NITROGEN FERTILIZER MANAGEMENT IN THE CONTEXT OF THE MIDWESTERN CORN AGRO-ECOLOGICAL SYSTEM: AN ENVIRONMENTAL SOCIOLOGICAL ANALYSIS

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Sociology—Doctor of Philosophy

2018

ABSTRACT

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Farmers' agricultural management behaviors are influenced by structural political-economic factors and overtly connected to the biophysical environment. However, to this point environmental sociology, a field dedicated to studying environment-society interactions, has given little consideration to agriculture as a topical context. Through this dissertation, I bring an environmental sociological approach to the study of farmers' behavior at the individual-level, focusing on their management of nitrogen fertilizer. Nitrogen (N) fertilizer is considered an agricultural input essential to supporting the food demands of the growing global population. Inefficient agricultural N fertilizer use in the United States contributes significantly to hypoxia, ground water pollution and climate change. Adoption and implementation of efficient N management practices could substantially mitigate this input's environmental consequences and adapt agricultural production in the region to the challenges of climate change. Preliminary research has argued numerous social and ecological factors at multiple scales influence farmers' N application management decisions, but the vast majority of current literature on the topic explores only individual-level demographic and psychological factors.

To enhance the current literature on farmer N management decision making, I utilize theoretical frameworks and concepts from sociology and environmental sociology to examine N fertilizer use among Midwestern corn farmers in five states: Illinois, Indiana, Iowa, Michigan and Ohio. Across these chapters, I broadly employ a Marxist political-economic approach to

examine how social structural context influences farmers' individual-level decisions and behavior related to N use. The deployment of this approach offers the current farmer decision making literature an environmental sociological perspective, revealing how farmers' management decisions are constrained by material (i.e. physical) macro-level political-economic factors and ideological (i.e. social-psychological) factors that emerge from this structural context. In connecting individual-behavior to macro-level social structure, this work offers a novel cross-scale (i.e. marco↔micro) application of political-economic frameworks, which to this point have primarily been applied at the macro-level. Through this approach, I strive to integrate an environmental sociological perspective into the agriculture and natural resource literature and bring the topical context of agriculture further into the gaze of the core environmental sociology literature.

To accomplish these goals, I use a three paper format. Across these empirical papers, I focus on farmers' application rate of synthetic nitrogen fertilizer, as it is widely considered the dimension of management most influential in determining the amount of N pollution levels from agriculture. In the first paper, I use Luke's Third Dimension of Power concept to understand why farmers' desired to maintain their current economically and environmentally inefficient N application rate. In the second paper, I examine how the political economy of agriculture influences farmers' adaptive management practice adoption in response to a material impact of climate change in the Midwest, heavy rain events. In the third paper, I extend the political-economy of technology literature and question the foundational assumptions of the agricultural literature by examining whether the adoption of nitrogen best management practices actually leads to less nitrogen pollution using application rate as a proxy measure.

ACKNOWLEDGMENTS

The completion of this dissertation (and really the completion of my entire PhD training) would not have been possible without many special people. A few individuals are particularly noteworthy. Diana Stuart has been extremely important in the development of my scholarly abilities, confidence and understanding how to balance life and work. Her kind support has been invaluable. My wife, Lauren, has been there for me every day, especially during the tough days of writing and revising this dissertation. Her stability and kindness has been the key to keeping me on track through this process. I am extremely grateful for her love and support. My daughter, Bennett, who was born almost exactly a year before the completion of this dissertation, has been a source of joy during the tough times this work brought forth. It is easy to be motivated to continue to work when I know my efforts can contribute to a successful and happy life for her. My parents, Dave and Deb, also are notable for their emotional and financial support. Lauren and I lived an amazing life as home-owners during my graduate career because of their selflessness. Finally and most importantly, Sandy Marquart-Pyatt was all I could have asked for in an advisor. She went far and above the normal duties to support my efforts. I cannot repay her for all that she did for me or sufficiently express my gratitude, though I will strive to mimic her style should I be fortunate enough to mentor students in the future.

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KEY TO ABBREVIATIONS

bu	Bushels
C-C	Corn-Corn
C-S	Corn-Soy
EPA	Environmental Protection Agency
ERS	Economic Research Service
ESPE	Environmental Sociology of Political Economy
GHG	Greenhouse Gas
ICCAC	Iowa Climate Change Advisory Council
IPCC	Intergovernmental Panel on Climate Change
lbs.	Pounds
MRTN	Maximum Return to Nitrogen
N	Nitrogen
n	Sample size
NASS	National Agricultural Statistical Service
US	United States

CHAPTER I— INTRODUCTION

Agriculture, as a realm of society-environmental relations, has been largely ignored by contemporary environmental sociologists. This dissertation considers agricultural production primarily through the lens of the political-economy vein of environmental sociology. In doing so, I strive to straddle and contribute to two literatures. First, my aim is that this work can contribute toward integrating the agricultural context into the core of the sub-discipline of environmental sociology. Second, in accomplishing the first goal, I intend to conceptually and empirically enhance the current literature on agricultural management decision making and practice adoption. The ensuing pages of this introduction set the stage for this work. I begin by outlining the inattention to the study of agriculture by my home field, environmental sociology. I include in this discussion preliminary arguments as to why this has occurred and suggest the relevance of the study of agriculture to environmental sociology, focusing particularly on the work of Karl Marx to illustrate this potential. I conclude my introductory discussion by briefly describing the specific context of this study, agricultural nitrogen fertilizer use, and outlining how my empirical chapters engage with the environmental sociology and the agriculture practice adoption literature.

Environmental sociology and the agricultural context

Environmental sociology emerged as a sub-field within sociology with the explicit intent to investigate the ways in which society and the *natural* environment interacted (Catton & Dunlap, 1978). This sub-field brought sociology's fascination with social context to studies exploring various dimensions of the human-environment relationship, emphasizing how bio-physical features of the world impact and are themselves influenced by social processes (Buttel, 1987).

Agriculture, as a topic of empirical research, has been given little attention in the environmental sociology literature to this point. Importantly, as I will discuss further below and throughout this dissertation, it is not that environmental sociology has entirely ignored agriculture. A vein of research has focused on this topic, but to a significant degree this work is concentrated in the early millennium and focused at the macro-level to describe the nature of the agricultural production in the capitalist system (Buttel, 2001, 2002; Madgdoff, Foster, & Buttel, 2000; Henke, 2008; Friedland, Barton, & Thomas, 1981).[1] Other work looks at the food system more broadly, focusing on the global social relations within which food is produced, rather than food or agricultural specifically (Burch & Lawrence, 2009; Friedmann & McMichael, 1989; McMichael, 2009). Rather, sociological perspectives on agriculture have simply remained on the relative outskirts of the field, particularly those that consider farmer behavior at the individual level.

[1] Establishing that most political economy agriculture work has occurred in the early millennium work requires a thorough literature review and a quantitative analysis of a data set emerging from this review. Here, I base my claim on my observation that the majority of widely cited articles on agriculture in the environmental sociology literature come from this time period; though more obscure work could exist between this time and the more recent literature I will focus on reviewing below.

Figure 1: The differences between environmental sociology and natural resource sociology (Buttel, 2002)

TABLE 1 Tendencies Within Environmental Sociology and the Sociology of Natural Resources

Dimension	Environmental sociology	Sociology of natural resources
Origins	Grew out of the environmental movement	Long-standing emphasis among rural sociologists, leisure/outdoor recreation researchers, and social scientists in resource agencies
Definition of environment	"Singular," encompassing, cumulative disruption	Local ecosystem or landscape
Main features of the environment stressed	Pollution, resource scarcity, global environment, ecological footprints	Conservation, (local) carrying capacity
Definition of sustainability	Reduction of aggregate levels of pollution and raw materials usage	Long-term sustained yields of natural resources, social equity in allocation and use of resources, reduction of social conflict over natural resources
Predominant cadre of practitioners	Liberal arts sociologists	Natural resource agency staff; college of agriculture/natural resources staff; rural sociologists
Scale/unit of analysis	Nation-state Metropolitan focus	Community or region Nonmetropolitan focus
Overarching problematic	Explaining environmental degradation	Improving public policy, minimizing environmental impacts and conflicts, improving resource management
Theoretical commitments	Highly theoretical, often metatheoretical	Deemphasis on social theory

Why is agriculture not seriously considered as a core context for studying the society-environment interactions central in environmental sociology?[2] I believe it has little to do with a lack of potential important contributions from sociological study of agriculture contributing to the wider sub-disciplines and more to do with long-standing divides in disciplinary and sub-disciplinary cultures. Regarding the prohibitive effect of disciplinary culture, the dimensions of two other sub-disciplines of sociology relevant to agricultural study significantly hindered the development of a more robust environmental sociology of agriculture literature.

Rural sociology's early dismissal of the relevance of environmental considerations in agricultural studies likely slowed the development of the environmental sociology of agricultural literature. Being explicitly focused on social problems in the rural context, studies of agricultural production are a natural topic for rural sociology. However, at the time of environmental sociology's emergence, rural sociology studies of agriculture were explicitly opposed to consideration of the environmental implications of farmers' behaviors and the implications of environmental processes for farmers' behavior (e.g. Buttel & Larson, 1979; Gartrell & Gartrell, 1979;). Reflecting the core sociology discipline, rural sociology at the time ignored environmental conditions relevant to farmers' behavior because they were not seen "theoretically relevant," according to Dunlap and Martin (1983, p. 211). As rural sociology was considered a key area for the sociological study of agriculture during this time (Buttel, 1982), its topical dominance may have directly discouraged environmental sociological consideration of agriculture. Also, it is plausible that indirect discouragement occurred as scholars with sociological interest in agricultural were siphoned from environmental sociology disciplinary training to rural sociology departments, the latter being seen as the area from which to receive

[2] In addition to the covered barriers, I would also note that the timing of the death of Fredrick Buttel likely significantly hampered the potential development of an agriculturally focused environmental sociology literature.

agriculturally relevant training. Despite rural sociology's early rejection of environmental sociological concerns, today rural sociology is a home to many environmental sociologists with interests in agricultural topics. These approaches are both widely represented in the Rural Sociological Society's Annual Conference and commonly published in the Rural Sociology journal.[3] While environmental sociologists interested in agriculture may have found a scholarly community in rural sociology, this turn to another sub-discipline's conferences and journals likely only re-creates the outcast status of agriculture in environmental sociology. The work of these scholars remains seen by only this rather insular topical audience, rather than being incorporated more broadly as a contribution to the understanding of society-environment interactions.

The disciplinary divide between environmental sociology and natural resource sociology is also a relevant barrier to the acceptance of agriculture in the environmental sociology literature. As rural sociology is considered a field within natural resource sociology, this divide's impact is related to that mentioned above. However, I considered it distinct as the differences between environmental sociology and the more broadly defined natural resource sociology do not exclusively relate to the degree to which the environment is considered in the work. This is suggested in the conceptualization of natural resource sociology by Buttel (2002)[4], who sees this field as defined by a number of differences in focus from environmental sociology (see Figure 1 from Buttel [2002, p. 207]). Across these noted distinctions, it might be broadly stated that natural resource sociology is (1) more practically focused than environmental sociology, working

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[3] This acceptance is likely a response to the declining support for rural sociology in both the broader discipline and the university system (few rural sociology departments remain in the United States).

[4] Buttel (2002) actually argues that the sociology of agriculture is reflected more in the environmental sociology than the natural resource sociology literature. However, as noted early in the article, his citations exclusively reflect the promise of this field at turn of the millennium, which was in my understanding the peak, rather than the beginning, of the agricultural environmental sociology literature.

on applied questions rather than theoretical deployment and development; (2) more interested in rural context, compared to the metropolitan; and (3) focuses on research at the meso- (i.e. community) and micro-level (i.e. individual), compared to the macro-level (i.e. global and national) focus of the environmental sociology literature. The vast body of agricultural literature produced in recent years, particularly that considering farmers' behavior at the individual level, aligns with the foci of natural resource sociology (individual level and applied) rather than environmental sociology (Baumgart-Getz, Prokopy, & Floress, 2012; Stuart & Gillon, 2013). Sociological studies of agriculture, particularly at the individual level, may be widely considered a context for natural resource rather than environmental sociology.[5] In consequence, environmental sociologists may not engage in agricultural research as they do not see the study of agriculture as able to legitimately offer sociological insights considered valuable (i.e. theoretical) to the discipline. Moreover, the theoretical leanings of environmental sociologists may discourage the acceptance of their manuscripts in primary journals for social science agricultural research. As natural resource sociologists sit on the editorial boards of many of these journals (e.g. Agriculture and Human Values; Society and Natural Resources), it is likely they too are disciplinarily predisposed to find the environmental sociological approach to agriculture unappealing. Both consequences of the disciplinary divide between environmental sociology and natural resource sociology, along with rural sociology's independent effect, are factors possibly discouraging greater acceptance of the study of agriculture, particularly related to farmers' behaviors, in the core environmental sociology literature.

Karl Marx and the relevance of the agricultural context to environmental sociology

Disciplinary traditions may hinder the consideration of the agricultural context by

[5] Consider layering with substantive focus in the future.

environmental sociologists. However, there is much to be said as to the relevance of agriculture to environmental sociology (and indeed, I would argue sociology proper as well). Core social topics of interest have been explored in past analyses in an agricultural context. These core topics include, but are not limited to: analysis of political-economic forces in contemporary capitalism, such as increasing control of farm land by finance capital (Gunnoe, 2014) and neoliberal reform in global food market regulations (Busch, 2010); expressions of social power and domination, such as the “disciplining” of farmers by monopoly seed companies (Carolan, 2005; Foucault, 1979; Stuart & Houser, 2018); exploring social movement theory in relationship to farmer social movements (Mooney & Majka, 1994); conceptualizing and understanding the impact of class and stratification related to farmers (Mooney, 1983); the construction of gender and identity (Wright & Annes, 2014); developing an understanding of the cultural and biophysical factors influential in environmental views and attitudes, particularly related to climate change (Asplund, 2016; Houser, 2018; Houser, Stuart, & Carolan, 2017); and, reflecting the environmental values literature (Dietz, Fitzgerald, & Shwom, 2005), the development of and impact of environmentally significant values, beliefs, and attitudes on farmer decision making (e.g. Arbuckle et al., 2013b; Reimer & Prokopy, 2014; Roesch-McNally, Arbuckle, & Tyndall, 2017). Clearly, sociological study of agriculture and agricultural producers has the capacity to contribute to the primary discipline’s understanding of the social world and environmental sociologist’s interest in it.

Agriculture is also a key dimension where humans and the natural environmental are overtly interconnected (Carlson, Lassey, & Lassey, 1981; Humphrey & Buttel, 1982). A researcher may be offered more clarity into the nature of the phenomena they are interested in by examining it in the context in which it is most pronounced (e.g. the reason Baran and Sweezy

[1966] focus on the United States in their analysis of monopoly capitalism). In this way, the context of agriculture can provide a clearer window into how social and environmental processes interact than contexts where the human-nature interface is less direct. Studies of agriculture may then offer ample opportunities for social-environmental theory development. This is of particular relevance given the foundational goal of environmental sociology to examine the interrelationship between society and the environment (Catton & Dunlap, 1978).

Potentially nowhere is the capacity for the study of agriculture to elucidate insights about both the social world and the nature of society-environment interaction better illustrated than by the work of Karl Marx. In the article that formally conceptually defined environmental sociology, it was argued that the ignorance of the founders of the core discipline to the relevance of environmental processes to human behavior was a primary barrier to sociology's consideration of environmental phenomena (Catton & Dunlap, 1978). In response to this critique emerged one of the most well cited articles across the environmental sociology literature: John Bellamy Foster's (1999) *Marx's Theory of Metabolic Rift: Classical Foundations for Environmental Sociology.* In this work, Foster mounts a defense to the accusation that the core founders ignored the environment, revealing that Karl Marx in particular had a well-developed recognition and theoretical conceptualization of human-environmental relations. Foster titles Marx's notion "Metabolic Rift."

For the purposes of this dissertation, there are two centrally relevant features of Marx's metabolic rift. First, in its original formulation, Marx's metabolic rift is fundamentally concerned with the context of agricultural production and specifically fertilizer use. And using this context, Marx generates broader theory about the nature of society-environment relationships in capitalism. As argued by Foster (1999), the metabolic rift concept was first developed by Marx during his analysis of industrial capitalism in England and its effect on agricultural production Using the term *metabolism*—which broadly can be understood to refer to any exchanges that occur between human society and the environment (Clausen & Clark, 2005)—Marx's discussion focused on how urbanization associated with then emerging industrial capitalism had influenced the "metabolic interaction between man and the earth," with a focus on agriculture's nutrient cycle (Marx, 1977, p. 637). Specifically, he noted that urbanization had swelled English cities' populations and in consequence rural agriculture increasingly depended on selling its products to these distant urban markets. Travelling with the crops were soil nutrients. Marx saw the nutrient's displacement from agrarian soils to disrupt, or "rupture," what was previously a regenerative cycle. An agrarian system once dominated by local consumption and subsequent composting of waste was made to be linear, where nutrients were no longer reincorporated. As Marx states, this separation created an "irreparable rift" in soil nutrient metabolism that previously was maintained by the reincorporation of nutrients through composting (Marx, 1977, p. 949). To Marx, the logic of capitalism and its material expressions were to blame for these issues. He states capitalist social relations, in both its demand for urbanization and its rational prioritizing profit, "prevents the return to the soil of its constituent elements consumed by man in the form of food and clothing; hence it hinders the operation of the eternal natural condition for the lasting fertility of the soil" (Marx, 1977, p. 637–38). In short, Marx's formulation of metabolic rift used agricultural production as a context through which to examine the society-environment relationship and his theory argues that capitalist structured agricultural production and therefore society-environmental relations broadly, in such a way that it would be fundamentally unsustainable.

The second relevant feature of Marx's metabolic rift theory is that it fundamentally emerges from what we would today refer to as an interdisciplinary perspective. At the time of Marx's writing of metabolic rift in *Capital*, the existence of soil nutrients had only recently been discovered by German soil scientist Justus von Liebig. Indeed, it was von Liebig, and not Marx, who defined the concept of nutrient metabolism (Foster, Clark, & York, 2010). Marx, becoming fascinated with the soil chemist's work, used von Liebig's concept and research on the effect of the then contemporary agricultural system on nutrient levels in soils and city waterways to develop his political-economic critique of agricultural production in 19th century industrial capitalism (Clark & Foster, 2009; Foster, 1999). This interdisciplinary perspective was vital to Marx in his study of capitalist agricultural production and therefore to his development of an argument as to the broader social and environmental implications of capitalist agriculture.

Marx, one of the most influential scholars in the history of sociology[6], saw agricultural production, specifically the use of nitrogen fertilizer (guano), as a legitimate topic through which to understand the social-environmental relationship. Moreover, his work was informed by the inclusion of interdisciplinary perspectives from the soil sciences. As suggested in the above discussion of metabolic rift, Marx was interested in how social processes were influencing the structure of agricultural production in his time and he used the insights from this study to draw conclusions about the nature of capitalism's environmental consequences. Given Marx's renown in sociology and environmental sociology, his perspective serves to illustrate the potential of environmental sociological study of agricultural production; a potential that has been realized by the multiple scholars noted above.

Suggested by this review, the identified barriers responsible for discouraging a fuller incorporation of the agricultural context in environmental sociology literature are based on

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[6] Indeed, recent empirical work using infometrics has identified Marx as the most influential scholar of all time (Kaur, Radicchi & Menczer, 2013).

disciplinary traditions rather than the actual potential for sociological study of agriculture to make intellectual contributions (to either the environmental or natural resource sociology literature).

