practices that yield less in the short term compared to input-intensive industrial practices (Darnhofer et al, 2005; Rodriguez et al, 2009).

Farmers experience barriers across micro- and meso-levels as well, which have been well-represented in the literature. For instance, the sociocultural norm of having a "clean" field may discourage farmers from adopting agroecological practices that look "messy" (Sutherland and Darnhofer, 2012). Or, farmers' skills and expertise may be limited to industrial models of production, discouraging them from attempting new knowledge-intensive endeavors (McCracken et al, 2015). Research shows that environmental attitudes, personal identity, and risk perception can also impact farmers' decisions to adopt conservation practices (Heberlein, 2012; McGuire et al, 2013; Knutson et al, 2011). When it comes to cover crop adoption specifically, farmers have described numerous constraints, including the cost of seed, increased workload, weather uncertainties, lack of equipment, lack of experience, limited information, and uncertainty about ecological benefits (ISU Extension, 2012; Wilson et al, 2017). That is to say, even farmers who wish to use cover crops or other agroecological practices face many limitations.

Constrained choice has important implications for farmers' adaptive capacity, which is closely aligned with farm resilience. While resilience refers to the level of disturbance that a system can absorb without fundamentally changing in structure or function, adaptive capacity refers to the ability to cope with disturbance and act in support of resilience (Berkes et al, 2013; Engle and Lemos, 2010). The resilience concept became common after being applied to describe ecosystem dynamics (Holling, 1973), but it has since expanded to also incorporate complex social and ecological interactions in response to change (Folke, 2006). The concept, therefore, integrates the role of social, cultural, and political factors across scales in building (or constraining) resilience (Zimmerer, 2015; Ingalls and Stedman, 2016; Walsh-Dilley et al, 2016). A key component of resilience thinking is the notion that shocks and unpredictability are not exceptions to the norm – rather, they *are* the norm, as the cycle of disturbance followed by a return to stability is a feature of any system (Botkin, 1990; Conway, 1987; Pimm, 1991). Given the increased frequency and severity of disturbances caused by climate change (Melillo et al, 2014) – which is projected to increase agricultural pollution (Bates et al, 2008) and hurt crop yields (Gustafson et al, 2015) – the ability to proactively prepare for these stresses and respond with flexibility is paramount.

Agricultural resilience, then, relies greatly on adaptive capacity, and despite operating within an unsupportive context in the U.S. Midwest, cover crop farmers in our sample developed creative strategies for adaptive management. In this paper, we therefore integrate these two perspectives – constrained choice and adaptive capacity – for a more complete understanding of transitions to cover cropping in the context of global change. To date, there is little research on *how* farmers overcome barriers to adopt alternative practices. Rather, much of the existing literature explores *why* – e.g., the factors and motivations that lead farmers to adopt conservation practices or not (Baumgart-Getz et al, 2012). We aim to contribute to the literature on adoption and adaptation, then, by building upon a much smaller body of research that specifically investigates how farmers change (Blesh and Wolf, 2014). We explore the resources and strategies cover croppers use so that we can learn from these “bright spots” and inform changes to policy that might support widespread innovation and improve the adaptive capacity of agricultural systems (Bennett et al, 2016; de Vries, 2005).

2.4 Overview of the Great Lakes region and study area

Policy environment in the Great Lakes region

Like most farms in the United States, farms in the Great Lakes region, where our study was located, are largely governed by federal Farm Bill policies. The consequences of these policies are clearly borne out in Lake Erie, which experiences recurring algae blooms due to eutrophication. Agriculture has been identified as a main contributor to this problem, in particular due to runoff of dissolved reactive phosphorus, as well as nitrate leaching (Carpenter et al, 1998). This problem has received widespread attention in recent years, especially after the City of Toledo shut off its public water system for two days in 2014 due to a toxic algae bloom (Williams, 2019). These events are only expected to worsen as the region experiences more intense rainfall, and therefore nutrient pollution, due to climate change (Diaz and Rosenberg, 2008).

As a result, farmers in the region face tremendous pressure to mitigate negative environmental externalities caused by industrial agricultural practices. The failure of the federal government to address the issue has resulted in action at the municipal level, including the Lake Erie Bill of Rights, a legal attempt to grant the lake personhood and the ability to sue for damages (Williams, 2019). Most recently in November 2019, Ohio announced a new statewide initiative, H2Ohio, "to ensure safe and clean water for all Ohioans." The program provides funding to farmers to voluntarily implement a suite of conservation practices, including cover crops, with the goal of preventing excess nutrients from entering the lake (H2Ohio, 2020). Overall, this region has been the target of much research, funding, and remediation efforts to address agricultural pollution from government agencies, NGOs, and foundations (Cousino et al, 2018).

Overview of the study area

Our study focused specifically on farms located in two sub-watersheds of the Lake Erie Basin: the River Raisin Watershed and the Maumee River Watershed (Figure 1). The River Raisin Watershed is 2,776 square kilometers (1,059 square miles) and is primarily located in Lenawee County, Michigan, with small portions extending into surrounding counties and Ohio. The soil types in the watershed vary widely, from the poorly drained Hoytville clay soil series to well-drained Morley and Blount loams (USDA, 1961). The watershed has 4,828 kilometers (3,000 miles) of underground field drainage networks. Roughly three-quarters of the watershed's land is in agriculture, primarily for grain production (River Raisin Watershed Council, 2009).

The Maumee River Watershed is the largest watershed in the Great Lakes region, at 21,538 square kilometers (8,316 square miles) spanning Ohio, Michigan, and Indiana (US EPA, 2020). In Ohio alone, the Maumee River Watershed reaches 18 counties across 13,012 square kilometers (5,024 square miles) (Ohio EPA, 2020). Farms in our study were located in the northern portion of the watershed near the Ohio-Michigan border, where the soil type consists mostly of poorly-drained clays that are heavily tiled (NRCS, 2020; Taylor et al, 1961). Much of the Maumee River Watershed was historically part of the Great Black Swamp, before the swamp was drained for settlement and agricultural production (Henry, 2017). Roughly two-thirds of the watershed is in agricultural production, and the Maumee River is the primary source of phosphorus to Lake Erie (Wilson et al, 2018).

In the spring of 2019, the Midwest experienced extremely heavy rainfall and historic flooding that prevented farmers from planting 7.85 million hectares (19.4 million acres) total across the nation. Ohio farmers reported not planting 601,330 hectares (1.49 million acres), and Michigan farmers reported not planting 357,620 hectares (883,699 acres) (FSA, 2019). Farmers could collect crop insurance payments on this land, and NRCS created a separate disaster relief program in select states as well. The program provided incentive payments for farmers to grow cover crops on unplanted land with the goal of providing financial support, suppressing weeds, maintaining soil health, and reducing water pollution. Therefore, the area experienced both a highly visible impact of climate change and an unusually high level of funding for planting cover crops during the study period.

3 METHODS

In order to better understand farmers' strategies for overcoming structural constraints to cover crop adoption, with a particular emphasis on how policy influences farmers' management decisions, we conducted 21 semi-structured interviews with farmers located in the Maumee River Watershed and the River Raisin Watershed. We chose farmers directly involved in growing cover crops so that they could draw upon personal experience using the practice and engaging with financial incentive programs.