Defining goals and background for this dissertation

Clearly, environmental sociological study of agriculture and agricultural producers has the capacity to contribute to the sub-discipline's understanding of how society-environment interacts and our primary discipline's understanding of the social world. In this dissertation, I contribute toward a further understanding of the nature of society-environment interactions through three theoretically guided empirical analyses of farmers' behavior in the Midwestern agricultural context. At least a partial motivation for this work is the above described relative position of the agricultural research in the environmental sociology literature. My work across the following three chapters engages with and builds upon the pioneering research of environment sociologists who examine farmer behavior and those from other disciplines, including interdisciplinary environmental sciences and agricultural economics, who work on the topic contributes to environmental sociology through a political-economic framework (e.g., Blesh & Wolf, 2014; Carolan, 2018; Dentzman, Gunderson, & Jassuame, 2016; Hendrickson & James, 2009; Levins & Cochrane, 1996; Schewe & Stuart, 2017; Stuart, 2009; Stuart & Worosz, 2012;).

Another motivation is the theoretical potential and relevance of considering farmers' individual behavior through a cross-scale perspective. Marx's work and the majority of the more recent scholars who have examined the context of agricultural in sociology stops at the same conceptual level of consideration: the structural or macro-level of agricultural production (e.g. Friedland et al, 1981; Gunnoe, 2014; Magdoff et al., 2000). This focus likely reflects this disciplinary barrier of sociology discussed above, but this exclusive macro-level examination is an incomplete study. While structural relations and the macro-level political decisions reflecting these relations are the context that set the stage for individual's behavior, critical realist scholars posit that individual's capacity to deviate from structurally set patterns of behaviors is the precedent for structural change (Bhaskar, 1998; Joseph, 2000, 2002). In other words, should enough individuals stop acting in accordance with social relations determined by social structures, then these structures will cease to be. That consent for power-relations is one of the key processes in their maintenance is one of Gramsci's (1971) central points in his discussion of cultural hegemony. Consequently, sociologists (and environmental sociologists) cannot ignore how (or if) structural social-environmental relations are maintained at the individual-level, as this is where the rubber of social structures meets the road of expressed reality. This is another reason I seek to connect farmers' individual behavior related to nitrogen use to the structural political-economic context of the US agricultural system.

Though pursuing this end, the framing and approaches of my empirical chapters broadly reflects the above described position of agriculturally focused research in environmental sociology. Specifically, I strive to balance my discussion and conclusions to appeal to both environmental sociology and natural resource sociology approaches (as well as other social scientists). Practically, this means that chapters integrate environmental sociology and sociology literature and perspectives into ongoing discussions and debates in the agricultural practice adoption literature, the latter seemingly more accepting of the former. Through integration of approaches common to sociology, but rarely used in studies of farmer behavior, this project contributes conceptually and empirically to the wide body of literature on farmer management decision making and practice adoption (see Baumgart-Getz et al. [2012] for a review).

In seeking to find the ideal balance between disciplinary traditions, this dissertation reflects the work of both established and emerging scholars who have successfully straddled the multiple approaches to the sociology of agriculture. Some names of these scholars that are particularly relevant to my work include: Frederick Buttel, William Burch, Lawrence Busch, Jennifer Blesh, Stephen Bunker, William Freudenburg, Linda Lobao, Thomas Rudel, Diana Stuart, Michael Carolan, and Steven Wolf.[7] As argued by Buttel (2002), if the merging of these two fields is well done, it can result in widely read and influential work; an argument that is strongly reinforced by the success of these scholars.

As a result, my project aims to better integrate environmental sociology perspectives in the natural resource sociology agricultural literature (i.e. practice adoption) and through this, to further suggest the relevance of the agricultural context to the environmental sociology literature. My point of entry in this endeavor is to explore agricultural nitrogen fertilizer use and associated pollution. Below, I describe the context of nitrogen use in agriculture, and then outline the state of the literatures with which I primarily engage. As these subjects will be discussed thoroughly in each empirical chapter, I provide only enough detail into these topics in the introduction to inform the reader of necessary background information.

Nitrogen use in the Midwestern corn system

Synthetic nitrogen (N) fertilizer is considered the cornerstone input of the US industrial agricultural system (Wolf & Buttel, 1996). Nitrogen (N) is a nutrient essential for plant growth. It contributes to the building of amino acids, proteins and is a component in cell DNA. It is therefore a central element of soil fertility and its availability is paramount to agricultural productivity. The use of synthetic N fertilizer in place of organic sources, along with labor

[7] This list of scholars is not intended to be exhaustive. It rather highlights the individual's work that reflects my scholarly goals.

saving technologies, such as pesticides and herbicides, sparked the Green Revolution in the 20th century. These agricultural developments are argued to have been both necessary for and successful in staving off the Malthusian threat of world hunger (Smil, 2000). However, they also have increased synthetic N fertilizer demand. This is the result of a (1) reduction in the generation of organic N, in particular through the increasing specialization (and therefore ecological simplicity) of agricultural production (i.e. less use of legumes crops for organic N fixing and less integration of animal and crop agriculture) and (2) through the adoption of technologies such as higher yielding seed varieties, which demanded higher soil fertility meaning more total N is now required. Because of the increasing adoption of the features of the contemporary agricultural system, synthetic N use has increased dramatically globally. Globally there has been a 10-fold increase between 1950 and 2008 (Robertson & Vitousek, 2009). It is for these reasons that synthetic N fertilizer is considered an essential agricultural input (Robertson & Vitousek, 2009).

The application of synthetic N fertilizer in agriculture is also associated with significant environmental consequences. While I will go into more detail about these consequences in each chapter, here I note that N use in the agricultural system has led to increased N in the broader ecosystem, a resulting of the applied N that escapes from agricultural fields in multiple forms. Increases in environmental N leads to degraded water quality, direct human health consequences, diminished atmospheric quality and further emissions of agricultural greenhouse gases (Robertson & Vitousek, 2009). While other sources of N pollution, such as industry and natural mineralization in part contribute to excess environmental N, N fertilizer from agricultural sources remains the dominant source, representing over 50 percent of all human contributions (Vitousek, Mooney, Luchenco, & Melillo, 1997).

The Midwestern states located in the "corn belt" are the epicenter of the US's N-related environmental issues. Most N fertilizer is lost from US states in the corn belt region (Ribaudo et al., 2011). And these states are severely impacted by or the dominant contributors to a number of environmental issues related to agricultural N use.[8] The Midwest's contribution to N pollution is likely related to the dominance of corn agriculture in these states. Corn receives the lion's share of N fertilizer in the US. About 50% of all N fertilizer in the US is applied to corn (Economic Research Service [ERS], 2012). Yet, corn has an exceptionally low nitrogen use efficiency and nearly half a decade of on-field studies show that around 50% of N applied to corn is lost to the environment as various forms of pollution (Allison, 1995; Cassman, Dobermann, & Walters, 2002). As this evidence suggests, Midwestern corn farmers' are currently using N in ways that contributes greatly to the pollution of the atmosphere, ground and surface water. And the need for a better understanding of the social and biophysical factors influencing Midwestern corn farmers' N use is widely acknowledged (Millar, Robertson, Grace, Gehl, & Hoben, 2010; Ribaudo et al., 2011; Ribaudo, Livingston, & Williamson, 2012; Robertson & Vitousek, 2009; Robertson et al., 2013; Stuart et al., 2015).

Two broad strategies could be taken in addressing the recognized environmental consequences of agricultural synthetic N use. From an agro-ecological perspective, restructuring the Midwestern row-crop agricultural system in ways that reduce or eliminate the need for synthetic N inputs would be the ideal response to these issues. This approach takes the long road and obviously demands a great level of buy-in from farmers, academics and policy makers alike.

[8] N runoff from agriculture in these Midwestern states is the hypoxic zone in the Gulf of Mexico's dominant source of N (Gooslby et al., 2000). Relatedly, waterways and ground water in Midwestern states, like Iowa and Illinois, have been found to contain some of the highest concentrations of N, particularly in agricultural areas. Concentrations can be up to 24 times greater than background levels (USGS, 2010). Finally, when measured on a carbon dioxide equivalent basis, N_2O is by far the dominant agricultural greenhouse gas in the Midwestern US (Larsen et al., 2007).

Likely reflecting these circumstances, only a minor amount of work has begun to empirically inspect this potential at the individual farm level (e.g. Blesh & Wolf, 2014). Rather than fundamental changes, it is argued that significant reductions in the environmental consequences of N use (40-50% in total N losses) could be achieved if farmers adopted a series of recommended best management practices within the general current structure of agriculture (Davidson et al., 2012). As I will describe further below, by far the primary focus of past literature has been on the drivers of farmers' adoption of these practices (Baumgart-Getz et al., 2012; Prokopy, Floress, Klotthor-Weinkauf, & Baumgart-Getz, 2008). A key intention of this dissertation is to enhance the agricultural practice adoption literature, and the various disciplines that contribute to it—for instance, environmental planning, agricultural economics, interdisciplinary agro-ecology and natural resource sociology—through the application of environmental sociological perspectives. For this reason, across my three chapters I engage with the best management practice adoption literature to connect my theoretical underpinnings to a more well established and widely read area of the agricultural literature. Specifically, the practical question addressed in my dissertation is: What factors are constraining Midwestern corn farmers' capacity to improve the environmental efficiency of their nitrogen fertilizer use? Having briefly outlined the applied context of this dissertation, I now turn to describing the current state of the scholarly literature on farmers' practice use and N management.

Past understandings of why N is not used efficiently: Agricultural Practice Adoption Literature

A number of studies have examined what factors lead to or reduce US corn farmers' adoption of conservation N management strategies. The majority of conservation practice adoption literature related to N management has focused on what social factors contribute to the adoption (or lack thereof) of conservation N management practices. To a large degree this literature has examined individual level processes. The most commonly explored factors include demographic variables, like farmer's age, education level, tenure as a farmer and income (Lasley, Duffy, Kettner, & Chase, 1990; Weber & McCann, 2015) or the influence of farm characteristics, like farm size (Lasley et al., 1990; Weber & McCann, 2015). Some studies have emphasized economic dimensions of farmers' decisions. Commonly discussed is the rationale of "insurance" N application, where N is applied in excess intentionally to protect farmers from incurring detrimental financial effects from minimal or low application rates when variability in weather, or other significant environmental factors, produce sub-optimal growing conditions (Babcock, 1992; Osmond, Hoag, Luloff, Meals, & Meals, 2014; Sheriff, 2005; Stuart et al., 2012). Aside from Stuart et al. (2012), these studies do not explore how structural features of the agriculture system may be motivating "insurance" application rates. The influence of structural factors is an important, yet overlooked factor in farmer N decision making. This area of the literature is extensive, yet simultaneously underdeveloped.

Other individual-level studies have examined social-psychological variables, particularly farmers' beliefs about or awareness of the environmental consequences of inefficient N application. Most often, lack of belief in or concern about anthropogenic climate change itself has been argued to be a barrier to corn farmers' use of more efficient N practices (Stuart, Schewe, & McDermott, 2014). Following the model or adapted models of theories such as *Value-Beliefs-Norms Theory* (Stern & Dietz, 1994), it is shown that farmers who believe in anthropogenic climate change are more likely to support adopting mitigation practices (Rejesus et al., 2013) and that those who perceive greater risks from climate change are more likely to respond with adaptive practice use (e.g. Arbuckle et al., 2013b; Roesch-McNally et al., 2017). *Mitigation* refers to actions that reduce anthropogenic contributions to climate change, while adaptation indicates practices that reduce the vulnerability of agriculture to climate change (Intergovernmental Panel on Climate Change [IPCC], 2007). Lack of belief or low levels of concern can significantly hinder farmers' desire to undertake these responses. For instance, Midwestern corn farmers generally report low levels of belief in anthropogenic climate change and farmers' who believe in humans' causal role in climate change have been found to be more supportive of mitigation efforts (Arbuckle et al., 2013b; Gramig, Barnard, & Prokopy, 2013). Specific to N use, Stuart, Schewe, and McDermott (2014) finds lack of belief/knowledge as one barrier to Michigan corn farmers' efficient application of N, finding that they are largely unaware of N fertilizers link to N_2O and climate change and moreover, generally do not perceive anthropogenic climate change to be real.

The influence of information sources on farmers' N management decisions is another factor prominently explored in the literature (Mase, Babin, Prokopy, & Genskow, 2015; Osmond et al., 2014; Stuart et al., 2012; Weber & McCann, 2015). These studies show farmers have access to a range of sources for recommendations on how to manage their annual N fertilizer strategies, including fertilizer and seed dealers, university extension or private agronomists. Current research suggests that what source a farmer uses for information about nutrient management may influence the efficiency of their N management practices (Osmond et al., 2014; Stuart et al., 2012; Weber & McCann, 2015). The use of a given source is commonly framed, explicitly or implicitly, as a choice, although few studies have empirically examined why a given source is used (see Luloff et al. [2012] as an exception). In consequence, current literature treats the influence of information sources as another individual-level factor.[9]

[9] Though some research suggests that structural factors, such as decreased funding for public university outreach, could be responsible for corn farmers' preference for a given source (e.g. McBride & Daberkow, 2003). This hypothesis has yet to be thoroughly empirically explored.

To summarize, the primary focus on literature addressing inefficient agricultural N use has been to examine the individual-level factors that influence practice adoption. This focus is unsurprising, given both that it reflecting the broader agricultural practice adoption literature (Baumgart-Getz et al., 2012; Stuart & Gillon, 2013) and the disciplinary traditions of natural resource sociology (Buttel, 2002; Field, Luloff, & Krannich, 2002).

The theoretical thrust and arguments of this dissertation

In this dissertation, my focus is on contributing to the N conservation practice adoption literature through sociologically directed examinations of farmers' N use. As a response to the individual-level focus of the vast majority of prior literature on farmers' N use decision making and broader work on agricultural practice adoption management, the primary and pervading goal of this work is to offer insight into how structural (i.e. macro) level factors influence farmers' decision making and practice use. I focus on the embeddedness of farmers' individual actions, revealing how the how political-economic factors that emerge from the structural context of the capitalist system influence farmers' behavior at the individual level (Granovetter, 1985). This focus emerges from the well-established body of earlier sociological studies of agriculture that reveal the role of political-economic factors[10] in this context and how these factors influence the environmental impacts of modern agricultural production (Buttel, 2001; Buttel, Gillespie, & Larson, 1990; Friedland et al., 1981; Magdoff et al., 2000; Levins & Cochrane, 1996). Across this work, classics like Friedland, Barton and Thomas (1981) and recent research like Henke (2008) and Gunnoe (2014) alike reveal how agriculture reflects, at a macro-level, the broader political economy of capitalism.

[10] Political economic factors include the structural conditions of economic production, with reference to the influence on other relevant dimensions of society (e.g. the state, institutions)

These studies emphasize the structural dimensions of the US agriculture system and how it impacts production practices, providing an important macro-level perspective. This exclusive macro-level focus in the political economy of agriculture literature likely reflects the above divisions between environmental and natural resource sociology. The political economy agricultural literature emerges from and reflects environmental sociology and thus likely in response to this field's biases, deems individual-level research less theoretically significant. In consequence, only a small number of scholars have begun to direct our attention to the ways farmers' N use at the individual level is influenced by macro-level processes (David et al., 2015; Stuart et al., 2012, 2014). This work emphasizes how macro-level processes, such a federal funding decisions (David et al., 2015), the practices of monopolistic agri-businesses (Schewe & Stuart, 2017; Stuart & Houser, 2018), and the predatory, competitive nature of Midwestern corn agriculture (Stuart et al., 2012) limits farmers' capacity to alter their N management practices at an individual level. Though relatively meager at this point, this research suggests exclusive examination at the individual level misses how farmers' decisions are constrained by larger social factors. Research on this question will answer recent calls for further cross-scale (i.e. marco↔meso↔micro) analysis of farmer N decision making (Stuart et al., 2015) and engage with the growing findings of the N conservation practice adoption literature (and that of larger general conservation practice adoption literature).

Across all three of my empirical chapters, I follow this prior literature and deploy some form of a political-economic framework to consider how farmers' individual-level N management behavior is influenced by the broader structural context of capitalist production. The specific approach used to consider the role of macro-level political economic factors varies in each chapter. These variations are intended to connect with and enable development of specific dimensions of both the political-economy literature in environmental sociology and the agricultural practice adoption literature. I briefly summarize each chapter's approach, argument and dual contributions below.

Chapter II: The political economy literature in environmental sociology strongly focuses on the role of material (i.e. physical) factors in influencing society-environment relations at the macro-level (e.g. Foster, 1999, 2000; O'Connor, 1988; Schnaiberg, 1980). This focus is shared by the scholars who have brought this perspective to the agricultural context (Friedland et al., 1981; Magdoff et al., 2000; see Henke [2008] as an exception). To this point, the role that ideological dimensions of the political-economy play in influencing environment-society relations has rarely been explored in the environmental sociology literature (Gunderson, 2015), nor is it visible in the political economy scholarship specific to agriculture. Ideology here refers to the system or set of beliefs that emerge from these structural material and cultural conditions and through which individuals (or communities, cultures, societies, etc.) make sense of their existence (Knight, 2006; Therborn, 1980).

In this chapter, I bring together Luke's theory of social power (Lukes, 1974) with political economy literature to indicate how ideological dimensions of capitalist system are held by farmers and influential in their desire to adopt more efficient N management practices. I examine the rate at which farmers apply nitrogen fertilizer, focusing on those in my qualitative sample of 154 farmers in Indiana, Iowa and Michigan who exceed maximum profitable application rates in their respective states (Millar et al., 2010). I find that these farmers' expressed two ideologies, the free market ideology and instrumental rationality, as justification for the perceived appropriates of their inefficient N use and lack of desire to reduce their N application rates. In this way, I offer preliminary insight to the environmental sociology literature as to how political-economic context influences environment-society relations at the individual level through endowing particularly ideological positions.

This chapter builds on the small amount of prior work in the agriculture practice adoption literature that has focused on farmer ideology, its relationship to structural context and its influence on their practice decision making (Ellis, 2013; Emery, 2015; Dentzman et al., 2016). In doing so, it reinforces the early insights of this prior work to the broader practice adoption literature. This insight suggests that even social-psychological processes are bound to and influenced by the constraints of the structural context in which farmers operate and live. The voluntarist assumptions (Dillon, 2013) implicit in the decision making approach of much of the agricultural practice adoption literature are then questioned in this chapter.

Chapter III: Environmental sociology, as noted, is fundamentally concerned with the totality of human-environment interactions, meaning that it is both interested in the effects of human actions on the environment and the causal role of environmental processes in human behavior (Catton & Dunlap, 1978). To this point, the political economy literature in environmental sociology has almost been exclusively concerned with the environmental outcomes of political-economic processes at a macro-level, giving little attention to causal role the environment plays in human-environment interactions (Foster et al., 2010; O'Connor, 1988; Schnaiberg, 1980; Walker, 2005). This chapter preliminarily engages conceptually and empirically with this research gap. Environmental science literature has predicted climate change to foster changes in ecological conditions that exacerbate challenges to efficient N fertilizer use (Suddick, Whitney, Townsend, & Davidson, 2013) and current evidence is showing it already has in the Midwest (Pryor et al., 2014). I use qualitative data from 154 farmers in the same states used in Chapter II to examine how farmers are altering their N management practices in response to the effects of climate change given the structural political-economic context of agricultural production in the Midwestern US. I focus specifically on the impact of heavy rain events, a specific expression of climate change in the region (Pryor et al., 2014). My results suggest that farmers actively respond to experiencing these biophysical processes with changes in their N management; however, the nature of these changes reflect the profit imperatives of agricultural production in the capitalist system. Specifically, rather than using recommended best management practices, most farmers used the cheaper and more economically dependable method of increasing their N application rates. While increased N rates can reduce vulnerability to weather events (Sherriff, 2005), they also lead to higher levels of pollution from agriculture (Millar et al., 2010). This suggests that while biophysical processes like heavy rain events can influence human behavior, the exact effect these processes produces are mediated by the social structural context in which they occur. This insight is one small advancement in the political economy literature of environmental sociology.

The agricultural practice adoption literature has largely focused on how farmers' intention to use best management adaptation behaviors are influenced by social-psychological factors (Mase et al., 2017; Niles, Brown, & Dynes, 2016; Wheeler, Zuo, & Bjornlund, 2013). In short, like much of the above mentioned agricultural literature, it is largely bound to the context of farmers' social-psychological processes. To this area, this chapter (1) develops a fuller recognition of how macro-level constraints can influence farmers' actual adaptation behaviors, thus building on the small amount of prior work in this area (Blesh & Wolf, 2014; Roesch-McNally et al., 2017), and (2) in doing so reveals how farmers' may be reacting to the risks introduced by climatic events in ways that do not accord with recommended strategies. This chapter can then be broadly seen to response to calls for a coupled-systems approach to understanding N management (Stuart et al., 2015).

Chapter IV: An increasingly well-developed vein of the political economy literature in environmental sociology focuses on conceptually and empirically examining the potential of addressing environmental issues through the use of "green" or more environmentally efficient technologies (e.g. Sellen & Harper, 2002; York, 2012, 2017; York & McGee, 2016). This work has shown that while technical solutions like agricultural best management practices may be capable of addressing environmental issues, their actual effects are highly dependent on their implementation. Social contexts, specifically the political economic structure, can encourage continual increases in production, meaning that more environmentally efficient technologies are often deployed to increase profits, rather than conserve resources (York, 2017). Because of this, it is frequently observed that there are few environmental benefits from the adoption of more environmentally efficient technologies (York & McGee, 2016).

Using this as my conceptual background, in this chapter I examine whether adoption of N best management practices leads to lower levels of N related pollution. In this analysis, I follow prior work's recommendations in using farmer's N application rate a proxy measure of N pollution (Millar et al., 2010). The results of this quantitative analysis of a sample of approximately 3000 farmers from the states of Illinois, Indiana, Michigan and Ohio preliminarily indicate that farmers who have adopted N best management practices apply N at rates that are on average higher than farmers who have not adopted these practices or adopted fewer of these practices (controlling for other relevant variables). This counterintuitively suggests that N best management practice use may lead to greater levels of N related pollution; a finding that the political economy of technology literature suggests is the result of the political-economic structure—i.e. the profit imperatives—of US agricultural production (York & Clark, 2010).

Empirical work demonstrating this relationship between efficient technologies and environmental benefits has primarily occurred at the macro-level (e.g. Sellen & Harper, 2002; York, 2017). For instance, regarding the failure of technical solutions to provide environmental benefits, York (2012) finds that in most nations of the world, over the past five decades, the generation of non-fossil fuel energy typically did not effectively displace the use of fossil fuels—non-fossil energy sources were for the most part added to, not used in place of, fossil energy sources. In consequence, this study can be seen to extend the political-economy of technology literature's hypothesis to the individual level.

Related to the agricultural practice adoption literature, research in this vein has focused almost exclusively on the adoption of practices and largely neglected to consider how adopted practices are implemented (Urlich-Schad, Garcia de Jalon, Babin, Pape, & Prokopy, 2017). Recent empirical work has suggested the need for further consideration of how adopted practices are implemented (Osmond et al., 2014). These studies reveal that even when a practice is adopted, it may not be implemented as intended or even fully utilized. For instance, Osmond et al. (2014) show that farmers were not altering their nutrient management in response to provided soil test recommendations and thus there was not environmental benefit from their adoption. As this suggests, it should not be assumed that adoption of a best management practice will result in environmental gains. This chapter's focus on whether adopted N best management practices are implemented in ways that lead to a reduction in N pollution from farmers is a response to the need for a greater attention to the implementation of adopted best management practices (Urlich-Schad et al., 2017

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CHAPTER II— Over Application of Nitrogen Fertilizer as a Non-Issue: Using Lukes to Explore the Ideological Barriers to Reducing Nitrogen Best Management Practice Adoption in Midwestern Corn Agriculture

INTRODUCTION

To this point, the farmer management practice adoption literature has largely view farmer decision making through a voluntarist lens (Dillon, 2013): Farmers are independent decision makers primarily influenced by their individual-level characteristics and social-psychological processes (Baumgart-Getz et al., 2012; Caswell, Fuglie, Ingram, Jans, & Kascak, 2001; Lasley et al., 1990; Morris et al., 2000; Napier et al., 1986; Napier & Camboni, 1988).[11] There is little doubt that farmers' practice adoption is the result of their individual-level decisions. However, when viewed with a sociological lens, the independence of this decision making process may have been overstated in prior work. This article suggests how social context influences farmers' perceptions of their management practice use and in this way can shape which and the extent to which management decisions are independently made by farmers.

I examine this in the management context of nitrogen fertilizer use. Nitrogen (N) fertilizer is an essential agricultural input (Robertson & Vitousek, 2009), contributing to crop yield increases that supply an estimated 40% of the global population with its nutritional needs (Smil, 2002). However, when lost to the environmental from agricultural fields, N becomes a potent environmental pollutant. Most N applied in the US is applied to corn—about 50 percent of all N fertilizer (Economic Research Service [ERS], 2012). Reflecting this high portion of N use, most agricultural N fertilizer lost to the environment in the US comes from states in the 'corn belt' region, which are the primary producers of corn in the US (National Agricultural Statistical Service [NASS], 2015; Ribaudo et al., 2011). Midwestern agriculture is responsible for

[11] Exceptions to this point exist. There is some research in this literature that has focused on constraints to farmer decision-making and practice adoption. See for example Besley and Case (1993) and Swinton et al. (2015).

approximately 75% of the hypoxic 'Dead Zone' zone in the Gulf of Mexico (Ribaudo, 2006); waterways and ground water in Midwestern states, like Iowa and Illinois, have been found to contain some of the highest concentrations of N, particularly in agricultural areas (U.S. Geological Survey [USGS], 2010); and nitrous oxide (N_2O), a greenhouse gas 300 times more powerful than carbon dioxide, is by far the dominant agricultural greenhouse gas emitted in the Midwestern US (Larsen et al., 2007).

Given these circumstances, scholars are increasingly attempting to understand how to reduce N's environmental costs while ensuring continued high agricultural productivity (e.g. Millar et al., 2010; Roberts, 2006; Stuart et al., 2015). From solely an environmental perspective, eliminating the use of synthetic N fertilizer in corn agriculture would be the ideal response. However, this option is currently not feasible, since it would require a revolutionary transformation of the conventional Midwestern agricultural system. This system is highly dependent on artificial nutrient inputs, so much so that N fertilizer is considered to be an "essential" component of the contemporary agricultural system (Robertson & Vitousek, 2009); particularly in systems where crop rotation is simple (e.g. corn-soy). At this time, ceasing N use all together is therefore not a realistic solution at this time. Efforts to reduce its environmental consequences benefit then by focusing on maximizing the efficiency of the use of N fertilizer; 'efficiency' being used here to refer to the amount of applied N captured by the crops and therefore not freely available to enter the environment (Robertson et al., 2013).

The rate at which N is applied to agriculture fields is widely considered the most important factor for determining efficiency levels, with higher N rates generally being associated with higher levels of N related pollution from agriculture (e.g., Hoben et al., 2011; McSwiney & Robertson, 2005; Ribaudo et al., 2011; Robertson et al., 2013). When N rates are used that exceed a crop's yield potential, this excess N does not contribute to profit increases and is instead free to enter the environment as pollution. Application above this threshold is particularly problematic when considering agricultural greenhouse gas emissions. N_2O increases at a rate more than proportional with amount of N applied when application rate exceeds crop yield thresholds (Hoben et al., 2011; McSwiney & Robertson, 2005).

N rate is therefore a key dimension of N management for determining pollution levels, particularly N_2O emissions and applying N at minimal rates, defined by crop yield and profit maximization levels, is a means to reduce these environmental consequences (Millar et al., 2010). Current evidence, however, suggests N was being applied above recommended rates[12] on more than a third of corn acres in the US in 2010 (Ribaudo et al., 2012). This high use of agricultural N is prevalent in the Midwestern corn belt states (Millar et al., 2010; Ribaudo et al., 2011). Given the importance of N rate for determining N pollution levels, research offering insight into the barriers to reducing the proportion of farmers' applying N at recommended rates in Midwestern corn agriculture is a contribution toward efforts to reduce the environmental consequences of agricultural N use.

Recent evidence suggests an under-explored barrier to examine: farmers' lack of desire to reduce their N rate. Midwestern corn farmers may increasingly feel that their N fertilizer application rates are "about right"; with 75% of Iowa corn farmers expressing this opinion in 2012 as compared to 61% in 2002 (Arbuckle & Rosman, 2014). At the same time, more than half of the farmers in this same sample believed that farmers intentionally over-apply N. Arbuckle & Rosman (2014) argue that together these results suggest the "normalization" of high use of N

[12] Ribaudo et al. 2012 define "recommended rates" as: applying no more nitrogen (commercial and manure) than 40 percent more than that removed with the crop at harvest, based on the state yield goal, including any carry-over from the previous group.

among farmers. This may indicate that farmers' comfort with their current (possibly high) N rates is one barrier to the reduction of N application rates and thus the environmental costs of agricultural N use. Stated alternatively, a portion of Midwestern corn farmers may not desire to reduce their N applications, and this lack of desire could be a barrier to improving the efficiency of agricultural N use. Exploring this possibility is the primary motive of this article. Specifically, I seek to address the research questions: Do corn farmers who are applying N above maximum profitable thresholds desire to reduce their N application rate? If not, what factors might discourage or somehow dampen this desire?

As I suggest above, in examining this question I do not take a voluntarist approach implicit in much of the prior agricultural management decision making literature. Instead, I focus on how farmers' perception of the appropriateness of their N rates is influenced by their social context through focusing on the role of ideological positions; *ideology* being here defined as a system or set of beliefs that emerges from structural material and cultural conditions and through which individuals (or communities, cultures, societies, etc.) make sense of their existence (Knight, 2006; Therborn, 1980). This research engages with the prior literature that has revealed how ideological elements of the contemporary "capitalist" agricultural system influences farmers' management decisions (see below) and extend the small but growing literature examining the barriers to Midwestern corn farmers' efficient use of N fertilizer to consider non-material constraints (i.e. in the realm of perceptions; Stuart et al., 2012; Schewe & Stuart, 2017).

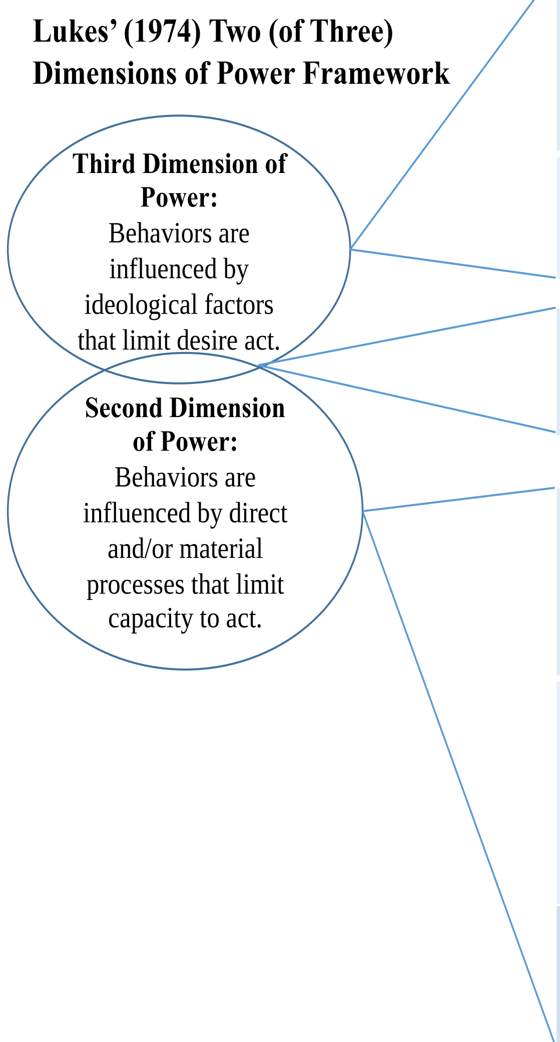
I address this research goal through examining qualitative data from 154 farmer interviews within the context of the Midwestern corn agricultural system, specifically in the states of Michigan, Indiana and Iowa. Ideology is likely but one of the factors that constrain farmers' N decision-making. However, as my results will suggest, ideological positions did discourage a significant number of farmers in my sample from desiring to reduce their N use, even when applying at rates that exceeded maximum economic returns. In consequence, this work offers important and novel insight toward further understanding the barriers at multiple dimensions to N best management practice option. To begin, I review prior literature on farmers' N management behaviors and the barriers to efficient N use. I discuss this work through the conceptual lens of Lukes' (1974) Three Dimensions of Power framework.

THEORETICAL BACKGROUND

Power, ideology and the political-economy of agriculture

In *Power: A Radical View*, Lukes (1974) set out to conceptually analyze the nature of power in society, working to quell disputes and move the field past hampering debates through categorizing various and contradictory position on the subject. Lukes saw past work on the nature of social power, which can be described as the capacity for influence in society (Hearn, 2012), as broadly fitting into one of three forms. These forms, or what Lukes called "dimensions" reflect the way in which influence (i.e. power) could be enacted. Lukes' second and third dimension of power are conceptually relevant for my purposes. Both dimensions can be used to understand why the behaviors of any individuals or any grouping of individuals persist, though far less literature has explored barriers to farmers' behavior at the third dimension of power (see below). I discuss prior work on barriers below through the conceptual lens of Lukes (see Figure 1).

Figure 2: Diagram illustrating past literature's conceptual engagement with Lukes' Two Dimensions of Power



Ideological factors' influence on farmers' behavior generally	Emery, 2015	Finds that the ideological positions of independence and individualism lead farmers to accept the social relations of the agricultural system
	Ellis, 2013	Shows how farmers' justify animal-farmer relationships through ideological positions.
Ideological factors' influence on farmers' integrated weed management approach adoption	Dentzman, Gunderson & Jassaume, 2016	Ideologies of techno-optimism and individuality constrains farmers' use of integrated weed management
	Dentzman & Jassaume, 2017	
Relationship between political economic material and ideological barriers to farmers' practice adoption	Hendrickson & James, 2005	Argues that structural context is degrading farmers' environmental ethics
	Stuart & Houser, 2018	Finds that seed companies influence farmers N rates through control of material technology and knowledge
Political-economic context of agriculture	Friedland, Barton & Thomas, 1981	Generally outline how agricultural system and production reflect capitalist social structure
	Foster, 1999	
	Magdoff, Foster & Buttel, 2000	
	Carolan, 2005	
Political economic factors' influence on farmers' management practice adoption	Roesch-McNally, Arbuckle & Tyndall, 2017, 2018	Shows market forces (i.e. inability to profit given markets) maintains lack of rotational diversity
	Blesh & Wolf, 2014	General focus on how capitalist structure of agriculture system bars transitions to agro-ecological farming systems
Political economic factors' influence on farmers' N use	Stuart, Schewe & McDermott, 2012	General exploration of political-economic barriers
	Stuart & Schewe, 2016	Examines role of seed corn farming, seed contracts and seed companies on N use
	Schewe & Stuart, 2017	

The second dimension of power describes how behaviors can be influenced through direct and material processes (i.e. coercive influence) or through strategies that prevent a decision related to an action, even if the action is desired (i.e. mobilization of bias, Bachrach & Baratz [1962]). This dimension of power has been the primary focus of past literature related to barriers to farmers' practice adoption. While little has examined the process of 'mobilization of bias'[13] specifically, the role of constraining contextual processes in limiting behavior has been the major focus of this small, but growing field of work (Carolan, 2005; Magdoff et al., 2000; Stuart & Houser, 2018). Agricultural production in capitalist economies is argued to be fundamentally profit driven (as other sectors of production are), and therefore prioritizing expansion of production and profits over environmental outcomes (Buttel, 2001; Foster, 1999; Magdoff et al., 2000). Due to forces such as competition, profit-seeking in capitalist agriculture is seen to be a constrained choice, rather than preference (Magdoff et al., 2000) and in this way this structural context limits what behaviors farmers undertake broadly (Friedland et al., 1981) and has been shown to bar farmers' adoption of conservation oriented practices (Blesh & Wolf, 2014; Roesch-McNally et al., 2018). A small but growing field of research has begun to examine how political-economic factors constrain farmers' adoption of N best management practices specifically (David et al., 2015; Stuart et al., 2012). Only recently have the barriers to N rate reduction been specifically explored in this work. These studies show that political-economic factors, like the increasing control of monopolistic agro-industries, encourage increased N application rates through the processes of the development of seed technology and contract terms (Stuart & Houser, 2018; Stuart & Schewe, 2016). These factors constrain farmers' N management decisions, encouraging environmentally inefficient practices even when farmers'

[13] Though some work farmers' climate change attitudes and their effect on management decisions can be said to be related to this (e.g. Houser, 2018).

desire to reduce the environmental impacts of their practices (e.g. David et al., 2015). Through its focus on the political-economic structure and the material barriers this structure presents, most prior literature on the barriers to practice adoption and N rate reduction reflects influence occurring in the second dimensional form of power.

Lukes' third dimension of power focuses on behavior as it is influenced by more covert processes. The third dimensional form of power refers to mechanisms of influence that produce inaction through limiting the desire to act differently (Lukes, 1974). Lukes' position, as it is relevant to my case, can be stated simply: individuals may not wish to act differently because their construction of events, processes, circumstances, i.e. reality, suggests it is not necessary to. Lukes, as others have, suggests that ideological positions are among the influences on individuals' construction of reality and in this way, are key processes shaping how individuals react to their world and behave within it (e.g. Mann, 2012; Poggi, 2002; Swidler, 1986). As I noted above, *ideology* is here defined as a system or set of beliefs through which individuals (or communities, cultures, societies, etc.) make sense of their world. Though not using the term ideology, Lukes (1974, p. 23) argues that ideological elements—beliefs, attitudes, knowledge—can be influenced by, "mundane forms [of influence], through the control of information, through the mass media and through the process of socialisation." Lukes, like others, sees social context as influencing individual's ideological positions and, through this, their desire to act (Althusser, 2006; Marcuse, 2013; Poggi, 2002; Therbon, 1980). In short then, the third dimension of power is where desire for action (i.e. behavioral change) is constrained by ideological positions, emerging from social contexts, that shape the construction reality, and in this way can lead individuals to desire to *not* act differently.

To this point, little work has explored constraints to farmers' behavior in the third dimension of power, but a few prior studies do indicate the relevance of influence at this dimension. Ellis (2013) reveals how commercial beef farmers' productivist activities are justified and thus self-perpetuated through multiple ideological positions. Farmers' inability to recognize and act against structurally exploitive conditions has been attributed to their conflation of the ideological positions of individualism and independence (Emery, 2015). Emery (2105) shows that farmers hold a strong sense of individualism, but that this value is confused as representing the capacity for independent action, which it may not correspond to as other recent farmer specific research has also indicated (Stuart & Houser, 2018).The ideology on the superiority of production technologies has been shown to reduce farmers' preference for and adoption of less technological solutions to production/environmental issues like the use of integrated weed management techniques to address herbicide resistance (Dentzman et al., 2016). Other studies have specifically focused on how the structural context of the political economy of agriculture, which prioritizes profit over environmental concerns (Magdoff et al., 2000), may influence farmers' ideological positions and through this their actions (Dentzman & Jussaume, 2017; Hendrickson & James, 2005). For instance, Dentzman and Jussaume (2017) show how the ideological dimensions of this structural context encourages farmer support for technological "quick-fixes" rather than integrated management practices. Together, this work indicates the relevance of the third dimension of power for farmers' behavior and specifically that structural context of capitalist production may drive farmers' behaviors through endowing various ideological positions.

Given this work and Lukes' theoretical position, it may be that the desirability of reducing (high) N rates to Midwestern corn farmers is influenced by their ideological positions and thus a product of the third dimension of power. This question has yet to be empirically examined, and there is an important conceptual distinction to be considered between N rate and practices examined in past literature. The above work focuses on the adoption of behaviors that are in the individual farmer's interest only in the long-term. Adoption of integrated weed management, developing a critical appraisal of the agricultural system of a whole and/or its treatment of animals and acting on this perspective all have immediate negative financial and potentially psychological costs to farmers. In contrast, reduction in N application rate to maximum profitable levels has both immediate financial benefits for farmers and reduces all forms of N related environmental pollution (Millar et al., 2010; Robertson et al., 2014). In consequence, it is both in the long-term and short-term interests of farmers to apply N at levels that do not exceed maximum-profit responses. Whether ideological positions similarly discourage farmers from desiring to apply N rates at or below recommended levels is a novel empirical and conceptual exploration given this distinction.