We chose an in-depth, open-ended qualitative approach to data collection in order to better understand the perspectives and most pressing concerns of our sample (Patton, 2001). Although we deliberately selected only farmers with experience planting cover crops on their land, they were nevertheless heterogeneous in their years of experience with the practice, the size and physical characteristics of their farms, their attitudes toward conservation, their level of engagement in social networks and government programs, and so forth. To analyze how these factors interact to influence farmers' decisions, it was necessary to let farmers share their experience in more detail and nuance than could be captured in a survey.

To identify farmers, we first connected with Soil and Water Conservation Districts (SWCD) – local government agencies that develop conservation policies and programs based on the unique needs of their area, explaining that we aimed to better understand the challenges farmers face in growing cover crops and learn about their experience with financial incentive programs. SWCD employees and elected supervisors in the Maumee River Watershed put us in touch with farmers in the area who plant cover crops. Using the snowball sampling technique, we identified future participants by asking interviewees for additional contacts in their watershed. The same process was used to identify farmers in the River Raisin Watershed, however, several contacts were also provided by a University of Michigan PhD student conducting research in partnership with farmers in the region. Altogether, we conducted 21 interviews between July 2019 and March 2020. Twelve participants were based in Ohio, and ten participants were based in Michigan.

The first four interviews were conducted in-person, while the remaining were conducted over the phone. Interviews lasted approximately 80 minutes, on average. Each interview followed the same guide with four sections: 1) Farm background, 2) Experience using cover crops, 3) Experience with policies and programs, and 4) Sources of information (see interview guide in Appendix A).

One farmer did not consent to being recorded, so extensive hand-written notes were taken during this interview. The other 20 interviews were recorded and transcribed by the lead author. Using a standardized template, memos were also written for each interview to capture emerging themes, patterns, and other salient or surprising pieces of information. Transcripts were then imported into NVivo and coded.

Coding began deductively with a template modified from a previous study in this region, which had identified factors that influence cover crop adoption (Wilson et al, 2017). We expanded upon this original codebook a priori by adding a section specifically on policy with the codes we expected to appear in the data. Data were then sorted into these categories. During the coding process, we subsequently used an inductive process to reorganize the codebook to better reflect recurring concepts and themes, eliminate codes that did not appear in the data, and add codes as they emerged.

Our analysis was an iterative process, with interviews, transcriptions, memos, and data analysis happening simultaneously at times. Interviews were revisited and coded multiple times by the lead author to ensure all relevant data were captured and consistently categorized into the appropriate codes. The most salient themes from the data are discussed in the results.

4 RESULTS

4.1 Interviewee characteristics

Farmers in our sample primarily grew corn, soybeans, and wheat as cash crops, although one farmer also grew a significant amount of produce that was sold at farmers markets. Eighteen of the farms grew three or more cash crops. Total farm size ranged from 57 hectares (140 acres) to 3,440 hectares (8,500 acres), the average being 633 hectares (1,564 acres). Two farmers had small cow/calf operations (>100 head) and another farmer had a medium-sized dairy herd (500 head). Farmers had a wide range of cover crop experience as well, from three years to over 30 years. According to Diffusion of Innovation theory, these farmers would be considered “innovators” and “early adopters” of cover crops, owing to the fact that cover crop adoption is still so low in their region and across the United States (Rogers, 2003; Padel, 2001). Most farmers used no till and other conservation tillage methods, while two farmers used conventional tillage methods. Farmers also had varying degrees of experience participating in different government programs at the federal and local levels, and all but three had participated in financial incentive programs specifically to support growing cover crops (Table 1).

4.2 Examples of farmers overcoming constraints

Farmers' motivations for growing cover crops and the benefits they hoped to achieve were largely consistent with prior research findings (Wilson et al, 2017), with the most salient drivers for cover crop adoption in our sample being soil health (e.g. increased organic matter, better soil structure, erosion control), weed suppression, and nutrient supply and retention. In addition, farmers often cited water quality improvements as a key motivator for cover crop adoption. However, to achieve their goals for cover cropping, interviewees reported encountering a number of constraints. Farmers described their own experience confronting these challenges and strategies to overcome them, which we provide in more detail below.

Broadly speaking, one of the greatest challenges farmers discussed had to do with managing cover crops – more specifically, the financial risk of potentially disrupting cash crop production, which can occur when planting is delayed following cover crop termination. Unpredictable weather compounds these uncertainties, as this can significantly alter farmers' schedules, workloads, and their ability to perform field operations. While farmers noted that information about cover crop management is now widely available, sifting through it is time-consuming; furthermore, because cover crop research often occurs far away from their fields in small test plots with different soil types, they called into question the transferability of these results to their farms. Finally, while most farmers in our sample were convinced that cover crops provided beneficial ecosystem services, some more recent adopters still had doubts. These concerns largely stemmed from the extremely tight profit margins farmers already face, which means they are less willing to pay additional seed and labor costs if there is no guaranteed return on investment. Given all this, interviewees described hesitating to deviate from known conventional practices and risk a crop failure, which could, in turn, invite judgment from peers. Interviewees also reported that planting cover crops on ground that is rented, rather than owned, is harder to justify, given the lack of incentive to build soil quality on land they may not farm long-term, given the uncertainties associated with lease agreements. The strategies and resources farmers used to overcome these complex barriers, described below, often allowed them to address multiple constraints across multiple levels at the same time.

Experimentation

The majority of farmers (13 out of 21) described partaking in a process of trial-and-error, which enabled them to gain experience and confidence with a new management skill on only a few acres. Through this strategy, farmers conducted their own site-specific research to identify their preferred management techniques without a high degree of financial risk or judgment from peers during this transition period:

> *I'll tell you this, that field wasn't right up by the road someplace. It's kind of back behind a ditch, kind of tucked away in a corner. So it's, I mean, some of that fear [of judgement] we talked about is real. And we had that a little bit, so we said, yeah, let's try it on this back piece. It's kind of uniform, it's back here. It worked. – Farmer 7*

In describing their transition to using cover crops, farmers also commented on the ecological benefits they witnessed while experimenting, like weed suppression and improved soil structure:

> *I was doing it more as just an experiment. Okay, does this work? Is it going to work? What's happening? What's going on? The thing I guess I noticed was, whenever you went out and dug around a radish, there were earthworms. – Farmer 12*

The increased presence of earthworms, an indicator of good soil health, offered evidence that cover crops were, indeed, making a difference in the soil. The visual cue provided important reassurance for this farmer to continue the practice and ultimately scale up his cover crop acreage. Thus, experimentation allowed farmers in our sample to learn a new knowledge-intensive skill and observe the efficacy of cover crops firsthand while limiting their financial vulnerability to a limited number of acres. And, by starting small, they could strategically situate test plots in obscured areas, away from the road, where they could freely "play" with the an unfamiliar practice without fearing judgment from peers for deviating from conventional practices or having a "messy" field.

Adjusting mindsets

Given that cover crop benefits result from biological processes and interactions in agroecosystems and may only be noticeable after a long period of time, farmers described needing to moderate their expectations. As would be expected, some long-time cover croppers reported seeing soil health benefits only after several years of sustained implementation; farmers newer to the practice remained optimistic they would eventually witness soil health benefits if they continued long enough. They often noted that cover crops were not a panacea, and that the impacts of cover crops could change year-to-year.