To address this novel area of research, this paper explore how ideological positions discourage farmers who are applying N at rates above maximum profitable thresholds from desiring to reduce their high N rates. Or, stated in terms of political-economic theory, I explore how the ideology of growth—the cultural, psychological, and ideological dimensions of the material capitalist system—acts to re-produce this system's destructive environmental practices through the enrollment of individual farmers in the agricultural sector. By focusing on the effect of ideology, I strive to contribute to the research on the barriers to N best management practice adoption by revealing constraints on farmers' decisions at the third dimension of power. In this effort, I also contribute to the current literature examining barriers at this dimension by empirically and conceptually extending this work through focusing on N rate reduction, a practice that would be in the immediate interest of farmers who are applying above yield thresholds.

METHODS

I address this research goal through examining qualitative data from Midwestern corn farmers in, Indiana, Iowa, and Michigan. This data was gather via one-on-one interviews with 154 corn farmers from Indiana (n=51), Iowa (n=53) and Michigan (n=50). Farmer recruitment for these interviews was primarily conducted in spring and early summer, with interviews beginning in May 2014. Because this time of the year is when fertilization, among other key agricultural activities, may be taking place, individual interviews were scheduled at the convenience of the particular farmer.

Initially a purposive sample design was used, where farmers who grew at least 100 acres of corn annually were sought out to ensure those farmers whose actions were viewed as having the largest impact on the environment were included (Wilke & Morton, 2016). Overall crop rotation was not a factor in recruitment and therefore varied across the sample. In consequence, “corn farmer” signifies that farmers’ annually planted >100 acres of corn. This purposive sample of interview participants was primarily recruited through university extension and other state resource professionals, with a reliance on snowball sampling thereafter to enable an expansion of the original sample size and maintaining the +100 acres criterion. Snowball sampling is considered a good method to contact subjects who are difficult to access (Faugier & Sargeant, 1997), such as farmers. Across all three states, 48% (n=74) of farmers were contacted through extension, 34% (n=53) through snowball sampling, 13% (n=20) through state or federal conservation offices or programs (Michigan Association of Environmental Professionals, Soil and Water Conservation) and 5% (n=7) were contacted through various other relevant sources

(Soybean Association, Practical Farmers and Field Days). For recruiting figures specific to each state, see Appendix A. Interviews covered a number of counties in each state. In Iowa, interviews took place across 27 of the 99 counties, covering 27% of all Iowa counties. Interviews in Indiana took place across 23 counties. Consideration for counties to gather interview contacts from was limited to 82 counties, after nine[14] counties from Indiana were eliminated due to their proximity to metropolitan areas and low planted acreage of corn. Consequently, interviews covered 28% of considered counties in Indiana. In Michigan, interviews took place across 17 of the 83 counties. The lower number of counties covered in Michigan reflects the state's limited geographical area where corn is produced. The 17 counties covered by sampling accounted for 42% of Michigan's total planted corn acres in 2014 (NASS, 2015). In Iowa, the average farm size of interviewees was 1236 acres operated, in Indiana 2216 and in Michigan 1519.

Importantly, as farmers were primarily contacted through University Extension, this sample may over-represent the number of farmers aware of and using university recommended N application rates. However, past analysis of this sample has shown that interviewed farmers consulted numerous agricultural information sources and often preferred private sector sources (e.g. fertilizer dealers) to University Extension (Stuart et al., 2018). This suggests sample bias from engagement to university sources is limited, as will the results I offer below.

I analyze and present results from this data in two steps. I first examine farmers' actual N application rate to explore if farmers are applying N at rates that exceed optimal economic thresholds. Each of the 154-interviewed farmers was asked about their N application rate. Some farmers gave unclear responses to this question, others choose not to answer and some, particularly in Michigan, grew multiple crops and used crop rotations for which estimates of

[14] The nine counties are: Marion, Dearborn, Ohio, Franklin, Switzerland, Monroe, Clark, Scott, Jefferson.

maximum profitable thresholds are unavailable. In consequence, I analyze 132 farmer interviews in total. I explore the appropriateness of their N rate through the Maximum Return to Nitrogen (MRTN) rates concept (Sawyer et al., 2006).[15, 16] MRTN N application rate thresholds are defined by economic limits. If rates exceed the high profitable rates defined by MRTN calculations, farmers will be "over-applying" N, as the cost of additional N exceeds returns from minimal gains in yield. In consequence, application of N at rates above profitable rate thresholds have a negative effect on profitability and thus unnecessarily contribute to N pollution and N_2O emission. To define maximum profitable rate thresholds for this study, I used average annual prices for anhydrous ammonia and average annual prices for corn between the years 2014-2009 to determine the 5-year average N-to-corn price ratio for this time period.[17] Anhydrous ammonia is both the least expensive and most widely used form of N in the US (ERS, 2017). In consequence, these results reflect the type of N the majority of farmers' use and are the most conservative estimates of price ratios for each year, as more expensive N products equate to higher price ratios. Across the five years calculated, a ratio of .09 was determined, which is conservatively .01 lower than the .10 annual N-to-corn ratio for the 2014 season in which

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[15] While the most environmentally beneficial application rate of N is 0 lbs./acre, the economic reality of corn farming must be considered when determining what an appropriate N rate is. An ideal rate of application minimizes environmental impacts of N application, without reducing farmers' profitably. Moreover, specific appropriate rates will be dependent on geographically dependent biophysical qualities and a farmers' rotation system. Millar et al. (2010) offer recommended rates that are economically *minimal*, which if farmers are to apply under their profits can be expected to decrease as yield would decrease, and economically *maximum*, which if exceeded would decrease profits as cost of N fertilize outpaces yield benefits of application. Recommended rates are split based on two of the most common corn rotation systems (Wallander, 2013) for states across the Midwestern corn belt with sufficient data for the previous agricultural season (2016). For Midwestern corn farmers, these rates reflect a threshold point, which if crossed at the low end offer little-to-no economic gain, and if exceeded at the high end, likely reduces profits (Millar et al., 2010). However, as the amount of N lost to the environment, particularly in the form of N_2O emissions, generally increases as N rate increases (Hoben et al., 2011; Sawyer & Randall, 2008), these rates can be seen as thresholds, which if applied within will minimize environmental impacts without hurting profitability.

[16] See Appendix B for an example table of MRTN rates from Sawyer et al. (2006).

[17] Average annual anhydrous price was drawn from Schnitkey (2018) and annual corn prices are an average calculated from data drawn from macro-trends.net This data is available at: http://www.macrotrends.net/2532/corn-prices-historical-chart-data

interviews took place. Using the Iowa State University MRTN calculator (available at: http://cnrc.agron.iastate.edu/), I then calculated MRTN rates for my sample. Yield potentials vary within state, resulting in both inter- and intra-state differences in MRTN thresholds.[18] For Iowa, the maximum profitable "upper limit" MRTN rates for a corn-soybean ratio system were 151 (main region) and 167 lbs/acre (SEIA region). For Indiana, 197 (NW and NC regions), 216 (C region); 235 (EC region); 240 (NE region); and 192 lbs/acre (WC, SW, SC & SE regions). Finally, only a single MRTN rate is available for the corn growing region of Michigan: 161 lbs/acre. For the study year of 2014 and the 4 years prior to it, farmers applying at these rates would have exceeded "recommended" MRTN rates in all 5 years and applied above the profitable rate threshold in three of the five years, two of which were 2014 and 2013. In consequence, these measures represent fairly conservative estimates of "over-application" for the 2014 season. Using these as threshold rates, I examine whether farmers' in each state (and within each region of each state) are "over-applying" N in the 2014 season, meaning they applied above maximum profitable levels and therefore unnecessarily contributed to N pollution.[19]

In the second stage of analysis I explore how ideological positions influence farmers' desire to reduce their N application rates. To do this, I analyze interviews of farmers' who were found to be over-applying N using an adaptive version of grounded theory (Strauss & Corbin, 1990). Importantly, no interviewed farmer felt they were over-applying, and most did not desire to reduce their N application rate. However, given the literature showing inefficient use of agricultural N fertilizer, I undertook a more careful examination of farmers' reported N rate in

[18] In total, there are 12 different regions MRTN considers for these states. Across these 12 regions, there are 7 distinct profitable N rate thresholds.

[19] Approaches other than the MRTN approach exist for estimating a 'best' or recommended N rate for corn seasonally. See Arnall et al. (2013) for a review. I used MRTN here based on the clear threshold rates it provides given economic context and the ubiquity of this approach throughout scientific literature and Extension outreach programs (e.g. Sawyer 2006; Millar et al. 2010; see Iowa's MRTN calculator page as an example: http://cnrc.agron.iastate.edu/).

light of calculated MRTN rates (e.g. Millar et al., 2010; Ribaudo et al., 2011, 2012; Robertson & Vitousek, 2009). This revealed that a substantial number of farmers who felt they were using N at appropriate rates were applying in excess of the MRTN threshold. Focusing on this dominant sub-sample, I examine how their expressed justification for desiring to maintain these rates reflect larger ideological positions. Results from these analyses are presented below.

RESULTS

Are farmers' applying N at rates that exceed optimal economic thresholds?

In the first section of my results, I discuss whether farmers in my sample were applying N above recommended rates, as defined by the MRTN maximum profitable N rate thresholds. Best management recommendations call for N to be applied at variable rates within and across fields to match yield potentials. Thus, ideally, farmers should have no single N application rate (Liu, Swinton, & Miller, 2006). Across the 132 interviewed farmers who gave N rate application responses, five used variable N rates across fields and only one farmer variable rate applied within and across fields. Rather than applying a specific rate to each field (or zones within each field), most farmers' who varied their rate discussed using two different rates across soil types, management zones (i.e. irrigated versus non-irrigated land, manured versus non-manured ground) or due to stipulations of a conservation reserve program contract on a portion of their land. As one Michigan farmer stated, "Some fields I know I won't be able to get as good of a yield, so on those normally we'll drop back to say 30 gallons [of N] per acre instead of 40, just depending upon the field and, you know, my knowledge of what it is capable of doing" (MI07). This dual-rate approach was used by 31 farmers in my sample. Only nine farmers discussed intentionally adjusting N rates every season, based on market price of N or corn, or other seasonal fluctuations. Most tried to keep N management practices and N rate specifically fairly consistent year to year, because they felt their strategy was successful. As one Indiana farmer put it: “We’ve kind of stumbled onto what we think works pretty well” (IN07).

Using the N application rate farmers described in interviews, average application rates across the sample and within each state for soybean-corn rotations were calculated. Farmers who varied their N rates significantly were excluded from this calculation and for the farmers who used dichotomous rates across their operation, the average of the two rates was used. Across 126 farmer interviews included in this calculation, the average application rate of N used was 173 lbs./acre. As should be expected, average N application rate varied by state: In Iowa, the average N rate was 160 lbs./acre, with a range between 120-240 lbs./acres; in Indiana, 196 with a range between 140-270; and in Michigan 163, with a range between 72-245 (See Table 1).

Table 1: Descriptive results for MRTN rate of farmers in a corn-soy rotation

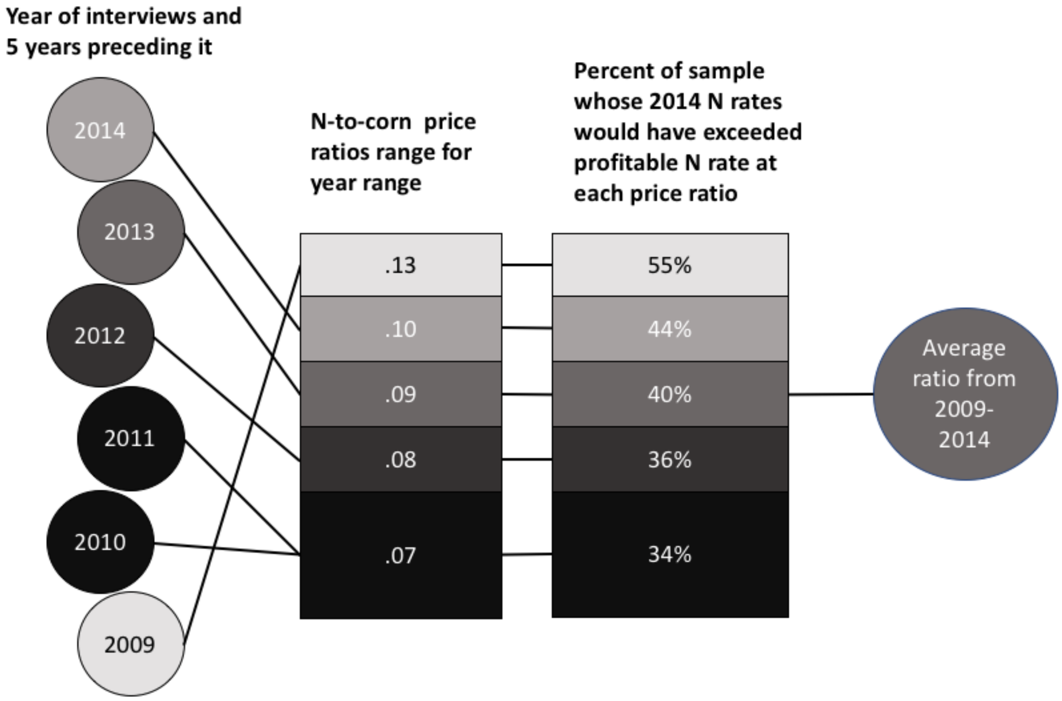
State	MRTN rate range for Corn-Soy Rotation (lbs. of N/acre)	Mean lbs. of N applied /acre	N application rate range /acre	% who applied above Corn-Soy MRTN rate	% who applied >10 lbs./acre above Corn-Soy MRTN rate	Sample Size
Indiana	192-240	196	140-270	30%	16%	43
Iowa	151-167	160	120-240	50%	24%	46
Michigan	161	163	72-245	35%	30%	43
Total Sample of Soy-Corn Farmers	NA	173	72-270	39%	24%	132

As noted above, each state and regions within it has a specific threshold rates for optimal profitable N application. Over 50% of farmers interviewed in Iowa (23 of 46) exceeded this rate. A nontrivial portion of interviewed Indiana farmers (30%) similarly reported applying N at rates that exceeded applicable profitable N rates (13 of 43[20]) for C-S rotations. Finally, this pattern continues with Michigan farmers, with over 35% (15 of 43[21]) applying in excess of profitable N rates.

Across the three states then, 51 of the 132 interviewed farmers (approximately 39%) applied N on corn following soybeans at rates that exceeded profitable 2014 N rates. Even when considering profitable N rates at the lowest N-to-corn price ratio (when profitable N rates are highest) of the 5-year period (.07), 34% of the sample (Iowa: n=19; Indiana: n=11; Michigan: n=15) exceeded profitable N rates. See Figure 2 for the percent of sampled farmers who would have "over-applied" at the N-to-corn price ratio for each of the five years between 2014-2009. Depicted in this figure, over a third of this sample would have consistently applied N above profitable rates across this five-year period if we assume consistent N use across this time. Importantly, farmers who only applied N at variable rates across their operation were included in this calculation as applying N at or below recommended levels. While research on the effects of variable rate application on N rate has not been widely conducted, it is not unreasonable to assume they applied N at recommended rates across their land, given the attention to detail and analytical sophistication it takes to use variable rate N application. This assumption is also made to ensure the most conservative estimation of the proportion of farmers who apply N above profitable threshold rates.

[20] The two Indiana farmers who applied N using a variable rate were included in this calculation as applying N below recommended levels.
[21] The four Michigan farmers who applied N using a variable rate were included in this calculation as applying N below recommended levels.

Figure 3: Summary table for N-to-corn price ratios between 2009-2014



Particularly revealing is that nearly a quarter of interviewed farmers (24%) reported rates that exceeded profitable N rate thresholds by more than 10 lbs./acre. This degree of over-application may be associated with significant profit losses. To roughly suggest the potential amount of profit loss, I assume the average acres of the farmers in this sample (approx. 1,600), the annual average price of anhydrous ammonia for 2014 and that farmers' consistently applied N at least 10 lbs./acre over profitable rates on each acre. At this acreage and excess N application level, farmers using anhydrous ammonia would have spent over $5,700 on N that likely contributed little to yield gains. Thus this figure largely represents a profit loss. This suggests not minor errors, but significant barriers to application of N at or below profitable maximum thresholds.[22]

[22] Use of a hired custom applicator was not considered in this study. It may be that a number of farmers who applied N in excess do not personally apply or determine their own N rates. This should be further considered in future research. In general, further specific consideration of these farmers who far exceeded MRTN rate is needed. Future work my benefit from specifically exploring this subsample of farmers to consider what is impacting their N use.

Following Lukes' conception of power in the third dimension—that individuals' desire to persist in a behavior can be influenced by ideological positions—I below discuss the ideological positions that discouraged farmers from desiring to reduce their N application, focusing on two that emerged as prominent themes across interviews.

Ideological barriers: The desire to maintain application of over profitable rates

The third dimensional form of power refers to mechanisms of influence that produce inaction through limiting the desire to act differently (Lukes, 1974). Suggested by this theoretical framing, farmers must first feel they can make a decision about N rates and if so, that they desire to make this decision (i.e. reduce N rates). Should either condition not be met, influence at the second dimensional form may be the exclusive way in which farmers' N management decisions are constrained. Before discussing specific ideological positions, I first offer results indicating that these two preliminary conditions exist for the majority of farmers in my sample.

Although farmers were not specifically asked if they felt they could make a decision regarding N rate, many emphasized that they could. Individualism and a sense of independence from external influence are strongly held values among US farmers (Dentzman & Jassaume, 2017; Mooney & Hunt, 1996). And in response to a question about what would prevent them from reducing N rate if they wanted to, farmers in this sample appeared to apply these values when considering their N application decision making. Farmers commonly expressed belief in their capacity to determine their N rate as they pleased. This emerged in farmers' perception that, as a number of farmers put it, "nothing" (IN40; IA16; MI33) would constrain their capacity to reduce N rates. One exchange between an interviewer and an Indiana farmer is particularly illustrative of the independence in N rate decision making that many farmers felt. The farmer first responded by repeating the question back seemingly in confusion:

> IN05: If I wanted to apply less fertilizer what would stop me from applying less?
>
> Interviewer: Yeah, [the question is] trying to get a sense of things that may constrain that decision for you.
>
> IN05: [pause] I'm not completely sure what the question is, because if I want to apply… The thing about being a farmer, you're so damn independent that 'hey, know what? I don't want to apply that much fertilizer, guess what?' I push the button and I'm simply not applying that much fertilizer.

Others similarly commented: **"**I don't know that anything would stop us from [reducing N rate]" (IN35) or, "I don't think anything [would]" (MI50). As these comments suggest, farmers felt that they could make a decision regarding their N application rate. This conclusion is further supported by the number of farmers who expressed lack of desire to reduce N rate as a primary barrier (see below), which conceptually indicates that N application rate is in the realm of decision making.

N application rate is perceived then to be a realm in which a decision can be made, but whether farmers desire to reduce N application rates is another question all together. Farmers' attitudes regarding their desire to reduce N application rate are reflected in their comments on the potential impact of reducing N rate on their yield. In response to what might prevent them from reducing N rate if they wanted to, nearly every interviewed farmer emphasized yield impacts, believing that any reduction in N rate would lead to yield and thus profit loss. As farmers believed reduced N rates would lead to yield loss, it was not that they could not reduce N rate, but that they did not desire to reduce their N rate. For instance, the farmer who above commented that, "I push the button and I'm simply not applying that much fertilizer," immediately followed up this statement with one indicating that he did not desire to reduce N rates: “However, I would just hesitate… I would hesitate to lower our fertilizer application… I’m going to say across the board with P K and nitrogen […] I reeeaaally am hesitant to lower our application rate because of a yield loss” (IN05).