Farmers described these mental adjustments as being crucial for succeeding with the practice. They were able to overcome cognitive barriers and shift from a short-term mindset to a long-term mindset by recognizing their farms as complex ecological systems. Farmers shared many observations of ecosystem functions that, prior to adopting cover crops, had been previously overridden by use of synthetic inputs:

> *...as we started doing that, we were getting a handle on some of that, we started seeing more of this biological stuff take place. We'd grow all this biomass and you'd see hardly nothing left when you go in there and you plant it green in April or May. By the time we'd harvest the corn or the*

soybeans, there'd be nothing left. All this biomass was consumed. And it was through biological [activity] – the earthworms and all the microbes in the soil. – Farmer 14

Detailed descriptions of complex ecological processes and interactions were common in our sample, and many farmers were deeply knowledgeable about soil biology and keenly attuned to even subtle changes occurring on their fields following cover crop adoption. With this awareness and mindset, farmers were willing to invest in cover crops for key ecosystem functions, rather than relying solely on external synthetic inputs to achieve yield goals.

Engaging in farmer networks

Fourteen out of 21 interviewees described engaging in farmer networks. These networks include farmers and their peers as well as other actors in the agricultural industry, such as agronomists, seed dealers, farming organizations, and so on (Isaac et al., 2007; Dolinska and d'Aquino, 2016). Networks that enable in-person learning have been described in the literature as both a key source of information and social support for farmers (Oreszczyn et al., 2010; Morgan, 2011; Hassanein, 1999).

Several interviewees indicated that speaking to other experienced farmers is the best way to learn about and gain confidence in managing cover crops. To do so, most attended local meetings hosted by their local SWCD or farmer-led organizations, and others traveled to nearby conferences in the region. Farmers found value in sharing experiences about site specific issues, like recent weather events, and hearing about others' mistakes and successes. Some farmers voiced skepticism about whether research conducted in other regions applies to their farms, indicating that local knowledge and experience is a more trusted source of information for managing their fields. Still others expressed their distrust agribusinesses as a source of information about cover crop management, with one farmer stating he prefers information from "someone who doesn't have a horse in the race" (Farmer 13).

Several farmers described operating within a highly competitive environment, where high yields and early harvest dates are key measures of professional success. These cultural norms and expectations can make deviating from industrial practices difficult, but farmers indicated that having a strong peer network provides reassurance to overcome social pressures:

> *You need to have a good base of people you can talk to keep reassuring you that you're gonna be okay. You've done the right thing. You live in a neighborhood where you're the only one [with] cover crops, there can be some peer pressure and societal pressure telling you that, you know, better not do that again because they're gonna laugh at me. – Farmer 20*

Some interviewees also noted that the competitive atmosphere in their farming community can lead to less information sharing among farmers. However, supportive networks can help fill the gaps, as one farmer described when discussing their association with No Till Farmer, an organization that strongly supports cover crops:

> *They're really happy to share their knowledge with you and their successes and their failures. It's kind of funny, because I have [neighboring] farmers who are conventional till guys, and they have really good dirt and they have really good yields, and you talk to them and everything is so secretive. They never want to tell you what kind of seed they're planting or anything. And then you talk to the no till or the cover crop guys, and they're just – they'll show you everything they're doing and tell you what worked and what didn't work. – Farmer 8*

Thus, farmers in our sample received both cover crop management advice and social support by engaging in social networks, helping them overcome both cognitive and sociocultural constraints.

Adopting complementary practices

Twenty out of 21 of the conventional grain farmers in our sample used no till or other conservation tillage practices, which they described as highly complementary to, or even a prerequisite for, cover cropping. Conservation tillage minimizes soil disturbance and is becoming increasingly popular because it reduces soil erosion, improves soil structure, and supports biodiversity in the soil (Nunes et al, 2020). Without tillage, however, farmers must use other methods to control weeds, typically applying herbicides. Farmers in our sample noted that cover crops helped to suppress weeds, and therefore lowered their use of chemical inputs, which helped justify the cost of cover crop seeds. The other benefits of conservation tillage that farmers listed included reducing management time, lowering fuel costs, reducing wear and tear on machinery, and improving soil health. Because of this, the farmers we interviewed were willing to take a potential reduction in yield given these savings.

Financial incentive programs buffer against the risk of adopting cover crops

Nineteen out of 21 farmers in our sample had experience using financial incentive programs to support growing cover crops at some point during their farming careers. The extent to which farmers participated in these programs varied greatly, however: one farmer only had experience with a local incentive program administered by his county's SWCD; ten had participated in only federal programs, like EQIP and CSP; seven had used a mix of local and federal programs; and three had never participated in either federal or local incentive programs. Some of the earliest adopters had very limited experience using financial incentive programs: their adoption of the practice long ago made them ineligible to participate in many programs today.

Despite this wide range of experiences, farmers uniformly described financial incentive programs as playing an extremely important role in cover crop adoption. Interviewees explained that, in an ideal situation, farmers would enroll in a program for several years, and in the process, gain confidence with cover crop management and witness the soil health benefits. By the end of the program, farmers would be motivated to continue using cover crops and pay for them out of pocket moving forward. One farmer, who started the practice out of concerns over impending regulation, confirmed:

> *When we got started this last go around to get serious at [growing cover crops], we got paid very well by the government to do it. And I guess the management goal was figure it out on their nickel before it's forced on me. You know? Not that I didn't believe in the soil health benefits or anything like that, but you know, it is expensive and until you get into it and observe the benefits, everybody's skeptical, including myself. Is this gonna work? Is it gonna pay? Not gonna pay? Well, it's gonna pay, there's no question in my mind now. – Farmer 16*

Thus, incentive payments significantly helped this farmer overcome financial constraints and the uncertainty that cover crops would provide enough benefits to be worth the extra seed and labor costs. Other farmers shared similar stories, also noting that financial incentive programs helped them make a sizable jump in the number of acres they planted to cover crops.

4.3 Incentive program outcomes fall short of intended goals

Even though most farmers described the supportive role of financial incentive programs, they also outlined a number of fundamental design problems that may limit their effectiveness. Generally, the unintended consequences of these problems include discontinuing the practice once financial incentives end, and limited participation in programs. The problems giving rise to these outcomes, and the solutions recommended by interviewees, are detailed below.

Financial incentive programs are used for revenue

Despite widespread agreement among the sample that incentive payments provide essential support for transitions to cover cropping, a main criticism of existing incentive programs was actually that they provide *too much* money. This was mentioned by nine farmers in our sample, who cautioned that if farmers only think of these programs as a money-making venture – instead of a soil health investment – they will be less likely to learn how to properly manage cover crops for maximum ecological benefit. Instead, they may kill the cover crop too early in the spring and diminish its soil improvement potential, making farmers less likely to continue the practice once the program ends:

> *Where they get into troubles that we've seen with the Lake Erie situation, they're paying too much money per acre. People are looking at it as a moneymaker. They can put cover out there, do a half-hazard job of it,*

throw it out there. Apply it for 25 dollars an acre, and they're gonna get paid 50, 60, 70 dollars an acre to do it. In my mind, the money for those sorts of programs is kind of to jump start it with the hopes that people will see enough benefits that when the money runs out, they'll hopefully continue to do it. That's how those programs are designed. Some place along the way, we've lost track of that. I don't know just how, but part of it is the fact that in my mind, they're paying just way too much. – Farmer 4

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My concern is that the only reason some of these guys are doing it is because they're getting money. I think the number of guys that are willing to do it purely because of the known conservation piece of it – water quality, soil health, things like that – it's catching on, but it's not caught on like wildfire yet. – Farmer 9

To solve this problem, farmers recommended lowering incentive payments, which, in theory, would cause farmers to take the practice more seriously in order to reap its full benefits. Another outcome of this change, not mentioned by farmers, would be the potential for wider distribution of funds, reaching more farmers.