Table 2: Yield loss as indicator of farmers’ perception of their minimal application

Responses to the question: What would stop you from reducing N rates?

Farmers’ Applying at Recommended Rates	*Farmers’ Applying Above Profitable Rates*
“Um…yeah, lower yields. Less revenue” (IA10).	“Lack of yield; lack of income” (IN46).
“I’d say that they big thing is profitability. I just feel like that right amount is used to get maximum profitability out of it” (IN1).	“If you’re short of nitrogen you’re going to hurt your yield. You can cheat the others a bit but not the nitrogen” (MI47).
“You know, you try and run that fine line of just the right amount of fertilizer to get your yield” (MI11).	“Concern about dropping our economics enough; sacrificing net profit” (IA14).

Importantly, while many farmers mentioned “yield loss” as the barrier, when probed they emphasized that what they meant was profit loss, using the two concepts interchangeably. As one farmer clarified: “Reduction in yield. Well, let me rephrase that, reductions in income. What’s the net” (IA33). Another confirmed this: “[We’re not] necessarily going for the top yields, but it’s going for the top economic yields” (IA08). Maximum economic yields, not absolutely maximum yields, were what farmers were concerned about dropping if N rates decreased.

Farmers’ position that reducing N rate will reduce profitability via yield reductions is not necessarily wrong (Robertson & Vitousek, 2009). However, for farmers who were exceeding profitable rate thresholds in their application rate, it is likely in their financial interest to reduce N rates. MRTN profit threshold rates are based on enabling the most profitable production given corn and N prices. N applied above these profit thresholds does not contribute to economically profitably yield gains. Exceeding profitable MRTN rates is then defined by reduction in profits.

Despite this, farmers who applied above their state's profitable N rate still deeply believed that their rates were the minimal allowable without sacrificing profits (as is indicated by comments in the right column of Table 1.). In consequence, they did not desire to reduce their high N application rates. This lack of desire despite high N rates is most dramatically illustrated by one Indiana farmer's comment. This farmer applied N on a C-S rotation at 210 lbs./acre, exceeding the profitable rate threshold for his region in Indiana by 13 lbs. However, he commented that the only way he would reduce N rates would be if he could no longer afford to buy N:

> IN43: I guess if things got bad enough that you couldn't finance it would be the thing, and they would have to be, I mean, pretty bad before you'd have that happen. Because I'd cut [Phosphorus] and [Potassium] before I cut nitrogen […] that would be kind of a last resort, and if that was the case you might even see a for sale sign out front.
>
> Interview: So not a realistic thing?
>
> IN43: No, it's not really going to happen.

Though far exceeding the profitable rate, this farmer expressed that he would only reduce his N rate if he could no longer afford to purchase N; indicating he perceived his current *high* application rate to be appropriate given profit concerns. While this farmer's assertion was particularly strong, it must be noted that among farmers in my sample who applied above recommended rates, none expressed the opinion that reducing their N rates would be in their financial interest. Rather, almost all believed just the opposite.

As this suggest, farmers in this sample appear to not necessarily be strictly rationally pursuing maximum profits. The implicit or explicit assumption of much of the literature discussing agricultural practice adoption is that practices or management strategies with environmental benefits will be adopted by farmers if these practices save farmers money or increase their net profits (e.g. Millar et al., 2010; Weber & McCann, 2015). Given the results presented in this section, it appears that the rational calculation of the monetary cost-benefits to achieve maximum profitability may not be the primary factor influencing farmers' decision making. This decision making process may be obscured or influenced by a more complicated set of factors than has been previously considered then. Below, I focus on examing one dimension of this more complicated set of factors: How farmers' ideological positions reflecting social contexts influenced their N application rate decisions.

Ideological positions constraining desire to reduce N application rate

Given the nature of profitable MRTN rates, how can farmers who exceed or far exceed these rates perceive their application of N to be appropriate or minimal given profit concerns? Lukes theorizes that lack of desire to change behaviors can be a function of individuals' ideological positions, which emerge from social context. In line with this theory, I describe two ideological positions that emerged as themes in farmer interviews: 1) The Free-Market Ideology and 2) Instrumental Rationality (Weber, 1978). These features were selected because farmers commonly expressed these positions to justify the perceived appropriateness of their high N rates and, in this way, these ideological positions at least in part produced the lack of desire to reduce N rates that exceeded maximum profit thresholds. Importantly, unless otherwise noted, all included quotes in the below sections are sourced from farmers who were identified to be applying N in excess of their state's profitable N rate.

The free market ideology

The capitalist "free" market is argued to be fundamentally self-correcting. This is most famously expressed by Adam Smith (1776), the founder of modern capitalist economic theory, in his argument that the ‘invisible hand’ of the market would guide self-interested profit seeking behavior to address numerous social-economic issues (Shrivastava, 1995). This self-correcting nature of the market has been argued to be a fundamental ideological element of the capitalist socio-economic system (Gladwin, Newburry, & Reiskin, 1997) and, when applied to environmental issues, has been referred to as the “free-market ideology” (Heath & Gifford, 2006). In this context, the free-market ideology, when held by individuals, is argued to both discourage acknowledgement of environmental degradation caused by capitalist production[23] and if it is acknowledged, to indicate that environmental degradation is solvable and indeed being solved through price mechanisms that increase the costs of undertaking environmentally harmful activities (Shrivastava, 1995).[24]

Likely reflecting its ubiquity in the broader social-system, the free-market ideology appeared to be commonly held by interviewed farmers’ and influential on their desire to reduce their N application rates. Comments indicating this influence emerged in response to questions about the environmental issues associated with N use. While few farmers in this sample believed in humans’ contribution to climate change (see Stuart [2018] for a full discussion), let alone knew that N use was related to N_2O and thus a greenhouse gas, most acknowledged that water pollution issues like hypoxia in the Gulf of Mexico were related to N use. However, many farmers who were aware of the connection between N use and water pollution believed that agriculture could not a primary contributor to these issues because they believed the price mechanisms of the marketplace dictated minimal or appropriate N application rates. N, though

[23] See particularly McCright & Dunlap’s (2010) anti-reflexivity argument for evidence that conservatives defend the free-market ideology in part through attacking the claims of that it is causing environmental degradation, i.e. climate change.

[24] While Ecological Modernization Theory could be accused of suggesting this, for the most part their work indicates state intervention to encourage price adjustment and green technology development, rather than correction through the “free” market proper (e.g. Jänicke & Jacob, 2004; Mol & Spaargaren, 2002).

inexpensive relative to corn at this time, is still a significant input cost to farmers. This cost, farmers argued, meant that they needed to apply N at minimal rates considering maximum profit potential. In this way, the price mechanisms of the "market" was thought to dictate economically *and* environmentally efficient N rates and thus to have solved or prevented the environmental issues. Farmers specifically argued that the price mechanisms of the market were already dictating minimally profitable application rates. This sentiment is expressed well by one Iowa farmer, who despite apply 9 lbs./acre over profitable rates, strongly believed that the price mechanisms of the market dictated the application of N at minimal rates: "So [I'm] not over applying [N…] now financially it's become necessary to make those applications precise because the inputs are so expensive" (IA38). Reflecting the free-market ideology, this farmer believed that the price-mechanisms of the market meant that the profit seeking behavior would lead farmers to necessarily apply N only at maximally profitable rates and not over them. In spite of this view, he was himself exceeding these rates. Other farmers who exceed profitable rates similarly expressed the opinion that the price mechanisms of the market were dictating minimally profitable N application rates (see Table 3).

Table 3: Farmers who applied N above profitable rates commenting on the role of the market in dictating minimal N rates
"And like I said, the fertilizer and seed is so expensive that, you know, we don't want to… We're not out here… This isn't a charity, we want to make money, you know, we don't have unlimited resources to throw out there, we just want to, you know, get the bang for our buck so to speak" (MI17). "I mean fertilizer is too expensive to just throw in the ground pointlessly" (MI10) "If it leaves your field, then you've thrown money away. I think we get blamed for it, but the motivation would be to keep what you put on. No one is out there putting [N] on hoping that it goes away. You spent money on it. You buy it hoping it ends up in a lake somewhere? It's counter-intuitive. It doesn't make any sense. The perception is that they're just out here putting fertilizer on willy nilly and I do not believe that to be the case at all" (IA62).

Table 3 (cont'd).
"I tend to stick pretty close to yield goals with nitrogen application. Cause it's a huge expense" (IA64).

Factors other than the free-market ideology may be influencing these farmers' perceptions of their N application rate. It is possible that many of these farmers are using older measure of "efficient" N application rates, like yield goal maximization ratios. Others might not be examining what is a profitable N application rate, developing a high level of comfort with their unprofitable (though not disastrously so) rates. This argument is suggested by the fact that no farmers who over-applied reported using aids, like Tissue Tests or Pre-Sidedress Nitrate Tests (PSNT), to determine the appropriateness of their N rates. While these processes may be important drivers of over-application, they do not directly counter the causal role of the free-market ideology argued here. Given the above evidence showing that farmers defend the appropriateness of their high N application rates through reference to the price mechanism of the market, it appears that the free-market ideology has at least of partial role in explaining farmers' resistance to reducing their high N rates, alongside these other potential drivers. Indeed, through leading to the assumption that over-spending is not occurring, the free-market ideology may actually discourage farmers from critically considering the profitability of their N use and in this way encourage farmers to develop a 'comfort' that discourages the desire to reduce N rates to economically and environmentally efficient rates. This possibility of an indirect relationship should be further explored in future studies.

Whether a direct or indirect cause, the free-market ideology appears to contribute to farmers' lack of desire to reduce their high N rates. My results indicate that the expression of this ideology was used by farmers to indicate how the market dictated the application of N at absolutely minimally profitably rates, even when the farmer applied above profitable rates. In this way, the free-market ideological position constrains farmers' decisions in the third dimension of power.

Instrumental rationality and increased rates

Gunderson (2015), pulling from the significant body of work of the Frankfurt School (e.g. Horkheimer, 1947) argues that "instrumental rationality" is a particular form as reason that undergirds human-environmental interaction in contemporary capitalist society. Reflecting Weber's (1978) original use of the concept, Gunderson argues that achieving an end in the most efficient way possible is the orienting maxim of this rationality, with an end being defined as reasonable to pursue only when maximizing the self-interest of the individual. Within capitalism, this self-interest is most often defined by the economic considerations of profitability. Thus, within this rationality the 'efficiency' of a means to achieve this end is judged solely in terms of a monetary cost-benefit ratio. By prioritizing profitability as the indicator of rational behavior, instrumental rationality justifies the environmental consequences of profit-seeking behavior through neglecting it as a realm of consideration in means-end decision making. In other words, through the lens of instrumental rationality, actions undertaken to increase profitability, even at the expense of environmental degradation, will be justifiable as the environmental costs are entirely neglected or only secondarily considered.

Gunderson (2015, p. 228-229) suggests that instrumental rationality be used as an "ideological variable" to examine "human-nature relations," and he argues that it is widespread across society, including in the agricultural sector: "Nearly every institutional- and individual-level cause of environmental harm – capitalist production, distribution, and consumption, extractive industries, industrial agriculture, transportation, etc. – is guided by instrumental rationality." Instrumental rationality is therefore thought to be a prominent (if not *the* prominent) ideological position in the capitalist society and thus likely available to the farmers acting within it.

Instrumental rationality appears to be an ideological position held by farmers and influential on their desire to reduce N application rates. The above farmers did not desire to reduce N rate because they felt they were applying at the minimum already, following the logic of free-market ideology. Farmers expressing instrumental rationality believed their N rates were appropriate for distinct reasons. A portion of farmers expressing this ideological position did not desire to reduce their N rates because they desired to increase them. While MRTN profit thresholds reflect maximum profitable levels, minor yield increases may be achieved by higher than profitable application rates. Likely reflecting this relationship, farmers believed increased N rates would enable greater profits and expansion of production: "It seems like [more N is] the most controllable and readily available way for the farmer to boost yield" (IA13). As predicted by Gunderson (2015), the undertaking of this action to increase production was done with little consideration of the environmental costs. One Indiana farmer's comment colorfully illustrates this:

> "My personal opinion is, since 2008 everything changed as far as the farm, because 2008 is when we went from consistently selling 2$ or $2.50 corn to consistently selling $5 corn. At that time, we went from being a farm to a business, and when you're talking five-dollar corn, you can't dicker around and short yourself on nitrogen. I know a lot of these people think they're going to save their way to prosperity and that's bull crap… Anyway, we don't screw around with nitrogen. We, a lot of times, we'll wind up with

> 200 or 250 pounds of nitrogen, and if I mention that to some people they go crazy and they want to call the cops on me, you know, or like the nitrogen police or something" (IN15).

Indiana's average profitable rate threshold for this farmers' region was 192 lbs./acre for corn-soy rotations between the years of 2009-2014. In 2014, this farmer exceeded this by up to 58 lbs./acre. And while he was already far in excess of maximum profitable rates, the desire to expand production and earn greater profits had lead him to increase rates in an attempt to ramp up yields. While he was clearly aware that some concerns exist regarding high N rates—"nitrogen police"—he ultimately found this issue wanting in merit compared to the desire to expand production. In this way, his comment illustrates the role of instrumental rationality in constraining desire to reduce high N rates through justifying profit seeking as the sole rational end to pursue. Others similarly saw increased N rates as a means to increase yield, and thus did not desire to reduce N rates:

> "…Last year we had our best corn ever putting 150 pounds of nitrogen down. We averaged over 180 bushel an acre of corn. And this year wanted to see if perfect storm and every lines up again, was nitrogen the determining factor from getting us higher? So bumped [our N rate] up there. We bought our urea really early at a really good price, cheaper than what it is today as a matter of fact. So when we did that we said we want to make sure that's not our limiting factor on yield, we're not skimping it too much on corn" (MI20).

And some explicitly illustrated the secondary concern of the environmental costs of high N rates, as compared to the perceived financial benefits: "This is an age-old question [about] nitrogen. 'Are we getting too much [N] in the Gulf of Mexico because we're putting too much on? Blah,

blah, blah.' And every time I've thought: 'You know I can cut this back 10, 15 pounds and acre,' [but] *before the year is over with I'm wishing I hadn't*. It shows up," meaning in his profits ([emphasis added]; IN30).

As these comments reveal, instrumental rationality's prioritization of profitability undergirds farmers' decisions to apply N at higher rates in efforts to expand production and achieve high profits (i.e. growth). In this way, the desire to reduce N rates is constrained by this ideological position justifying and prioritizing the pursuit of further growth. This position is reflected in a number of interviewed farmers' comments showing increased N rates and desire to use them to increase yield (see Table 4).

Table 4: Farmer comments illustrating profit seeking behavior encouraging higher N rates
"Is there much interest in trying to cut nitrogen fertilizer rates? Because I'm wanting to put on more. 200, 220, 240 is not out of line when I'm raising 200-bushel corn" (IN14). "I've been increasing [N rate] a little bit the last couple years" (IA48). "Our demand [for N] is going to be where we have to have these higher yields. Well, you're not going to be cutting drastically back on the fertility end of it and your yields keep going up; it won't work. We've seen that in the past with our fathers and stuff, when they didn't put on as much material they didn't get the end result, so the economics still work the same way" (IN11). "If you have an ideal spring and you decide you're gonna apply 160 pounds of nitrogen or whatever and the spring looks excellent. And the crop comes up out of the ground and everything is looking very good, I would probably say there is more yield potential here than what I was planning on. I would probably apply a sidedress application [of more N]. I did that this year" (IA65). "And our goal is 200 plus corn. We plant 37,000 [corn] population, so we're looking for good yields (as justification for high N rate)" (IA40). "Sometimes that little bit of extra nitrogen may or may not get you more yield and a year that we have 6.50 or 7-dollar corn we'll go ahead and dump it on for the safety factor" (IN19).

Instrumental rationality and insurance N

The ideological position of instrumental rationality constrained farmers' desire to reduce their N application rate in one other way. A number of farmers sought to reduce the chances they would have low yields/profits through intentional application of N at rates that exceeded crop demand and MRTN rates. "Insurance" N use denotes the intentional use of high N application rates to bolster yields in the face of seasonal environmental variabilities and thereby ensure that while some N may be wasted, crop yields will be maximized over the course of the growing season in the face of good or bad growing conditions (Babcock, 1992; Sheriff, 2005; Stuart et al., 2012). The use of insurance N application was acknowledged by a number of farmers who applied N above maximum profitable-rates in this sample. Farmers commented that "a little extra N" could both prevent yield and profit loss due to poor seasonal conditions and ensure that during the occasionally growing season that ideal conditions occurred, yields and profits would be maximized. One Indiana farmer put it simply: "It's a type of insurance" (IN03). Additional comments reflecting the intentional use of insurance N are displayed in Table 5.

Table 5: Farmers illustrating the use of "insurance" N application rates to promote yield maximization
"Boy you can really lose a lot of yield fast if that corn goes short on nitrogen, you know. Especially when you come through this high priced corn period, relative to nitrogen, it didn't matter. That's 8-dollar corn. Or even 6-7-dollar corn. Boy, if you lose twenty bushels if you didn't have enough nitrogen that is huge. That is in the back of every farmer's mind" (IA02).
"The uncertainty and the reduction in the yield would be the only thing [stopping me from reducing N rates]. If you were gonna tell me that I needed to cut 50 pounds of nitrogen you'd have to prove it to me that you could do it on a more than one-year basis because there is flukes when the weather is just perfect, yes you could" (MI45).

Table 5 (cont'd).
"If I wanted to apply less? Oh…I guess possibly the fear of not having enough. Not maximizing the potential of your crop […] you hate to give up the potential of [yield]…that's what tends to make you vulnerable. You go 55 gallons [of N] instead of 52, you think, 'Oh it's pretty nice, maybe I ought to put a little more on.' Everyone, I don't think that's any different. I was gonna say someone doing their yard. They think well I better put just a little more stuff on" (IN02).

These comments suggest that the over-application of N to ensure maximum yields given variable seasonal conditions is intentionally undertaken by some farmers, in this case by those who applied above profitable rates. Importantly, while farmers' recognized that they were using insurance N rates, and thus wasting some N as well as contributing to increased levels of N pollution, none expressed the opinion that they felt like they could reduce their current N rates (as noted above). This suggests that excess N, in this way, is 'minimal' N to these farmers, as application below 'insurance' rates are perceived to put them at risk for the more serious economic consequence of not maximizing seasonal yields. And even though they are likely consistently losing some profits through over-application of N, the financial benefits of yield gains versus minor profit losses from overuse of N lead this to be a reasonable decision given instrumental rationality: "We may over apply a little bit more than necessary, but a year like this it's better to do it than not do it" (IA34).

As this discussion suggests, insurance N application is not about profit maximization, but it still reflects the ideological position of instrumental rationality. Instrumental rationality, as used here, is about achieving production goals in the most efficient way with little consideration of environmental effects. Farmers undertaking this activity focused on the financial security of consistent yields that insurance N provided then, and indicated by the lack of comments on the issue, not on the environmental costs associated with their intentionally high N rates. This emphasis on profits in practice-use consideration, rather than environmental costs, is reflected in other recent work related to farmer decision making (e.g. Roesch-McNally et al., 2017). Importantly, farmers' individual risk preferences may be at least in-part motivating the use insurance N rates (Daberkow & McBride, 2003). However, that it is a relatively unquestioned practice to ensure economic success knowingly at the expense of environmental outcomes is a function of instrumental rationality. In consequence, the ideology of instrumental rationality may be but one of many factors that are likely conjointly driving farmers' to intentionally practice insurance applications.

Across this second half of the analysis then, I suggest that instrumental rationality is the ideological position behind a number of farmers' practice adoption decisions examined across this literature. Related specifically to N rate decisions, this ideological position limits farmers' desire to reduce high N application rates in two ways: for some farmers, the position encouraged increased N rates, rather than reduction of currently high; for others, consistent though not maximum profitably via over application was perceived as justifiable and thus not desirable to change given prioritization of (consistent) profits over the environmental costs of this practice.

DISCUSSION

At the beginning of this article, I justified my exploration of the ideological barriers to reducing N application rates of Midwestern corn farmers through reference to Arbuckle and Rosman's (2014) comment that overuse of N fertilizer may be becoming 'normalized' among farmers. My data presented above confirms and build on this hypothesis in a number of ways.

First, through analysis of Indiana, Iowa and Michigan farmers' reported N application rates on C-S rotations, I show that a substantial proportion of interviewed farmers (51 of the 132) applied N on corn following soybeans at rates that exceeded profitable thresholds for their states. As these thresholds are defined by profitable levels of N application, these results indicate that approximately 39% of farmers in this sample applied N at rates that exceeded maximum profitable levels. These rates thus cut into farmers' profitability and unnecessarily contributed to environmental pollution of multiple forms (Millar et al., 2010). While studies have suggested that farmers are over-applying N for a number of reasons (Babcock, 1992; Sheriff, 2005; Stuart et al., 2012), few have actually empirically demonstrated this (Arbuckle & Rosman, 2014; see Ribaudo et al., [2011], [2012] as exceptions). Importantly, the percent of farmers found to be exceeding rates in this sample may be inflated compared to other years. As indicated by a number of comments, corn prices were high in the spring of 2014, the time period that most interviews took place. Past work has demonstrated that N rates increase when the N-to-corn price ratio is highly in corn's favor (Ribaudo et al., 2012). This may suggest that this large portion of farmers' exceeding N rates is a result of particular temporally defined circumstances; though the results displayed in Figure 2 above indicate that a substantial portion (>30%) of this sample would have over-applied at any price-ratio between 2009-2014.

Lukes' (1974) work suggest that constraint of individuals' behavior occurs not only through processes that materially limit the capacity to act, but through ideological factors that reduce the desire to behavior differently. Building on Lukes' insight, this study revealed how ideological positions reduced farmers' desire to lower their high N application rates, and in this way constrained their behavior. While many farmers were found to be applying N above recommended rates, farmers in this sample felt that how much N to apply was their decision to make. However, none, even those that were found to be applying at rates that cut into their profitability, wished to reduce their N application rate. My interpretation suggests that alongside factors such as risk preferences or alternative understanding of profitable N use, at least two ideological positions reduce farmers' desire to lower their application rates: free-market ideology and instrumental rationality.

Many who were found to be applying N above recommended profitable rates argued their N rates were necessarily only as high as would produce a profitable yield return. They justified this position through the free-market ideology, claiming that because the free-market demands economically rational use of N, that farmers, including themselves, could not be applying N at rates that exceeded maximum profitable thresholds. As they believed themselves to already be applying minimally given this market logic, this ideological position reduced farmers' desire to lower their high N application rate. In many ways, this result reflects past work examining the effect of this ideological position. High levels of belief in the "free-market ideology" has been found to reduce belief in humans' contribution to environmental issues and in this way discourages the desire to act to address them (Heath & Gifford, 2006). As noted above, this position likely affects farmers' perceptions of their N rate indirectly, through discouraging the use of tools or technologies that would enable a critical consideration of the profitability of their N rates.

The second ideological position discussed was instrumental rationality. Instrumental rationality reduced farmers' desire to lower their high N application rate by justifying (1) further increases of N rate in search of expanded production and (2) making 'insurance' N applications appear as a reasonable practice to consistently undertake. In both cases, concern for profits over environmental well-being is the foundational motivation, as high rates in both cases are justified in that they either strive to achieve higher profitability through increasing yields or they ensure (i.e. "insure") consistent profits given seasonal variations in weather. Consideration of a behavior only in terms of its profitability is reasonable when judged through this ideological positions foundational maxim: "meeting an arbitrary goal (usually profit-maximization) through the most suitable (efficient) means available" (Gunderson, 2015, p. 228). Distinct from the above farmers who defended their N application as being absolutely minimal given profit concerns, farmers who justified their current rates through instrumental rationality did not claim to be at the bare minimum of application. Rather, they did not desire to reduce their high application rates because they perceived them to be appropriate given the economic benefits they provided (expansion of production or risk reduction). Half of the Iowa farmers surveyed by Arbuckle and Rosman's (2014) believed farmers over applied N, and it may be in reference to this grouping of farmers in particular that this attitude emerged.

Both of these ideological positions are thought to reflect and emerge from the broader ideological structure of the capitalist economy and agricultural production system within it (Gladwin, Newburry, & Reiskin, 1997; Gunderson, 2015). These results therefore suggest how this structural context influences individual-level behavior through social-psychological means. By focusing on how desire to act is constrained by ideological positions, this study contributes to the small, but growing body of literature dealing with constraints to farmers' behaviors at the third dimension of power (Ellis, 2013; Emery, 2015; Dentzman et al., 2016; Dentzman & Jussaume, 2017). Like much of this prior work, my findings revealed how ideological elements of the agricultural system, and the broader capitalist socio-economic system in which it is embedded, are held by farmers and influential in what practices they actively desire to undertake. Unlike this prior literature, my findings reveal how ideological positions can reduce desire to undertake behaviors that are in the immediate economic interest of farmers. Applying N at or below maximum MRTN thresholds is argued to be the most profitable strategy for farmers to pursue regarding their N rate decisions. My results indicate that ideological positions may influence how farmers' perceive their N rates, discouraging them from even trying to apply N at or below this recommended and most profitable level.

In this analysis, I have focused on ideological positions and constraint at the third dimension of power. However, I believe this to be a preliminary barrier maintaining farmers' high N rates. Beyond desire is actual capacity and how farmers' capacity to act is limited by their material circumstances (i.e. the second dimension of power) cannot be understated. Even if many farmers wished to reduce their high N rates, past work has shown the significance of factors like seed-company monopolization on dictating higher N rates for Midwestern corn farmers (Stuart & Houser, 2018). I see these constraining mechanisms, the ideological and the material, as deeply connected. Swidler (1986, p. 277) argues that through endowing cultural capacities (i.e. "cultural toolkit") for particular sets or types of behaviors, material circumstances shape what behaviors individual's desire to undertake: "people will come to value ends for which their cultural equipment is well suited" (citing Mancini, 1980). Following Swidler, it may be that the material effects of the political economy of agriculture revealed in past literature limit what N application rate behaviors farmers are capable of undertaking. In order to maintain a sense of autonomy within this constrained circumstance, which past work has shown to be extremely important value for farmers (Emery, 2015; Mooney & Hunt, 1996; Stuart & Houser, 2018), farmers justify the maintenance of their behaviors through the above identified ideological positions, even to themselves. This argument does not negate the significance of ideology or influence on farmers' behavior at the third dimension. Farmers will first need to desire to reduce their N application rates before they begin to confront material political-economic barriers. The ideological positions identified here constrain farmers from desiring to do so. Future work would benefit from continuing to explore constraints to farmers' behavior at both the second and third dimensions of influence. In this way, the material and ideological forces that influence human-nature relations within modern capitalism could be better understood, thus addressing a key under-examined topic in the environmental sociology literature (Gunderson, 2015).

CONCLUSION

This study found that a significant number of farmers applied N above profitable N rates in their state. The significant number of farmers exceeding profitable N application rates indicates that inefficient N use is not another example of a behavior causing environmental degradation that fits neatly into the 'tragedy of the commons' model (Hardin, 1968). This model suggests that environmental degradation of common pool resources (e.g. Gulf of Mexico or Climate in this case) is a function of the aggregate effect of individuals undertaking environmentally degrading activities in order to maximize their individual economic outcomes (Hardin, 1968). N use, particularly related to N rate, is a key source of degradation, and it is certainly used by farmers to gain individual profits. But, the proportion of farmers who applied N at rates that exceeded MRTN proftable thresholds (and therefore reduced their profits) suggests that absolute profit maximization is not the only driving factor of farmers' N rate. A more complicated set of factors than exclusively profit-maximization may then explain application in excess of recommended rates.

I focused on offering a preliminary explanation into how factors at the third dimension of power in part contribute to high N application rates in the Midwestern corn agricultural system (Lukes, 1974). Through this focus, this study revealed that the ideological positions of "free-market ideology" and "instrumental rationality" lead farmers to perceive their high N rates as justified and thus acted as a barrier to reducing N application rate through constraining the development of the desire to do so. Practically, this finding suggests that outreach encouraging farmers to apply N at MRTN rates will preliminary encounter the barrier of the perceived appropriateness of farmers' current high rates. Developing strategies that specifically address this barrier and counter the reinforcing effects of theses ideological positions may be a key step forward in reducing environmental issues associated with agricultural N use while maintaining the profits and productivity of farmers. As this study examined farmers who were over-apply N, it necessary neglected the smaller number of farmers who were apply N at appropriates or wished to reduce their high N rate, but felt they could not. Future analysis focusing on farmers who apply N at or below MRTN rates may reveal the characteristics and circumstances that motivate (or enable) farmers to reduce their N application rate. Importantly, suggested by this even though farmers' N management decisions are influenced by structural circumstances and the ideological positions that emerge from them, the potential for individual to overcome these constraining factors clearly exists. More work should address both structure and agency in the future.

APPENDICES

Appendix A: Sampling approach

The approach varied some for each state. In Iowa, 53 was the final sample size. Contacts were generated through relevant organizations, such as a program run by Iowa State University Extension[25] (≈23% of the sample) county Soil and Water Conservation District offices (≈23%) Practical Farmers of Iowa (≈6%) at events, such as field days (≈4%), but largely through snowball sampling (≈45%). Interviews took place across 27 of the 99 counties in Iowa. In Indiana, 51 was the final sample size. Purdue University Extension was the primary source of the contacts (≈59%), followed by those obtained through snowball sampling (≈33%) and via other relevant organizations, such as the Indiana Soybean Association (≈4%) and county Soil and Water Conservation district offices (≈4%). Interviews in Indiana took place across 23 counties. Consideration for counties to gather interview contacts from was limited to 82 counties, after nine[26] counties from Indiana were eliminated from consideration due to their proximity to metropolitan areas and low amount of corn planted. Consequently, interviews covered 28% of included counties in Indiana. In Michigan, 50 was the final sample size. Snowball sampling was not as successful in Michigan and most of the contacts were made through MSU Extension (64%). Snowball sampling was used to generate the majority of the remaining contacts (24%), with some additional contacts made through lists of Michigan Agriculture Environmental Assurance Program (MAEAP) participants (12%). Interviews took place across 17 of the 83 counties in Michigan. It should be noted that these counties accounted for 42% of Michigan's total planted corn acres in 2014 (NASS, 2015). Across all three states, 48% (N=74) of farmers were contacted through extension, 34% (N=53) through snowball sampling, 13% (N=20) through state or federal conservation offices or programs (MAEP/Soil and Water Conservation)

[25] (http://www.extension.iastate.edu/ilf/page/partners)
[26] The nine counties are: Marion, Dearborn, Ohio, Franklin, Switzerland, Monroe, Clark, Scott, Jefferson.

and 5% (N=7) were contacted through various other relevant sources (Soybean Association, Practical Farmers and Field Days).

Interviews were conducted between May and December 2014 in the three states. Matt Houser conducted all interviews in Indiana, Riva Denny all interviews in Iowa, and Adam 60% of interviews in Michigan, with Matt and Riva splitting the remaining interviews. The majority of interviews were conducted in person on-farm, with a small number conducted over the phone. All interviews were audio recorded with the permission of participants. Interview recordings were transcribed verbatim by Matt and Riva through the first half of 2015. Respondent's average farm size ranged by state. In Iowa, farm sizes ranged from 170 to 5,000 acres, with an average size of 1,236 acres. In Indiana, farm sizes ranged from 200 to 9,000 acres,[27] with an average size of 2,216 acres. In Michigan, farm sizes ranged from 200 to 4,500 acres, with an average farm size of 1,529 acres.

We utilized a structured interview guide that included prompts and opportunities for open-ended responses on defined topics. We asked participants to provide some basic information about their farm operations and use of nitrogen fertilizers. In addition, we asked farmers about their use of nitrogen efficiency practices (similar to the practices included on the descriptive survey), as well as sources of information about nitrogen fertilizers, influence of policy and market drivers, and the influence of private companies. Lastly, we asked participants about their perceptions of environmental problems related to use of nitrogen fertilizers and views of climate change. The shortest interview was done in Michigan, lasting 22 minutes, the longest at 2.5 hours in Iowa. The recruitment methods we used to generate interview contacts could be a source of bias in our data. In Michigan and Indiana, interview contacts were largely made

[27] This latter number includes only acres farmed in Indiana—5,000 more acres of cropland were operated on in Mississippi by this farmer.

through MSU and Purdue University Extension. Data from our study and others indicate that extension is not the most common source of information on nitrogen management for farmers. Those farmers who have relationships with extension educators are potentially different from those who do not, especially in their N management practices. A number of farmers in Michigan were also recruited through an environmental stewardship program and may not be very representative of the typical Michigan corn grower.

Appendix B: Example MRTN rates

Figure 4: Example MRTN rates from Sawyer et al. (2006)

Table 5. For CC, the MRTN and profitable N rate range within $1.00/acre of the maximum return for several N:corn grain price ratios (nonresponsive sites not included).

	MRTN			LOW**		HIGH**	
Price Ratio*	N Rate	Net	Yield	N Rate	Yield	N Rate	Yield
$/lb:$/bu	lb N/acre	$/acre	bu/acre	lb N/acre	bu/acre	lb N/acre	bu/acre
Illinois							
0.05	213	156.32	154	184	152	239	155
0.10	176	135.19	152	156	149	199	154
0.15	154	117.08	149	136	146	174	151
0.20	137	101.09	146	122	142	154	149
Iowa							
0.05	200	158.98	144	179	142	234	145
0.10	174	138.36	142	153	139	196	143
0.15	152	120.53	139	138	136	171	141
0.20	140	104.34	137	125	133	156	139
Minnesota							
0.05	148	129.66	153	133	151	168	153
0.10	136	114.09	152	123	150	150	153
0.15	126	99.69	151	114	148	139	152
0.20	118	86.23	149	103	146	131	151
Wisconsin							
0.05	165	105.61	165	140	164	197	166
0.10	139	89.21	164	124	162	157	165
0.15	127	74.62	162	111	159	141	164
0.20	112	61.38	159	97	156	129	162

*Corn grain price held constant at $2.20/bu; N prices at $0.11, $0.22, $0.33, and $0.44/lb N.
**LOW and HIGH approximates the range within $1.00/acre of the MRTN for each price ratio.

Figure 5: Example MRTN rates from Millar et al. (2010)

State	System	PNRR *low*[A]	PNRR *high*[A]	Linear (Tier 1)		Non-linear (Tier 2)	
		N rate ($kg\ N ha^{-1}$)		N_2O reductions[B] ($kg\ N_2O\ ha^{-1} yr^{-1}$)	CO_2e reductions[C] ($Mg\ CO_2\ ha^{-1} yr^{-1}$)	N_2O reductions[B] ($kg\ N_2O\ ha^{-1} yr^{-1}$)	CO_2e reductions[C] ($Mg\ CO_2\ ha^{-1} yr^{-1}$)
Iowa	C-C	184	212	0.44	0.13	2.63	0.78
Illinois[D]	C-C	185	217	0.51	0.15	3.12	0.93
Minnesota	C-C	152	173	0.32	0.09	1.46	0.44
Ohio	C-C	206	237	0.48	0.14	3.36	1.00
Wisconsin[E]	C-C	145	166	0.33	0.10	1.46	0.44
Iowa	C-S	128	155	0.42	0.13	1.66	0.49
Illinois[D]	C-S	174	205	0.49	0.15	2.77	0.83
Indiana[F]	C-S	180	207	0.42	0.13	2.45	0.73
Michigan[F]	C-S	135	160	0.41	0.12	1.67	0.50
Minnesota	C-S	110	133	0.37	0.11	1.25	0.37
Ohio	C-S	180	212	0.49	0.15	2.91	0.87
Wisconsin[E]	C-S	113	137	0.37	0.11	1.28	0.38

[A] The *high* and *low* Profitable Nitrogen Rate Range (PNRR) values for each system in each state are the fertilizer N rates that provide a net economic return to N of \$1.00 $acre^{-1}$ (\$0.40 ha^{-1}) above *(high)* and below *(low)* the maximum return to N (MRTN) fertilizer rate

[B] N_2O and CO_2e reductions calculated using Eqs. 1 and 2 with EF_1 default value of 0.01 (see text)

[C] N_2O and CO_2e reductions calculated using Eqs. 1 and 2 with EF_2 regional value of $0.012 \times \exp[0.00475 \times (F_{SN}+F_{ON})]$ (see text)

[D] Data for Central region of Illinois

[E] Data for high to very high yield potential soils in Wisconsin

[F] Data for corn–soybean rotation only in Indiana and Michigan

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CHAPTER III— How the Political Economy of Agriculture is Influencing Farmers' Reactions to the Biophysical Effects of Climate Change: The Case of Heavy Rainfall and Nitrogen Fertilizer Use

INTRODUCTION

Can the material effects of climate change stimulate a pro-environmental shift in agricultural production? Agricultural production in the modern capitalist economy is a key contributor to climate change and deeply threatened by the environmental changes climate change will induce (Weis, 2010). If the dual implications of climate change to agricultural production are to be addressed, management strategies must be undertaken that both reduce vulnerability to the effect of climate change and minimize further emissions of greenhouse gases (GHG), along with other forms of pollution (Blesh & Drinkwater, 2013). Achieving this shift in production is likely only to become more difficult. Climate change, through increasing the variability and intensity of in-season weather events, is widely expected to further exacerbate the challenges to efficient agricultural production (Robertson et al., 2013). However, this does not preclude the possibility that in the face of these challenges, farmers will respond with practice adoption that both reduces vulnerability and contributions to climate change.

To understand how farmers will deal with the effects of climate change while reducing further emissions, recent literature has begun to examine the management practice decision making of individual farmers in response to climate change and the social-psychological factors that impact these decisions (Arbuckle et al., 2013b; Haden, Niles, Lubell, Perlman, & Jackson, 2012; Rejesus, Hensley, Mitchell, Coble, & Knight, 2013). To this point, this literature has emphasized that individual-level perceptions, concerns or attitudes of farmers' matter for whether they respond to these challenges. In this study, I build on this work through presenting an alternative perspective on what shapes the actual practices implemented by farmers. United

States (US) farmers' management decisions have been shown to be highly constrained by the political-economic structure of agricultural production to prioritize profitability over environmental outcomes (Friedland et al., 1981; Hendrickson & James, 2005; Schewe & Stuart, 2017; Stuart, 2009; Stuart & Houser, 2018; Stuart & Schewe, 2016). Reflecting this literature, I argue farmer decision-making and practice implementation in response to the effects of climate change will likewise put immediate profits over long-term environmental well-being given the political-economy of US agriculture. In consequence, farmers' practice implementation in response to the material impacts of climate change will reduce immediate economic vulnerability, but maintain or even exacerbate the environmental consequences of capitalist agricultural production.

I examine this hypothesis within the context of Midwestern corn farmers' adaptive responses to the effects of heavy rainfall events, focusing on their use of nitrogen (N) fertilizer. As I describe further below, N fertilizer is a key input for corn agriculture and a major contributing source of agricultural greenhouse gas emissions (GHG), among other forms of pollution. It is also vulnerable to the impacts of climate change in the Midwest (Robertson et al., 2013); the increased frequency and intensity of heavy rainfall being a key dimension of climate change in this region (Iowa Climate Change Advisory Council [ICCAC], 2008; Karl, Melillo, & Peterson, 2009; Pryor et al., 2014). To address how biophysical processes and structural political-economic contexts merge together to influence farmers' N management practices in response to heavy rainfall events, I employ a conceptual framework that brings together the literature on climate change adaptation and environmental sociological political-economy (Foster, 2000; Smit & Skinner, 2002;). I apply this framework to a sample of 154 farmer interviews from the states of Michigan, Indiana and Iowa. My results suggest that the majority of farmers perceive and thus are actively responding to the risks heavy rain events introduce. However, most farmers are doing so in ways that increase, not decrease, pollution and agricultural contributions to GHG emissions from N fertilizer.