Incentive programs are burdensome and bureaucratic

Farmers often discussed their dissatisfaction with specific program requirements, especially on the federal level, saying that these requirements can be confusing and out of touch with the realities of farming. Drawing on personal experience, farmers noted that EQIP's seeding rate requirements were generally too high, or the planting window was too inflexible and narrow, making management more difficult and limiting potential benefits. Sometimes, farmers expressed uncertainty as to what was expected of them, as deadlines and seeding rates vary program-to-program and year-to-year:

> *And at the policy end, you know, "Well, let's go to Soil and Water to help you." And then they hand you an EQIP contract, and the EQIP contract is just crazy. I mean, it's not crazy, but it's a little more complicated than it probably needs to be. Especially the guys that's just trying to get going, you know? – Farmer 15*

Several farmers also described confusion surrounding the different programs and often found it difficult to remember which programs they had participated in, noting that the number of programs and acronyms involved can be difficult to sort out. They also discussed the amount of paperwork required from these programs and suggested this is a barrier that prevents farmers from participating:

> *One of the hardest things for these programs is figuring out what can you do and what can't you do within the program. And what's available in one program that's not available in the other. And you know, when someone from that office, NRCS, stands up, they're saturated in that environment all the time. It's easy for them to speak in acronyms that a lot of growers*

don't know what that acronym stands for. So they don't know the right question to ask. – Farmer 7

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If it's the hodgepodge programs that they've been doing, it doesn't have much of an effect because again, guys who've never done it, they're not seeing the advantage. They're like, "Oh I don't want more paperwork, I don't want more hassle." – Farmer 16

To address this problem, farmers suggested making program requirements simpler, which would also give new adopters the chance to ease into the practice and learn proper management techniques before moving on to a more complex regimen. They also suggested streamlining paperwork and better coordinating between agencies to lessen the mental burden of navigating the various programs. Farmers often described their preference for programs administered by their local SWCD not only because these have fewer "hoops to jump through," but also because district employees know intimately well their local farming community's needs.

Financial incentive programs have barriers to enrollment

Farmers who already adopted cover cropping as a conservation practice no longer qualify for many incentive programs, since these are mostly intended to expand the adoption of a given practice to new farms. Farmers expressed mixed reactions to this: some thought this was how the programs should work in order for adoption to spread, while others saw this limitation as a kind of punishment for "doing the right thing."

Furthermore, farmers are not guaranteed to be accepted into a financial incentive program, as these are often competitive and use a ranking system. With EQIP, for example, farms that enroll more acres receive a higher score and have a greater chance of receiving funding. This may result in some farmers not even filling out applications if they believe the odds are stacked against them:

> *I think the policy end – they don't do a very good job of sorting out people like me. You know, they would much rather give an EQIP contract to a 2,500 acre farm because they knocked out a bunch of acres, and it doesn't even really matter if people are really passionate about it. – Farmer 15*

Smaller incentive programs administered by local SWCDs, on the other hand, may have smaller caps on the number of acres a farmer can enroll, with less funding to cover the cost of seed and labor. These limitations may result in farmers believing the effort to apply is more work than it is worth, depending on the size of their farm:

> *Six bucks an acre for 100 acres max. Well, okay, we'll probably sign up for it. There's no guarantee you're going to get in. [SWCD has] got limited funds. First come first served. So is it really worth the effort? You know, if I only farmed 100 acres, sure, that would be. Why not? Sign me up. But you know, if you farm 2, 3, 4,000 acres – I'm gonna get 600*

bucks? Why bother? But if you tell me I'm gonna get six bucks on every acre I sign up, and I'm guaranteed in, different ballgame. Completely different ballgame. That's the hodgepodge-ness of it makes guys dislike that. Oh, 100 acres? Well who cares? And I might not get in? Why waste my time? You know, I'm gonna waste a half a day to get signed up and get shot down? Forget it, I'm not gonna waste my effort. – Farmer 16

To address these challenges with enrollment, several farmers suggested developing programs that are consistent year-to-year and that guarantee acceptance.

Contracts should be longer to realize the full benefits of cover crops

Contracts for incentive payments generally last one to three years (Claassen et al, 2008), but farmers in our sample often noted that short contracts generally do not allow enough time for farmers to gain sufficient confidence with cover crop management or experience the soil health benefits, as these can take several years to fully realize. Since visual indicators like weed suppression, earthworms, and soil aggregate stability convey to farmers that they are getting a return on their investment, several farmers believed that the longer the contract, the more likely farmers would witness benefits, and the more likely they would continue the practice.

More research on cover crop benefits is needed

Farmers also discussed wanting more research on the benefits of cover crops. One farmer noted that while the agricultural industry has made significant investments in techno-chemical research and development, far less investment has been made in agroecological practices. Another farmer wished for more empirical data collected on local farms for more site-specific evidence of ecological benefits (e.g. microbial activity, organic matter accumulation) over time. Still another wondered if cover crops were truly making an impact on water quality improvement efforts:

> *And you know, because economically, farmers are putting in an extra effort to help out with this Lake Erie issue, this algae issue, and we want to know if the money and effort we're spending is working. The only way we're going to know it is if there's some good research on that. – Farmer 3*

Notably, several other farmers were interested in knowing more about the financial benefits of cover crops. As noted, a key barrier to long-term cover crop adoption is cost, and many farmers are uncertain if they will get a return on their investment given the structure of farm policy and market conditions. While farmers in our sample described using fewer inputs when cover cropping and, if coupled with conservation tillage practices, less fuel and machinery wear-and-tear, these savings are not well-documented or studied:

> *I still think the one message about cover crops that we need to get out to farmers is that they pay. They don't cost. I mean, that's the thing that they are so hung up on the cost of them or the financial liability. They don't see the financial benefits. And I don't think we've done a really good job of being able to measure those and get those out to people. You know, the cover crop's gonna not hurt you financially and they'll probably benefit you. – Farmer 20*

Rather than focusing solely on yield for a financial measure of success, these farmers believed that more information on the long-term savings due to cover crops would encourage greater adoption.

4.4 The threat of regulation is a key driver of cover crop adoption

While we did not set out to identify specific factors that influence cover crop adoption, it is notable that nearly every farmer in our sample (20 out of 21) discussed water quality, or specifically Lake Erie, to some extent, despite not being asked about it directly. This suggests that this issue weighs heavily on farmers' minds and plays a role in management decisions. Longtime cover croppers who had used the practice for many years noted that water quality only recently became a driver for adoption following the toxic algae bloom in Lake Erie that caused the city of Toledo to shut off its water in 2014. Farmers indicated that since then, they have felt tremendous pressure from politicians, the public, and the media to address agricultural pollution, primarily phosphorus runoff. They attributed the region's recent swell of research and funding, including government programs that support cover crops, to Lake Erie's water quality problems.

Nevertheless, farmers held a wide range of perspectives on the issue: some believed they have a responsibility to change practices in order to improve and protect water quality; others, however, expressed skepticism about the extent to which agriculture contributes to problems in Lake Erie, noting that other sources of pollution, like lawns and sewage treatment plants, should also face scrutiny.

Regardless of their beliefs, 15 out of 21 farmers across this spectrum contemplated the potential for future regulations if algae blooms in Lake Erie persist. Several noted that their impetus for adopting cover crops was to stave off government mandates:

> *And then of course all the Lake Erie watershed issues started to crop up, you know. What can farmers do? And they came out with these programs with cover crops. And I sat down with my son one day and I said, you know what? If this continues, and it's gonna continue with Lake Erie, eventually they're gonna force us and tell us how to farm. We better figure out how to do it. – Farmer 17*

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> *We can't say we're not part of the water quality issues as some of the runoff, the dissolved reactive phosphorus that's making it to the lake, is coming from farms. You can't deny that. And if we're part of the problem, we need to be part of the solution. So we'd rather take the right steps right*

now and help correct our issues with it. You know, agriculture as a whole is part of it, rather than being told later on through some kind of government regulation, "This is what you're going to do, and you have to do it." – Farmer 21

It is worth noting that improved water quality was but one of many benefits of cover cropping that farmers listed, with soil health improvements (like building organic matter or alleviating compaction) constituting the primary motivation behind the practice.

5 DISCUSSION

5.1 Overcoming constraints to increase adaptive capacity using cover crops

Because they provide key ecosystem functions and can mitigate water pollution, there has been increased interest in using cover crops as an adaptive management tool. This was clearly demonstrated during our study period, for example, when unrelenting rainfall and unprecedented floods resulted in the worst planting season in United States history. Across the nation, 19.4 million acres of insured cropland went unsown due to poor weather conditions, mostly in the Midwest, with Ohio and Michigan among the hardest hit states (FSA, 2019). This extreme, prolonged weather event and its devastating consequences have been linked to climate change (Schwartz, 2019).

This major disaster brought not only financial hardship upon farmers in our sample, but also tremendous ecological challenges as well: heavily saturated soils are susceptible to compaction and the loss of beneficial soil organisms; and, without vegetation shielding the ground from wind and water, valuable topsoil is highly vulnerable to erosion (NRCS, 2019). In response to this catastrophe, the USDA strongly advised farmers to grow cover crops on their unplanted land, and the agency's Natural Resources Conservation Service (NRCS) in several states (including Michigan and Ohio) offered special incentive payments through EQIP to assist farmers in adopting the practice (USDA, 2019). This program supported cover crops, in particular, because of their many ecological benefits that include building organic matter, improving soil structure, supporting biodiversity in soil, and preventing existing weed seed banks from overtaking fields. Several farmers in our sample reported that because of these financial incentives, they were able to significantly scale up their cover crop acreage compared to prior years and experiment with species mixtures they otherwise would not have used.

While it could certainly be argued that a key motive behind this particular program was to help farmers avoid financial ruin after experiencing a significant loss in profits, cover cropping as an agroecological practice was specifically promoted to improve soil health, head off future ecological problems, and "ensure long-term productivity" (NRCS, 2019). Thus, these financial incentives were, in large part, also intended to increase farmers' adaptive capacity – their ability to prepare for and respond to disturbances (Berkes et al, 2013). While it remains to be seen how these specific conservation programs impact long-term cover crop adoption and, therefore, adaptive capacity, there is no doubt that farmers in the Midwest (and around the world) will require additional adaptive management tools in order to cope with impending environmental changes caused by climate change. The Great Lakes region, for instance, is becoming warmer and is projected to experience both longer droughts and more intense precipitation (Kling et al, 2003). These environmental changes will likely result in not only a loss of farmer income due to decreased crop yields (Gustafson et al, 2015), but also more frequent algae blooms in Lake Erie due to increased agricultural runoff (Bates et al, 2008) – which will almost certainly amplify the intense public pressure farmers already face to address negative externalities from farming.

Even before the intense downpours that ravaged the Midwest in 2019, however, cover crops had been gaining more attention for years. Between 2012 and 2017, cover crop acreage increased by roughly 50 percent (USDA, 2017). Financial incentives for cover crops increased as well: EQIP funding for cover crops nearly doubled between 2015 and 2016 to $90 million – more than any other conservation practice in the program (NSAC, 2017). As acknowledged by farmers in our sample, much of this support is attributable to a heightened interest in soil health and awareness of the positive impacts cover crops have on water quality. Clearly, there is widespread acknowledgement that cover crops provide both on- and off-farm benefits.

Still, even with increased interest over the last decade, only about 4% of cropland in the United States is planted with cover crops (USDA, 2017). Their adoption is complicated by the highly consolidated and competitive system in which farmers operate, where management decisions are largely shaped by top-down federal policies and economic conditions, as well as complex ecological and sociocultural factors across levels. Farmers in our sample faced numerous constraints, like narrow profit margins, a lack of agroecological management knowledge, and cultural expectations to conform to industrial practices – all of which encourage farmers to prioritize yield and profitability over long-term soil health and water quality. In this context, farmers' ability to deviate from industrial production models and adopt agroecological practices is severely restricted, with important implications for both environmental sustainability and adaptation to rapidly changing environmental conditions on farms.

In spite of this context, however, farmers in our sample developed strategies to overcome these substantial barriers and adopt cover crops. Our focus on understanding how they made the transition to cover cropping revealed that farmers drew upon knowledge and resources across micro-, meso-, and macro-levels in order to both increase their confidence in cover crop management and mitigate risk. They did so by experimenting on their farms, adjusting mindsets and expectations with the recognition that their farms are complex ecological systems, and seeking local knowledge from peers; in most cases, cover crops complemented the use of conservation tillage practices by providing weed suppression and enhancing soil health benefits; and, as noted above, farmers participated in government financial incentive programs to lower their financial risk. Decision makers can learn from these farmers to design policies that leverage existing resources and provide a clearer path for the adoption of agroecological practices that improve adaptive capacity.

5.2 Policy implications for financial incentive programs

Given the intense production pressures and associated constraints to crop diversification that farmers experience, it is unsurprising that farmers in our sample overwhelmingly agreed that incentive payments play an important role in cover crop adoption. In Ohio and Michigan, farmers who enroll in EQIP can receive up to about $60 per acre to grow cover crops. Given that the national median cost of cover crop seed is $25 per acre, the program often pays well beyond implementation costs, which significantly lowers farmers' financial risks during a highly vulnerable transition period (SARE, 2019).

Our findings build on prior research that has identified financial incentive programs as an important factor in the use of agroecological practices. Singer et al (2007) found in their survey of U.S. Corn Belt farmers that the availability of financial incentives played a significant role in cover crop adoption; other studies have found that participation in conservation programs is highly responsive to both cost and incentive payment rates (Cooper and Keim, 1996; Cooper, 2003; Lichtenberg, 2004). These economic factors are considered especially important for certain practices, like cover crops, where some soil health benefits only become apparent after several years of sustained implementation (Ryan et al, 2003).

Even so, farmers in our sample identified key weaknesses in the long-term effectiveness of such programs, which are exacerbated by other constraints related to farmers' thin profit margins, lack of management knowledge, and uncertainty about cover crop benefits. In particular, interviewees described numerous examples from their communities where recipients of incentive payments planted cover crops in the fall, only to terminate them too soon in the spring before they gained sufficient biomass for ecological benefits to be fully realized. Since cover crops can delay the planting of primary crops, terminating cover crops early allows farmers to reduce the risk of disrupting their commodity crop production (Snapp et al, 2005). However, in doing so, they avoid learning a new management skill and likely benefit little from the ecosystem services from cover crops, which depend on biomass production (Blesh, 2018; Finney and Kaye, 2016). A key concern, then, is that some farmers enroll in the conservation program simply to earn money off the difference between the incentive payment and the implementation cost – not necessarily to achieve ecosystem functions from cover crops. Once their incentive payments stop, farmers who view cover crop programs primarily as a revenue source may therefore be less likely to continue the practice.