This effort extends the literature on climate change and farmer decision making to consider both the material impacts of biophysical processes and the influence of political-economic context on farmers' actual behavioral response to climate change. As such, this analysis can be seen to respond to calls for further consideration of how farmers' behavior is motivated by cross-scale (micro↔macro-level) processes (Stuart & Gillon, 2013); as well as to those that similarly call for further analysis of how biophysical and social processes influence farmers' relationship to climate change using qualitative methods (Houser et al., 2017). I begin by discussing prior literature on the topic.

LITERATURE REVIEW

The challenges that climate change presents agricultural production generally could be reduced using on-farm adaptation practices (Robertson et al., 2013). Adaptation is defined here are as on-farm practices undertaken to reduce vulnerability to climate change and climatic events (Intergovernmental Panel on Climate Change [IPCC], 2007; Smit & Skinner, 2002). Generally speaking, adaptive practices can reduce agriculture's vulnerability to climate change, ensuring continued production, and minimize excess pollution caused by climate change. Adaptive management practices depend on the event, agricultural type, and area of farm management. While I will speak more about adaptive practice specific to N use later, general dimensions of adaptive management include: altering crop variety, increased use of water management technologies, use of management techniques to reduce water logging and nutrient leaching associated with rainfall increases, alter timing and location of crop management activities, diversifying income in various ways; practicing strategies to improve the effectiveness of pest, disease, and weed management practices; use of climate forecasting to reduce production risk (Howden et al., 2007).

What motivates farmers' decisions to adopt various adaptive management practices that reflect these broad dimensions and what forms these practices take has been discussed conceptually as related to environmental and social processes conjointly (Howden et al., 2007; Roesch-McNally et al., 2017; Smit & Skinner, 2002). Related to environmental factors, farmers' adaptive responses are argued to be preliminarily driven by climate "stimuli," or biophysical climatic events like the climate variabilities described above (Smit & Skinner, 2002). Through disrupting the stable-state of a system—whether forcing coastal communities to move inland due to sea-level rise (Wetzel, Kissling, Beissmann, & Penn, 2012), or in the case of this paper, impacting the productivity and environmental relations of agricultural systems –climate change and climatic events introduce risks in one form or another that deem an adaptive behavior (O'Brien & Wolf, 2010; Smit, McNabb, & Smithers,1996). Climatic events may then prompt the need for adaptive practice adoption, but what or if adaptive behavior is undertaken has been argued to be a function of social processes and contexts. As Smit and Skinner (2002, p. 88) comment specifically about agriculture: "[A]daptation in agriculture does not function and evolve with respect to these climatic stimuli alone. Non-climatic forces such as economic conditions, politics, environment, society and technology, clearly have significant implications for agricultural decision-making, including adaptive decision-making." Biophysical and social processes at multiple levels—macro to micro—are argued to drive adaptive behavior in an agricultural context.

To this point, most empirical literature on agricultural adaptation in the context of developed countries has largely focused on exploring what factors encourage farmers' supportive attitudes for adaptation generally or intentions to adopt specific adaptation practices (e.g. Arbuckle et al., 2013b; Roesch-McNally et al., 2017; Niles, Lubell, & Haden, 2013). This literature follows social-psychological frameworks such as Theory of Planned Behavior (Ajzen, 1991) in suggesting that behavioral intentions are key predictors and thus good proxies of farmers' actual behavior. Following the conceptual work discussed above, this literature has explored how experience with local biophysical climatic events (or perceptions of local biophysical events) interacts with social processes to influence farmers' intention to use adaptive practices. To this point, the vast majority of this literature exploring farmers in developed countries has focused on micro- or individual-level social processes, following the focus of the general farmer practice adoption literature (see Baumgart-Getz et al. [2012] as a review). The adaptation literature has focused on social-psychological characteristics, including values, beliefs, perceptions and concerns/perceived risks (Arbuckle, Morton, & Hobbs, 2013a; Arbuckle et al., 2013b, 2014; Haden et al., 2013; Rejesus et al., 2013). The smaller amount of emerging research examining actual adaptive practice use has followed a similar model as that exploring intentions, focusing on individual-level factors social-psychological processes in their consideration of social processes influencing adaptive practice adoption (Mase, Gramig, & Prokopy, 2017; Niles, Brown, & Dynes, 2016; Wheeler, Zuo, & Bjornlund, 2013).[28]

As this suggests, the majority of research on agricultural adaptation in developed countries to this point has focused on farmers' attitudes toward adaptation, rather than their actual adoption of adaptive practices. In exploring the drivers of intended or actual practice

[28] Niles, Brown, and Dynes (2016) show that intention to adopt does not predict actual adoption of adaptation practices and is a poor predictor of actual mitigation practice adoption. In short, their study fundamentally questions the vast majority of prior literature on this topic and suggest future work should focus more on actual practice adoption, as intentions may be but a poor proxy.

adoption, prior work has examined both biophysical and social processes, but primarily considered social variables that are at the individual social-psychological level. This work's insights are important, as social-psychological factors are commonly considered key predictors of environmentally significant behavior (Stern & Dietz, 1994) and findings relevant to intentions are considered important for the development of policy (Floress et al., 2017). However, as I discuss further below, an emerging vein of sociological literature on agriculture has emphasized how farmers are constrained in their management decisions by macro-level political-economic factors (e.g. Schewe & Stuart, 2017; Stuart & Schewe, 2016). Following this emerging vein of literature, in this study I focus on building on prior adaption research through focusing on how macro-level political-economic factors constrain what adaptive practices farmers actually adopt in response to the impact of climate change.

The influence of political-economic context on farmers' adaptive behavior is mentioned in the literature (Smit & Skinner, 2002; Smit, McNabb, & Smithers, 1996). But only recently has empirical work begun to inspect how political-economic factors influence farmers' adaptive practice use (Blesh & Wolf, 2014; Roesch-McNally et al., 2017, 2018). For instance, Roesch-McNally et al. (2018) find that the predominance of corn agriculture and lack of available markets for alternative crops led farmers to perceive crop rotation systems more diversified than corn-soy to lack economic viability, this being a significant barrier to their adoption of this adaptation practice. This work sheds important insights on how economic context external to any individual farmer may prevent consideration of or actual adoption of various best N management practices. I extend this small amount of prior literature through revealing political economic imperatives that constrain which practices are implemented, not that farmers are absolutely constrained in their use of adaptive measures. Below I present some background on the sociological political-economic literature through which I address conceptualize the influence of the political-economy of agriculture.

THEORETICAL BACKGROUND

To explain the constraints on farmers' adaptive practice use, I discuss briefly discuss the political-economic literature from environmental sociology to conceptually frame the structural context that shapes farmers' adaptive response to climate change.

Political-economy from an environmental sociological perspective emerged to explain the structural (i.e. macro-level) drivers of environmental degradation, arguing that capitalism was the central driving force (Foster, 1999, 2000; O'Connor, 1988; Schnaiberg, 1980). This literature specifically derives largely from Karl Marx's original conception of the growth, or profit, imperative of firms, or farms in this study's case, in capitalist systems. Marx's argument, as outlined in Capital (1999), is that as capitalist production is intended to produce profits, not commodities per se, and thus there is no sufficient amount of production as profits can always be greater. [29] In Marx's words, this drive to continually acquire greater profits gives production sectors in capitalism "no rest" and "continually whispers in [capital's] ear: "Go on! Go on!" (Marx, 1999). This desire to achieve greater profits is made an *imperative* by the material force of competition in capitalist production. In terms of my case here, as each farm seeks to maximize profits, farms that fail to do so are at risk of being undercut or eliminated as they are either bought out or their consumer base is taken by the successful firm(s) (Marx, 1999). Accordingly,

[29] The emphasis of capitalist production on profits, rather than commodities, is illustrated in Marx's (1999 [1867]) famous M-C-M formula. He states as compared to non-capitalist production, which is commodity focused and thus exchanges produced commodities (C-), for money (M) to purchase a specific commodity (C-M-C), capitalism is money or profit focused, and thus uses money (M-) to make commodities (C) to acquire more money (M-C-M). As such, it is not the commodity that is the focus of capitalist production, but it is money, and more specifically *more* money. This has been referred to as "chrematistics," which is the processes of individuals amassing abstract wealth in the form of money, having no connection to the material well-being of society.

driven by both the rationality and this material threat of “extinction”, firms are compelled to pursue profitability “interminably” in capitalism (Marx, 1999, n.p).

Environmental sociologists built on Marx’s foundational political-economy work by illustrating how the structural force of capital’s growth imperative drives society-environment relations (e.g. Foster 1999, 2000; Schnaiberg, 1980). Marxist environmental sociological political economy (hereafter ESPE) literature has generally argued that capitalist profits imperatives demand that all barriers to profitability, including environmental barriers, be overcome, rather than solved. Specifically, when presented with environmental barriers to continued production expansion, firms within capitalist production seek only to overcome these barriers through substitution of alternative resource stocks. This is illustrated by the case of depletion of organic nutrients in 19th century England’s agricultural soils from the export of crops, taking the nutrients with them, to distant consumers. This issue was temporarily overcome, rather than addressed, through importing Peruvian guano, which led to a range of associated social and environmental issues, but was the more profitable option (Clark & Foster, 2009). As this suggests, by ignoring through “overcoming” immediate environmental barriers profits can be pursued. But the original environmental issue is not addressed and often a new environmental problem is created (Clark & York, 2008; Foster et al., 2010).[30] In short, the Marxist ESPE literature widely suggests that the structural profit imperatives of capitalist production constrain the capacity of capitalist firms or sectors from adequately addressing the environmental issues caused by and presented to them; rather they pursue profit first and environmental concerns are only secondary motivations of production behaviors at best (Foster

[30] In the case of 19th English agriculture and Peruvian Guano, the fish stocks around the islands where guano was sourced, which local populations used as a primary food source, were depleted due to eutrophication of the water from guano mining runoff (Clark & Foster, 2009).

2002). While perspectives exist that counter the premises of the Marxist ESPE (e.g. Mol, 1995; Mol & Spaargaren, 2002),[31] empirical analysis has generally confirmed the arguments of the latter literature. Generally examining society-environment interactions at a macro-level, including national, regional, or community level, a significant body of empirical work indicates that structural capitalist profit imperatives constrain the capacity to address or even reduce the environmental consequences of capitalist production (Gould, Schnaiberg, & Weinberg, 1996; Pellow, Schnaiberg, & Weinberg, 2000; Schnaiberg & Gould, 1994; Weinberg, Schnaiberg, & Gould, 1995; York, 2012, 2017; York, Rosa, & Dietz, 2003).

In terms of this study, the Marxist ESPE literature indicates that the structural conditions of the capitalist socio-economic system, namely political-economic forces, like competition, that introduce risk into production make it an imperative to prioritize profitability over environmental concerns, and this structural condition will constrain individual farmers to respond to the effects of climate change only in ways that first achieve profitability—meaning that the environmental consequences of an action will not be the primary consideration. The relevance of this theoretical position for the agricultural context is indicated by emerging literature. While the effects of the political-economic structure on individual farmers' decision making and practice use has not been a primary focus of past agricultural literature (Stuart & Gillon, 2013), prior literature does reveal both the presence and effect of structural political-economic factors in the US agricultural system. Macro-level political economic features matching those described above have been

[31] I am here alluding the literature on Ecological Modernization (e.g. Mol, 1997). This work can be broadly said to indicate that a reduction in the environmental consequences of production are possible within capitalism, and that profitability will be a key mechanism that motivates the development of technologies that lead to a reduction of environmental degradation. Importantly, much of this work emphasizes that significant social change and state policies will need to be in place for this change to occur. While this predicted occurrence of these changes has been widely empirically dismissed (see Schnaiberg, Pellow & Weinberg, 2003 for a full discussion), ecological modernization's premise should not be overly simplified to suggest that capitalist production will internally turn to improved environmental outcomes through modernization.

shown to be prevalent in the US agriculture system, including profit imperatives (Buttel, 2001; Buttel et al., 1990; Magdoff et al. 2000; Levins & Cochrane, 1996). Reflecting this work, recent evidence suggests the increasing prevalence or intensity of some of these political-economic factors, such as increasing competition for and consolidation of agricultural land, rising average farmer debt and the increasing monopolization agricultural capital suppliers, such as seed and equipment companies, that put further pressure to produce a profitable crop (Kloppenburg, 2004; MacDonald et al., 2013; NASS, 2012).

These structural conditions reflecting capitalist production have been shown to impact farmers' decision making about practices (Friedland et al., 1981; Henke, 2008; Hendrickson & James, 2005; Stuart, 2009). Literature specific to N management, the primary management context of this study (more on this below), has revealed that farmers' N use decisions are constrained by the structural context of a political-economy of agriculture, which compels farmers to make management decisions that prioritize yield and profitability at the expense of the environment (Schewe & Stuart, 2017; Stuart et al., 2012; Stuart & Schewe, 2016; Stuart & Houser, 2018). This work has to this point primarily focused on how powerful actors like seed-companies compel farmers to undertake economically oriented practices over environmental one (Schewe & Stuart, 2017; Stuart & Schewe, 2016; Stuart & Houser, 2018). For instance, Stuart and Houser (2018) show that in pursuing their own profit imperatives, seed companies are increasingly monopolizing control and influence over farmers' N rate decision making. As a result of this process, corn farmers are compelled to increase N rates at the expense of environmental quality. Less work has focused generally on how the structural context of capitalism produces its own contextual effect, via profit imperatives, on farmer decision making, particularly specific to N and what work has offered this perspective has only given limited attention to this structural context (Stuart et al., 2012).

As this discussion suggest, the capitalist socio-economic system is argued to prioritize profits over environmental outcomes and this has been empirically shown to prevent the reduction of environmental harms at the macro-level. The presence of the structural imperative of capitalism—profits—is considered a prominent feature of the US agricultural system. In this study, I focus on how this structural condition of profit imperatives (over environmental outcomes) influences farmers' adaptive response to the physical effects of climate change. Through deploying this approach, I advance the agricultural adaptation literature through (1) inspecting how individual-level decisions are influenced by this structural context of agricultural production and (2) build on the small amount of prior work on this topic through empirically demonstrating how the political economy of agricultural does not only absolutely constrain the adoption of recommended agriculture practices, but shapes which agricultural practices are implemented to prioritize profitability over environmental outcomes. In doing so, this study can be seen to extend the Marxist ESPE literature, which has almost exclusively been macro-focused to describe the functioning of the capitalist system, to the micro-level of individual farmers' behavior.

STUDY CONTEXT

Following this theoretical premise, I specifically examine how the political-economic structure of the agricultural system influences Midwestern corn farmers' adaptive practice management adoption related specifically to nitrogen (N) fertilizer. Here, I provide sufficient detail into agricultural N use, how it is being impacted by climate change in the Midwest and what strategies the above theory suggests farmers will employ.

N is a nutrient essential for plant growth. Pre-industrial agricultural systems met agricultural nitrogen needs through recycling of organic waste, crop rotations including nitrogen fixing legumes, and planting of leguminous cover crops. Today these processes have largely been supplemented or completely replaced by the production and application of synthetic N fertilizers (Smil, 2002). Many crop varieties receive N, but the lion's share of N applied in the US is applied to corn. Corn receives about 50% of all N fertilizer applied in the US, with the majority of this N being applied to corn grown in the Midwestern "corn-belt" states (ERS, 2012; Ribaudo et al., 2011). This high proportion reflects corn's biological demand. Briefly stated, corn puts on most of its biomass during a 6-week period of exponential growth, during which N uptake demands can reach 4 kg N per hectare (ha) per day (Robertson, 1997). This demand, though of a relatively short duration, cannot be met solely by the microbial mineralization of soil organic matter, which might provide about 1 kg N per ha per day. To avoid yield reductions, sufficient N must be applied to the soil before the period of high growth to ensure that enough is available when the corn plant needs it (Below et al., 2007). In this way, the use of synthetic N fertilizer in sufficient quantities is an essential input for corn agriculture (Robertson, 1997) and synthetic N has been considered the cornerstone input of industrial agriculture more broadly (Wolf & Buttel, 1996).

While N use is vital for Midwestern corn agriculture, it is also a major source of environmental pollution. N that escapes through surface and groundwater runoff contributes to high nutrient concentrations in surface waters resulting in hypoxia (low dissolved oxygen), which disrupts ecosystem processes and harms aquatic communities (Ribaudo et al., 2011). N that leaches into groundwater contaminates drinking water and threatens human health (Gupta et al., 2000). Finally, nitrous oxide (N_2O), a greenhouse gas (GHG) that is approximately 300 times more effective at heating the atmosphere than carbon dioxide, is primarily released in the US from agricultural N fertilizer application (U.S. Environmental Protection Agency [EPA], 2015). N's contribution to these issues is primarily related to the amount of applied N lost to the environment. Loss occurs when N is applied, but not taken up by the crops. Placing N application far from crop roots, applying N at times when crop demand is low or in forms that are more volatile, and especially applying N in amounts that exceed crop capacity for uptake all increase the likelihood and amount of N loss. The ratio of applied N to the amount lost to the environment (i.e. not taken up by the crop) can be referred to as the "efficiency" of N use (Robertson et al., 2013).

Climate change is expected to make efficient N use in agriculture more difficult (Davidson et al., 2012). Of the multiple effects of climate change on N use, in this paper I focus on farmers' practice adoption in responses to N loss associated with heavy precipitation events and it is important to understand why. Heavy precipitation (or rainfall, used interchangeably hereafter) events are defined as the heaviest 1% of all events (Karl et al., 2009). As a result of shifts in average temperature and precipitation conditions, the frequency of heavy precipitation events has also increased in the region (ICCAC, 2008; Karl et al., 2009; Pryor et al., 2014). Heavy rain events are associated with high levels of N loss from agricultural soil and if the events occur during the spring, they can delay planting and fertilization—thereby preventing N application at all (Dobbie & Smith, 2003; Robertson et al., 2013; Ruser et al., 2006). The occurrence of heavy rainfall events not only increases the loss of agricultural N, along with other nutrients, as non-point source pollution (Mitsch et al., 2001), but in doing so they pose economic risks as N loss increases the chance that yields will suffer due to N deficiency (Robertson et al., 2013). Across the region, the increased occurrence of heavy rainfall events has been linked with declines in production efficiency (the ratio of measured output, such as crops, livestock, and goods and services, per unit of measured inputs, such as land, labor, capital, and resources) and total average decline in yield (Liang et al., 2017). The loss of N from agricultural systems is already one of the most widely recognized environmental problems today (Davidson et al., 2012). And through the increased occurrence of heavy rain events, climate change will likely lead to increased levels of loss, creating by wider environmental issues and threatening the economic viability of individual farms. Given the increasing occurrence of heavy rainfall events in the Midwest and their significant impact on N loss and agricultural productivity, I focus in this study on how farmers respond via adaptive management adoption in response to these events and their impact on N use.

Midwestern corn farmers thus face significant objective economic risks from the impact of heavy rain events on N use, particularly N loss. A range of adaptive measures are available to them that can effectively reduce their vulnerability to these consequences. For the purposes of this paper, these measures can be broadly divided into two categories: (1) Best N adaptive management practices and (2) Increased N rate. Best N adaptive management practices are those practices that are recommend to farmers, as they balance economic and environmental concerns by reducing vulnerability to climatic events such a heavy rainfall without increasing environmental costs. Related to N management and heavy rainfall, these practices could include: use of cover crops, which can provide organic N and reduce N loss from rain events (Blesh, 2018); applying N near the crop and under the soil (i.e. injection); applying N at the times of the season when the crop's N demand peaks (i.e. in-season application); and using N products or formulations that make N more resistant to climate variability (i.e. stabilizers) (Robertson et al., 2013).[32]

The above best adaptive management practices reduce the vulnerability of N to heavy rainfall events and thus help to ensure viable agricultural production while reducing environmental pollution levels. Farmers may alternatively undertake N management practices that reduce vulnerability to climate change, but at the expense of increased environmental degradation. It is generally argued that increased application rates, sometimes called "insurance N," is a commonly used strategy to ensure (i.e. "insure") maximum yields given seasonally variable weather patterns (Babcock, 1992; Sheriff, 2005; Stuart et al., 2012). Increased applied rates can mean that a little extra N is left behind to support crop growth when weather/climate events diminish N levels in agricultural soils. As N pollution levels are highly linked to the rate at which N is applied, this practice also would dramatically increase agricultural contributions to GHG emissions, among other forms of pollution related to N (Hoben et al., 2011; Millar et al., 2010; Ribaudo et al., 2011). Though it is widely asserted, thorough evidence of the occurrence of 'insurance rates' is sparse, with few studies empirically investigating if farmers are using this as an adaptive strategy (Arbuckle & Rosman, 2014).