According to our sample, large incentive payments alone may not be enough to achieve long-term cover crop adoption, since economic pressures to maximize commodity crop yields currently outweigh the ecological benefits that can be achieved through proper cover crop management. In addition, even though these payments substantially mitigate financial risks of cover crop use, they do not address other key constraints related to a lack of knowledge about managing diverse crop rotations or uncertainties about long-term cover crop benefits. Incentive programs could contribute to addressing these gaps based on key recommendations offered by farmers in our sample. For instance, lowering incentive payments might motivate farmers to learn better management techniques in order to maximize cover crop benefits on their farms, and lengthening contracts would give farmers more opportunity to witness ecosystem changes and benefits, therefore increasing the likelihood that they will continue the practice without incentive payments in the future. Given the enormous economic pressure to maintain simplified crop rotations, more research on the potential financial benefits of cover crops (e.g. savings on reduced inputs) could also help ameliorate farmers' concerns about getting a return on their investment (Roth et al, 2018).

Another barrier to achieving greater adoption of conservation practices may concern the underlying logic of some incentive programs. Due to budgetary constraints, incentive programs are often competitive and use a ranking system to determine which contracts receive funding. One important criterion is cost effectiveness. In EQIP, for instance, farmers apply to the program and indicate the number of acres they want to enroll, where, and which conservation practices they plan to use. NRCS screens these applications and favors those expected to achieve the greatest environmental objectives (as defined by the program) per dollar. Thus, applications that enroll more acres in specific locations and use more highly ranked best management practices will have a better chance of getting funded (Claassen et al, 2008).

This approach to allocating conservation funding, however, runs counter to the strategies farmers in our sample employed to overcome knowledge barriers. By and large, farmers thought it was best to experiment on fewer acres, starting with simple cover crop species that are easy to establish and terminate, in order to gain experience and confidence with new management techniques, the importance of which has been widely discussed in prior research (Rosmann, 1994; Ghadim et al, 2005). Thus, a conflict seems to exist between EQIP's ranking system and farmers' inclinations to ease into new, unfamiliar practices.

Rather than giving precedence to cost effectiveness, incentive programs like EQIP could instead prioritize maximizing the number of participants who adopt conservation practices like cover cropping, which have large potential to address nutrient pollution from grain fields. If incentive payments were lowered and caps were placed on the number of acres one could enroll, program funding could be spread across a greater number of farmers. Using this logic, more farmers would receive financial support to grow cover crops, albeit with a smaller payment on fewer acres. Again, as recommended by farmers in our sample, these contracts could also be lengthened to give farmers more experience with the practice and more opportunity to witness ecosystem benefits. In theory, by strategically designing a program specifically to maximize farmer participation, cover crops could become more prevalent on agricultural landscapes. Doing so would also create a larger pool of cover croppers in farmers' social networks with whom they could give and receive management advice. Prior research has found these networks to be influential in promoting conservation practices (Floress et al, 2011; Prokopy et al, 2008), as well as participation in conservation programs (Morris, 2004).

It is worth noting that these recommendations for policy changes come from farmers who are considered "innovators" or "early adopters" in Diffusion of Innovation theory, who are characterized as being risk tolerant and self-propelled to explore new innovations (Padel, 2001). Many farmers in our sample were motivated to grow cover crops by their own curiosity or conservation ethic, and therefore did not need the same kind of support as later adopters, who are characterized as being more skeptical and risk averse. Therefore, more research should be conducted to understand how incentive payments affect the continuance or discontinuance of cover crops, especially for middle and late adopters.

5.3 Voluntary vs. mandatory conservation practices to address water quality

Farmers in our sample were keenly attuned to the relationship between agricultural practices and water quality. Even when they weren't specifically asked, every interviewee but one discussed water quality to some extent. Especially after the intense public backlash in 2014 when the city of Toledo was forced to shut off its public water supply due to a toxic algae bloom in Lake Erie, the connection between water quality and agriculture is an inescapable issue for farmers in this region. For our study, it can be reasonably assumed that the appeal of cover crops dramatically increased specifically due to this public pressure, particularly from urban areas (Williams, 2019). Several farmers in our sample explicitly stated that addressing water quality issues now, through voluntary measures, is preferable to government mandates and oversight; thus, the extra costs and the effort required to overcome barriers of cover crop adoption is worth it, if they help farmers avoid future regulations.

By and large, farmers expressed a desire for water quality improvements, as this was often mentioned as a key benefit of cover crops. However, farmers' beliefs about the relationship between agriculture and water quality were variable and more nuanced.

While some felt considerable responsibility to address nonpoint source pollution from agriculture, others tended to downplay the degree to which agriculture contributed to harmful algae blooms, citing sewage treatment plants and lawns as other sources of pollution, despite ample evidence that agriculture is the primary culprit (Howarth et al, 2002).

Thus, even early adopters in our sample who voluntarily took steps to use agroecological practices on parts of their land performed "discursive maintenance" to legitimize and justify the industrial system regardless of its contradictions and flaws. Discursive maintenance can help individuals overcome the psychological discomfort of cognitive dissonance, which occurs when a person's values and behaviors are misaligned (Houser et al, 2020). Here, to rationalize their primary use of industrial practices in order to meet intense production pressures, a number of interviewees deflected blame for water pollution away from agriculture to cast doubt on the environmental harm caused by their actions.

These attitudes and actions, then, call into question the efficacy of voluntary measures – suggesting it is unreasonable to expect to achieve environmental objectives solely by relying on farmers' sense of individual responsibility to address environmental problems created by their farms. To be effective, conservation practices depend on farmers' long-term commitment, yet farmers face tremendous political and economic pressures that could easily lead them to discontinue their use, especially if they do not believe in their value. As an example, Stuart and Gillon (2013) found that when corn prices increased following policy changes to federal Renewable Fuels Standards, farmers in Iowa removed thousands of acres from the Conservation Reserve Program – a popular land retirement program in which farmers are paid to remove sensitive land from crop production in order to minimize erosion and protect water quality – because suddenly these farmers could earn a larger profit growing corn on this marginal land. Thus, given the economic pressures that result from federal farm policy and associated market conditions, it is unlikely that intrinsic motivation to adopt conservation practices alone will lead to necessary improvements in environmental health. In this sense, environmental catastrophes, like toxic algae blooms in Lake Erie or the "dead zone" in the Gulf of Mexico, are a product of the system itself – what Prudham (2004) refers to as "normal accidents" of neoliberalism and regulatory failure. In other words, the existing political framework – rather than individual farmers – is responsible for producing risks that make such events inevitable.

This is clearly demonstrated, for example, by the dearth of environmental regulations for agriculture in the Clean Water Act. This legislation was created in 1972, during an era in United States history when neoliberal ideology started gaining political traction. The Act was ostensibly drafted to strengthen federal regulatory powers over waterways, but it intentionally excluded diffuse nonpoint source pollution (e.g. farm fields) from government oversight – instead favoring economic gain of the agricultural industry over environmental protection (Milazzo, 2006). Thus, the legislation significantly weakened the government's ability to address agricultural pollution and enforce standards. In accordance with the key tenets of neoliberalism, environmental objectives for agriculture now almost entirely rely on voluntary measures that use cost-benefit analyses, and require less administrative oversight and fewer resources (Dowd et al, 2008).

Numerous examples across the country demonstrate the shortcomings of voluntary approaches in making significant environmental changes. For instance, due to its contributions to the Gulf of Mexico's "Dead Zone," the state of Iowa developed a Nutrient Reduction Strategy in 2013 to support farmers in voluntarily adopting a number of conservation practices aimed at limiting nutrient pollution. But a recent analysis shows that, given current voluntary adoption rates, the state will not reach its goal of 12.6 million acres in cover crops until the year 2110 (IEC, 2019). Meanwhile, in the summer of 2019, the Dead Zone nearly reached its record size of 8,776 square miles – roughly the same area as Massachusetts (NOAA, 2019). Likewise, despite the widespread interest and funding for conservation practices in our study area, annually recurring algae blooms in Lake Erie persist. Thus, a policy focus on changing behaviors and tweaking practices on an individual, voluntary basis has repeatedly failed. The current regulatory framework, which in fact shirks responsibility to regulate nonpoint source pollution, all but guarantees these "normal accidents" will continue occurring, at least until major political reforms (e.g. mandatory conservation practices) are made.

5.4 Macro-level constraints remain a primary barrier

Even with mandatory regulations, however, additional constraints to diversification, which serve to sustain the broader industrial agricultural system that sits at the center of so many environmental problems, would also need to be addressed. During interviews, farmers described many constraints to cover crop adoption across micro- and meso-levels, yet many of these seem to be ultimately rooted in macro-level constraints. For instance, farmers discussed competition between neighbors, sociocultural pressures to have “clean” fields, and having little knowledge about diversified farming systems – all of which could be traced, potentially, to political and economic pressures, and investments in research and development, that support high yielding commodity crops and specialization.

The overarching structure of the Farm Bill is a primary driver of this system, with commodity production prioritized above all else (Imhoff, 2012). The commodity and crop insurance programs in the Farm Bill provide direct income support for farmers to produce commodities – especially corn and soybean – that would not be profitable otherwise, given poor market conditions. In the 2018 Farm Bill, these programs were allocated a combined $142.5 billion by Congress, compared to $59.7 billion for conservation (NSAC, 2018). During the Farm Bill’s annual allocation process, conservation programs are often the first thing to experience budget cuts, and because they are chronically underfunded, they cannot meet demand. In recent years, for instance, EQIP has only had enough funding to accept less than half of the applications it receives (NSAC, 2017).

There are numerous inherent contradictions in the Farm Bill, owing to its complexity and the varied interests of many stakeholders that exert influence over policymakers during the contentious negotiation process (Barnett, 2014). For instance, while there are attempts to increase farmers' adaptive capacity to climate change and natural disasters (e.g. by providing financial incentives to support cover crop adoption), these efforts are at odds with the dominant federal support that farmers receive for production of commodity crops in monocultures. This contradiction was demonstrated in a study on behavioral responses to extreme heat, where Annan and Schlenker (2015) found that subsidized crop insurance acted as a disincentive for adaptation, since farmers were guaranteed to collect a payment even if their crops failed. Meanwhile, uninsured crops were less sensitive to heat, indicating that farmers had taken adaptive measures on those fields to protect crops.

A second example involves the EQIP working lands program that, broadly speaking, recognizes the potential for crop diversity to not only reduce environmental pollution but also regenerate ecosystems through positive ecological interactions. However, contrary to its intended purpose of supporting conservation practices, a significant portion of EQIP funding is instead used to "offset the cost of regulations" (Claassen et al, 2008). For instance, in 2016, concentrated animal feeding operations (CAFOs) were allocated 11% of EQIP funding ($113 million), and the practices that received the most support included waste storage, manure handling, and animal mortality facilities (NSAC, 2017). In an ironic sense, then, EQIP funds the continued specialization of agriculture, when at the same time it supports diversification to correct for the very environmental damages created by specialization.

These examples of macro-level policies that sustain specialization hinder farmers' ability to adopt diversified, agroecological practices that can actually prevent, rather than simply limit or intercept, pollution. For instance, prior to the Green Revolution, cover crops were regularly grown on farms as part of diversified crop rotations: cover crops provided key ecosystem functions to support crop production, and diverse rotations offered more windows of time in which to grow them. As an example, several farmers in our sample explained that after harvesting wheat in July, they then establish cover crops in those fields. This rotation provides the cover crops with a long growing period before the winter, giving them ample time to produce sufficient biomass and achieve soil health benefits before being killed by frost or terminated in the spring, if overwintering.

However, political and market conditions have made wheat less profitable. Following trends in the Corn Belt, Michigan – once the nation's leader in wheat production – is turning to favor corn and soybean production instead (NASS 2018; Perkins, 2020). This specialization has made cover crop establishment more difficult. In our study region, corn and soybean harvest can extend into November, with the average frost date occurring in early October (NWS, 2020), which leaves farmers with extremely narrow windows for planting cover crops. To overcome these timing constraints, corn and soybean farmers are increasingly finding creative solutions to sow cover crops in their low diversity rotations. One method, for instance, is by aerial seeding cover crops into standing corn and soybeans before harvest, which gives cover crops more time to germinate and establish before winter. While this may be better than not cover cropping at all, this seeding method may result in less environmental benefit, since aerial seeding is less consistent than seeding directly into the soil and uses substantial fossil fuel energy (Iowa NRCS, 2010; EPA, 2020).

Interestingly, when asked what would make cover cropping easier, major structural changes to grain agriculture in the U.S. were rarely mentioned by farmers in our sample. Most farmers offered policy suggestions that were limited in scope to tweaking the design of financial incentive programs as currently structured. One farmer wished for "eight dollar corn" because this would create a wider profit margin and lessen the financial risk of growing cover crops – but he stopped short of explaining what it would take to achieve a consistently strong commodity price. This would seem to necessitate other structural policy changes, like managing the supply of commodities – an approach that, for decades, was a primary policy tool in the Farm Bill (Barnett, 2014).

Yet, simply improving markets for single commodities like corn or soybean would not address the inherent environmental problems caused by grain production in large-scale monocultures. One farmer in our sample *did* speak directly to a structural change that would support greater crop diversity and, therefore, greater cover crop adoption:

> *If you're in this basin, here's what we're gonna subsidize. It's gonna be wheat, barley, alfalfa, no more corn and bean. You know, we gotta change it up. 'Cause otherwise – what's driven the monoculture of corn and soybeans is the subsidy programs. – Farmer 14*

It is difficult to imagine large structural changes in the industrial agricultural system, perhaps because the system itself is incredibly complex, multilayered, and deeply entrenched. Consolidation in the food system has led to the concentration of power among few actors, who exert tremendous influence over policy formation to maintain the status quo, given that research and development into diversified agricultural and food systems would put their profits in jeopardy (Howard, 2016). Nevertheless, envisioning how the industrial agricultural system could change to be based around agroecological principles is a critical step toward broad, systemic transformation.

6 CONCLUSION

This study provided insights into the strategies employed by grain farmers to adopt cover crops despite numerous constraints across scales, many of which are rooted in macro-level economic pressures and top-down federal policies that encourage agricultural industrialization and specialization. To overcome barriers, farmers in our sample experimented with cover crops on their farms, adjusted their mindsets and expectations about agroecological practices, sought local knowledge from peers, used complementary management techniques (e.g. conservation tillage), and enrolled in government conservation programs.

While important for reducing the financial barriers to growing cover crops, farmers in our sample indicated that incentive payments, like those used by EQIP to encourage program enrollment, are sometimes viewed only as a revenue source by farmers. This mentality may lead to improper management and cause farmers to discontinue the practice once contracts and payments end. However, farmers in our sample offered several suggestions to improve the effectiveness of these programs for achieving long-term cover crop adoption. For instance, lengthening conservation program contracts would give farmers more time to witness the positive ecological benefits of cover crops, providing greater motivation to continue the practice once payments end. Furthermore, decreasing large incentive payments would give farmers more reason to learn proper cover crop management techniques in order to maximize ecosystem services that justify adoption costs. In this way, the design of these programs could change so that they address not only financial barriers, but also barriers related to knowledge and uncertainty as well.

For this study, we specifically interviewed innovative farmers who are considered early adopters of cover crops, who could shed light on the process of farm diversification. As such, many in our sample were largely motivated by their own curiosity to try a new practice and did not require incentive payments to experiment with cover crops initially. Therefore, speaking to only this small subset of the farmer population is a limitation of our study. Future research should explore the role of incentive payments for long-term cover crop adoption by interviewing middle and late adopters as well. Finally, to assuage farmers' uncertainties about getting a return on their investment from cover crops, more research should be conducted to better understand the potential for longer-term financial benefits from this practice (e.g. savings from decreased use of inputs).

Although we did not set out to identify factors that influence cover crop adoption, our interviewees strongly indicated that pressures from urban actors to improve water quality – and the threat of regulation – are currently major drivers of this practice in the Great Lakes region. Nevertheless, it is unlikely that voluntary measures alone will lead to sufficient environmental improvements. As several farmers in our sample acknowledged, other major regulatory changes, like mandatory conservation practices, may be needed to truly address nonpoint source water pollution from farms. Ultimately, much broader systemic reforms are needed so that incentives to industrialize and specialize – the fundamental cause of so many environmental and social problems created by agriculture – are eliminated. Decisionmakers should take meaningful steps toward systemic transformation by learning from farmers in our sample and designing policies that fully address the unique set of social-ecological constraints farmers face. These polices should work toward improving farmers' adaptive capacity and resilience to global change, and, therefore, provide a clearer path for farm diversification and the widespread adoption of agroecological practices.

TABLE 1. Descriptive characteristics of interviewees, including management practices and participation in incentive programs offered by both federal and local government agencies.

Farmer ID	Location	Farm size (acres)	Primary crops					Livestock	Tillage method	Years of cover crop experience	Incentive programs used
			Corn	Beans	Wheat	Alfalfa	Other				
1	MI	300	X	X				N	No till	10	EQIP, local
2	MI	1200	X	X	X	X		N	No till; conservation till	10	EQIP
3	MI	630	X	X	X			N	No till	8	CSP, EQIP, local
4	MI	2500	X	X		X		Y	No till	20	Local
5	MI	500	X	X	X			Y	No till	30+	None
6	MI	1800	X	X	X		X	N	No till	3	None
7	MI	1100	X	X				N	No till; conservation till	10	EQIP, CSP, local
8	MI	900	X	X	X	X		Y	No till	8	EQIP, local
9	MI	350	X	X	X			N	No till	3	EQIP
10	MI	1600	X	X	X			N	Conventional till	30+	EQIP
11	OH	140	X	X				N	Conservation till	12	EQIP
12	OH	200	X	X	X		X	N	No till	10	None
13	OH	560	X	X	X			N	No till	8	CSP
14	OH	1600	X	X	X		X	N	No till	10	EQIP
15	OH	660	X	X	X			N	Conservation till	5	EQIP
16	OH	2000	X	X	X			N	No till; conservation till	9	EQIP, local
17	OH	2200	X	X	X			N	Conservation till	5	EQIP
18	OH	1100	X	X	X			N	No till; conventional till	5	EQIP
19	OH	3000	X	X	X	X		N	No till; conservation till	15	EQIP
20	OH	2000	X	X	X			N	No till; conservation till	10	EQIP, local
21	OH	8500	X	X	X	X		N	No till; conservation till; conventional till	5	EQIP, local

FIGURE 1. Map of River Raisin Watershed and Maumee River Watershed. Farmers located in the Maumee River Watershed were located near the Ohio-Michigan border.

APPENDIX A: Interview Guide

Section I: Farm background

1. Tell me about your farm.
    a. How long has it been in your family?
    b. How long have you been making decisions?

2. How many acres do you farm?
    a. Own
    b. Own but rent/lease to another farmer
    c. Rent/lease from others

3. Do you have any animals?
    a. What type?
    b. How many?

4. What crops do you grow?
    a. What crop rotation have you used primarily over the last 5 years?
    b. How many acres do you grow of each crop?

5. What types of soil do you have on your farm?

6. How is the drainage?

7. What is the primary tillage method you use?

8. What is your primary source of Nitrogen (fertilizer, legumes, manure)?

9. What would you say is the most pressing environmental or resource concern you have for your farm (erosion, drainage, weeds, pests, etc.)?

Section II: Experience using cover crops

10. How long have you been growing cover crops?

11. Tell me about your cover crops over the last few years. How do they factor into your crop rotation?

12. Where do you get the seeds?

13. What are your main management goals with them?

14. Tell me the story of how you first got started growing cover crops.
    a. How did you first make this decision? Was there something that pushed you over the edge?
    b. Where were you getting your information about cover crops at that time? Did you feel like you had all the information or resources you needed?
    c. What were the different stages that you went through to get from where you started to where you are today?
    d. Can you discuss some of the challenges you had to overcome?
    e. How confident did you feel when you started that cover crops would make a difference on your land?
    f. What effect, if any, did owning/renting land have on your decision to use cover crops?

15. What do you think stops over farmers from adopting cover crops?

16. So far, have your expectations for cover crops been met?

17. Have they made any noticeable improvements (or changes) to your farm?

18. Did planting cover crops impact your Nitrogen application rate?

19. [If they use herbicides to kill cover crops] Has herbicide use changed on fields where you plant cover crops? Do you think it has increased, decreased, or stayed the same?

20. Have you increased or decreased the acreage in cover crops over time?
    a. By how much?
    b. If decreased: Why did you make that decision?

Section III: Experience with policies and programs

21. Did you use any programs to support growing cover crops?
    a. Do you still use any of those programs?
    b. What was your experience like using those programs?

22. How much of a role do you think policy plays in whether or not farmers adopt cover crops? What role did it play for you?

23. What do you want decisionmakers to understand about cover crops?

24. If you could make any change you wanted to make it easier for farmers to grow cover crops, what changes in policy or programs would you make?

25. What types of policies or programs would you like to see at the federal level? State level? Local level?

Section IV: Sources of information

26. Where do you get most of the information that helps you make decisions about your farm (e.g. cover crops, fertilizer application, nutrient management)?

27. Who do you interact with mostly about cover crops?

28. How do you interact with other farmers specifically with regard to cover crops?

29. When you started growing cover crops, was there any concern about what neighboring farmers would think? What about now?

30. What kinds of messages do you think would resonate the most with farmers who are on the fence about cover crops?

Section V: Closing

31. What issues did we not get to that you think are really important?

32. Is there anything else you would like to share with me?

33. Is there anyone else you suggest that I talk to for this project?

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