As this discussion suggests, heavy rain events are impacting N use in corn agriculture in the Midwestern US and the practices farmers adopt in response the physical impacts of climate change matters. Best management strategies can reduce vulnerability to climate change and contributions to environmental pollution; but it is frequently argued that farmers may be using increased N rates to reduce vulnerability, which would result in increased GHG emissions and

[32] Studies of the impact of no-till use on N loss in various forms have been inconsistent and therefore the benefits of no till specific to N management as an adaptive practice are still considered unknown (Robertson et al., 2013) or largely dependent on integrating no till with a suite of practices (Daryanto, Wang & Jacinthe, 2017). Future work may benefit from considering the predictors of farmers' use of this suite of adaptive practices, rather than single practices as is considered here.

other forms of pollution. Marxist ESPE literature would suggest that given the structural constraints of capitalist US agricultural system, the strategy that farmers perceive to be most profitable will be pursued, even if farmers are aware of and concerned about the environmental costs of this strategy. Following this premise, I below explore Midwestern corn farmers report that their N use is being impacted by heavy rain events and if structural profit imperatives are a primary driver of their adaptive responses to these impacts.

METHODS

To address this, I examine qualitative data gathered from 154 interviews with corn farmers in three Midwestern US states: 53 interviews in Iowa (IA), 51 in Indiana (IN) and 50 in Michigan (MI). Interviews were conducted on a one-on-one basis between a researcher and the farmer between May 2014 and December 2014.[33] The majority of interviews were done in person on-farm, with a small number conducted over the phone. All interviews were audio recorded with the permission of participants.

Initial interview participants were primarily recruited through university extension and other state resource professionals. The initial round of contacts represents a purposeful sample (Wilke & Morton, 2017), where farmers who had connections to agricultural information sources and were likely to be using a range of agricultural N management tools were intentionally sought out. After initial contacts were gather, snowball sampling, where preliminary contacts are used to gain access to additional respondents, was used to enlarge and potentially diversify this initial sample. Snowball sampling is considered a good method to contact subjects who are difficult to access (Faugier & Sargeant, 1997), such as farmers.

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[33] Importantly, it may be that farmers who were interviewed in the spring were more likely to report experiencing heavy rainfall, based on the increased occurrence of these events at this time (Pryor et al. 2014). This is not fully accounted for in this study, but should be considered in future analyses.

Across all three states, 48 percent (N=74) of interviewed farmers were contacted through extension, 34 percent (N=53) through snowball sampling, 13 percent (N=20) through state or federal conservation offices or programs (e.g. Soil and Water Conservation) and 5 percent (N=7) were contacted through various other relevant sources (Iowa Soybean Association, Practical Farmers of Iowa[34] and extension organized field days). Farm sizes of interviewed farmers ranged from 170 to 14,000 acres. As most contacts were identified through university extension, farmers in my sample may be more familiar with recommended adaptation strategies. This is an ideal group then to explore how the political-economic structure may drive farmers' decisions as compared to individual-level motivations like their exposure to conservation information.

A semi-structured interview guide was constructed to focus on farmer and farm characteristics, N management information sources, influences on N use, perception of water pollution and climate change, and of N's contribution to these issues. Interviews lasted between 22 minutes and 2.5 hours. Upon completion, interviews were transcribed and analyzed using NVivo software. As farmers were not explicitly asked how they were being affected by and reacting to climate change, this analysis draws on the entirety of each interview. A text search of all interviews was performed in NVivo using a series of terms identified during preliminary analysis of farmers' climate change adaptation and impact statements.[35] Following an adapted version of grounded theory (Strauss & Corbin, 1990), open coding was performed in an initial round of coding until core themes began to emerge. Axial coding was used at this point to identify further comments matching with (or suggesting alternative) climate impacts and

[34] Practical Farmers of Iowa is a farmer-led organization that shares information and encourages and supports on-farm research on management practices with the intention to improve agricultural productivity and conservation in Iowa. For more information, see: http://www.practicalfarmers.org

[35] Terms used in the NVivo text searched included the following: inches, rain, rainfall, extreme, longer, temperature, weather, season, ponding, N loss, heavy, warmer, wet, hot, and dry.

adaptation strategies (Charmaz, 2006). Importantly, considering the coding of farmers' adaptive practice use, I coded responses to reflect the above definition of adaptive practice use: farm practices undertaken to reduce vulnerability to climate change and climatic events (IPCC, 2007; Smit & Skinner, 2002). This definition implies intentional use of a practice to reduce vulnerabilities, and following this I coded a farmer to be using an adaptive practice when it was reported that this practice was adopted or used because it was perceived to reduce their vulnerability to climate events in some way. In consequence, practice use figures reported only reflect the number of farmers using the strategy to explicitly adapt to climatic events and do not reflect the total use of the practice across the sample.

Below I present the primary themes that emerged in axial coding related to farmers' experiences with biophysical events that match the scientific account of climate change in the Midwestern US, discussing how farmers see these changes/events to impact agricultural production and N use. I then show how farmers are undertaking adaptive N management strategies in response to these vulnerabilities. I finish the section by contextualizing their responses using political-economic concepts introduced above. As not all farmers were asked about these topics, the majority of these comments emerged organically in response to interview questions on other subjects. In consequence, these numbers may underrepresent the actual proportion of farmers who felt they had been impacted by climatic events.

RESULTS

Noted in my above discussion, past literature has suggested that farmers' adaptive N management practice use related will be conjointly (though not necessarily evenly) driven by the biophysical impacts of climate change and the structural political economic context of agricultural production. The role of the biophysical is considered first in my discussion of results.

Heavy rain events in the Midwest and N management

Across all three states in my sample, around half of all interviewed farmers (n=75) reported noticing trends of change in climatic conditions over time (see Table 6) and a slight majority (n=87) commented that their farm had been impacted in recent years by at least one specific, singular event that reflects the scientific account of climatic events in the region. Specific to the considerations of this study, 71 farmers discussed witnessing and/or being impacted by at least one heavy rain event in recent years. The number of farmers who reported witnessing or being impacted by at least one heavy rain event in recent years varied across states, with 33 farmers in Iowa, 25 in Indiana and 13 in Michigan. The much lower number of farmers in Michigan may reflect that a higher number of these interviews occurred later in the season, with sometime between heavy rain events in the spring and interviews, or may have results from some variation across states in actual biophysical conditions that season or in recent past season.

Farmers who noted the occurrence of heavy rain events perceived a number of impacts on agricultural N use. The loss of applied N was the effect of climatic events most prominently noted by interviewed farmers, with just under a third (50 of 154) of the sample commenting that they had experienced N loss or potential N loss as a result of heavy rain events in recent years. Of the 60 farmers who reported their N use being impacted by heavy rain events, 16 commented that heavy rain events occurring in the spring specifically had made accessing fields for spring N application more difficult, and thus threatened their capacity to apply N at all. Five farmers reported both experiencing N loss and difficulty accessing fields for spring N application. These results are displayed in Table 1. As the majority of farmers' noted that heavy rain events were causing N loss, reflecting my above discussion on the relationship between this event and impact, I focus on this relationship and farmers' adaptive response to N loss for the remainder of the paper. Please see Appendix C for a table of results for all reported climatic impacts on N use and a table showing farmers' reported response to heavy/spring rain's impact on application timing.

Table 6: Farmers' reporting N loss to have occurred from climate impact

Climatic Event	*n*	*Impact*
Heavy Rain (general) or Heavy Spring Rain (N=61)	44	Perceived nitrogen loss
	6	Potential for nitrogen loss
	16	Increased difficulty of successfully applying N during the spring (using sidedress)

Interviewed farmers' noted effects of heavy rain events on N use reflect expectations of past literature. Heavy rain events have been empirically linked to increased levels of N loss in prior research (Basso, Hyndman, Kendall, Grace, & Robertson, 2015; Dobbie & Smith, 2003; Ruser et al., 2006). Indeed, this is one of the main reason's efficient N management is expected to become more difficult in the face of climate change (Robertson et al. 2013). Likely reflecting this actual relationship, interviewed farmers perceived N loss to occur from rain events, and particularly from heavy rain events. Heavy rainfall events were seen to impact already applied N via disrupting its stability and leading to N loss from fields. Farmers' correctly recognized both how N's stability in-fields is tied to precipitation events: "[N is] a very mobile nutrient and it can get flushed out of the system [by rainfall events]" (IA02) and that heavy rain events were particularly impactful on in-field N stability: "When we have heavy rains, [N] leach[es] away easier" (IA57). Some farmers who noted the impact of heavy precipitation events on N commented on trends of impacts, feeling that the occurrence of heavy rain events had increased and that this was driving more N loss from soils on a seasonal basis: “It seems like we have more extreme weather…[20 years ago] it didn’t seem like we got [N] washed out [of the soil] as much as we do anymore” (IN18). However, most farmers who perceived heavy rain to have impacted N loss on their farm either commented on how N loss had occurred in response to an event in recent years. Illustrative of this perception, one Michigan farmer stated: “We lost quite a bit [of applied N] with the [amount of] rain we had last year” (MI27). Other farmers attached a specific season to the rain events, noting that spring rain was particularly problematic as this is when N is being applied. While variations existed, there was a general consensus across farmers discussing N loss and rain events. Given the nature of the nutrient, rain can and often will inevitably cause N loss from agricultural soils. A comment from a farmer in Iowa indicative of many others who noted how N loss is to a degree an inevitable consequence of rain events: “When you apply nitrogen in the spring and it rains, it’s a leaky system and you’re gonna lose some of it” (IA06). Many others commented similarly (see Table 7).

Table 7: How heavy rainfall events impacted farmers’ applied N
If you dump a ton on and then its gonna rain, you know, 4 inches afterwards, there’s not much that’s gonna stick around afterwards in the plants. It’s gonna run off or leach down through” (IN1). “In sandy ground I use less [N], which this year with the amount of rain we got, I don’t think that was a very good decision [because the N leached away]” (MI14). “Somebody was saying the day after this five-inch rain, ‘Is there any nitrogen left?’ You know, I don’t know, haha! It certainly didn’t help it any” (IA23). If we get several big rains, and get ponding [we could] lose nitrogen” (IN3). “In this past month in June we’ve had 11 inches of rain and that is tough to control, or we can’t control that and so it’s very tough to plan for that when you do a nitrogen management program because we surely lost some nitrogen at that point” (IA37). “I think it can stay in the soil more easily, if I would have put anhydrous on last week and then get 5 inches of rain like we did this week, then perhaps more of that nitrogen would be more available for the crop later in the season” (IA04).

Table 7 (cont'd).
"But nitrogen, yeah, you can lose it just because you get too much rain at the wrong time. And you do what you can to keep that from happening, but there is a limit to what an individual farmer can do. I'm sure we've had too much nitrogen get into the tile lines, cause of excess spring nitrogen after the ground warmed up, so until they find a way to keep that from happening. That's beyond my pay grade I guess. Haha" (IA08). "And if it rains a whole lot, that nitrogen, some of that, will wash away and go down in the dead zone of the Gulf of Mexico" (IA09).

The occurrence of heavy rainfall events and their impacts on agricultural N use discussed by farmers in this section match well with scientific expectations of how climate change is and will continue to challenge N use in the Midwestern US corn agricultural production (Robertson et al., 2013). While interviewed farmers' perceptions of the impacts of these events on in field N levels reflects an established empirical relationship, the exact amount of loss associated with a particular rain event is more difficult to determine and whether a given event actually caused any loss should not be assumed. Some farmers admitted to their uncertainty of this exact relationship: "Somebody was saying that the day after this five-inch rain, is there any nitrogen left? You know? I don't know [laughs]! It certainly didn't help it any" (IA23). While uncertainty in the particulars exists, the general perspective that heavy rains events were resulting in greater amounts of N loss matches with scientific data. This suggests interviewed farmers' comments are not mere perceptions, but reflect a material, or actual, effect of climate change on agricultural N use.

That almost one-third of farmers in my sample discussed their applied N was being impacted by heavy or spring rainfall suggests that a significant proportion of farmers in the Midwestern US may be noticing the impacts of climatic events on their agricultural N use and actively perceiving the challenges these events are presenting. As these responses emerged without a standard question on the topic across interviews, potentially a higher proportion of farmers than what is reported here feel similarly.

Having established that the N use of farmers in my sample is being actively challenged by the material effects of climatic events, I now to turn discussing how farmers reacted to N loss resulting from these climatic events.

Table 8: Farmers' reported adaptive responses to N loss resulting from precipitation events (n=43)		
Types of reactions	*n*	*Illustrative quote*
Increase N application rate	37	"Most part, this crop is out of our control; it's in mother nature's control, so we are vulnerable to that, other than if we get excessive amounts of rain and looks like we lose a lot of our nitrogen, I'll be hunting some way to get some more nitrogen on it [in that case]" (IN14).
Used increased number of application timings*	10	"We've had a lot of wet springs, with those late spring tests, under that 25 parts per million or whatever the numbers are [...] Uh, and so we've, that's when we started doing some sidedressing" (IA08).
Used stabilizers	5	"[We started] adding the Instinct [an N stabilizer] because we felt like we had some wet springs that we lost nitrogen, and so it's just kind of… You know, getting enough nitrogen out there and plus the Instinct to stabilize it so if we get some wet times it's still there, and that's kind of where we came up with that" (IN43).

Table 8 (cont'd).		
Planted cover crops	3	"Hopefully, they're gonna not let people put on these huge amounts of nitrogen in hopes of getting these massive yields. Because with the weather the way it is, with the water that we get, the runoff is substantial. So we also plant a lot of cover crops" (IA07).
Reactions that were reported by only one farmer: Altered rotation (1) Use of crop insurance (1) Use of injection N application (1) *farmers' coded as using increased application timings did not use additional timing of application to exclusively increase N rates, farmers who were coded as using increased rates did.		

Adaptive responses to N loss resulting from precipitation events

Perceived risks are considered to be key motivators of adaptive practice use in the agricultural adaptation literature (Gardezi & Arbuckle, 2017; Mase, Gramig, & Prokopy, 2017; Niles et al., 2016). As N is key nutrient for supporting corn growth, deficient levels can result in yield loss (Robertson, 1997). Reflecting this relationship, farmers in my sample emphasized that N loss could lead to deficient N levels and through this reduced yields and profitability. One Iowa farmers' comment illustrates the awareness of this relationship well: "Boy, if you lose twenty bushels if you didn't have enough nitrogen that is huge [in terms of profits]. That is in the back of every farmers' mind [… and] by the time that corn shows nitrogen deficiencies, it's too late" (IA02). As interviewed farmers were professional corn producers, the fact that many explicitly noted that sufficient N levels are needed for optimal yield and maximum profitability should not be surprising. As this suggest, N loss from heavy rain events can and were perceived to present objective economic risks to farmers, as deficient levels will lead to yield and profit loss. Likely in response to the recognition of the risks these events posed, a significant portion

(43 of 55) of the farmers who above described perceiving N loss from heavy rain events reported undertaking some form of adaptive response (see Table 8). This results bolsters findings that have suggested farmers are highly likely to be frequently adapting behavior in response to variable climatic conditions (Houser, 2018; Smit et al., 1996).

While a substantial portion of farmers were adapting in some way, variations existed in the exact strategies used. Described earlier, I focus on two broad categories of strategies for farmers to deal with climatic events causing N loss, best adaptive management strategies and increased N use. Best adaptive management practice are those strategies that reduce the vulnerability of N to precipitation events while simultaneously reducing agricultural contributions to environmental degradation (Blesh & Drinkwater, 2013; Robertson et al., 2013). These included: use of cover crops, which can provide organic N and reduce N loss from rain events (Blesh, 2018); applying N near the crop and under the soil (i.e. injection); applying N at the times of the season when the crop's N demand peaks (i.e. in-season application); and using N products or formulations that make N more resistant to climate variability (i.e. stabilizers) (Puntel et al., 2018; Robertson et al., 2013; Setiyono et al., 2011; Zhao et al., 2017). Together, slightly under half the farmers who noted using an adaptive strategy employed at least one of these best adaptive management strategies (n=18). Of these farmers, most had begun to use an increased number of application timings (n=10), followed by those using a given stabilizing product (n=5) and finally a few farmers had begun to plant cover crops in recent years to deal with N loss resulting from heavy rain (n=3). Only one farmer reported using injection of N to reduce the effects of heavy rain events.

Compared to farmers using at least one recommended strategy, a larger portion of farmers commented that they were increasing their N application rates as an adaptive response to

N loss from rain events (N=37). Importantly, increased rates were also used by a number of farmers who reported using at least one best management practice. Of the 10 farmers who used sidedress, a method of in-season application, to reduce the chance of N loss from heavy rains, six also reported using increased N rates. And two of the five farmers who used stabilizers for this purpose also reported using increased N rates. In all, 43 farmers reported adapting to N loss from heavy rains, but only 10 exclusively used at least one best management practice. The vast majority reported increased N rates as an adaptive strategy to reduce the impact of heavy N rains and associated N loss on production outcomes.

Among farmers using increased N rates, different adaptive approaches were taken with regard to "timing." Timing refers to when adaptation takes place, and can include anticipatory (i.e. proactive) and responsive (i.e. reactive) actions (Smit & Skinner, 2002). The use of "insurance N" has been commonly argued in the agricultural best management practice literature as a likely strategy farmers pursue to deal with seasonal variability in weather conditions (Babcock, 1992; Osmond et al., 2015; Sheriff, 2005; Stuart et al., 2012); though there is actually little empirical evidence that the practice occurs (Arbuckle & Rosman, 2014). Insurance N use appears to be an anticipatory adaptive strategy pursued by some farmers' in this sample. They assume that a precipitation event will occur in season that leads to N loss, so it is better to consistently over-estimate N needs. A number of comments illustrate this practice (see Table 9).

Table 9: Farmers' comments illustrating the use of insurance N
"What's the weather gonna be? Do I need to be putting on 150 pounds [of N per acre], cause that's plenty, or is it gonna be really wet and you better have some extra nitrogen out there available, cause Mother Nature says she's gonna change her mind" (IA18).
"I put on this extra 30 pounds [of N], which I'm glad we did because of the rainfall we've had, I think we would've been short without it" (IN33).

Table 9 (cont'd).
"Yes, it was very wet this spring […] I could probably get by on as little as 75 pounds of nitrogen, for corn on soybeans, if I didn't have a wet year. But we usually put on about 110 pounds on soybean stubble and 170-75 pounds if it's corn on corn just to make sure if we have a really wet year, like we had last year and how this year is turning out, that we still have some nitrogen left over" (IA09).
"Only cause we seem to keep going through this and every year the conclusion is that in general people are probably over-applying a little bit, but you never know what's going to happen from the time you apply it to the time the crop needs it" (IN04).

As this suggests, insurance N use is pursued by some Midwestern farmers as a strategy to deal with potential N loss from heavy rain events. Some farmers discussed how they had adopted insurance N applications as an intentional and long-term shift in management practice in response to recognizing a trend of increasingly frequent and heavy precipitation events. The adaptation literature has previously discussed this as a "strategic" response to indicate the intention long-term shift in practice (Smit et al., 1996). Strategic increased rates were discussed by a minority of farmers, but some did note adopting an intentional, long term change in their N rate in response to trends in weather reflecting regional climate change and how they intersect with other dimensions of change in the agricultural system. As one Michigan farmer discussed: "So I'm actually putting on more nitrogen [now than I used to], but I think this year with all the water we've had a little extra nitrogen seems to help…But with all the rain we've had this year, I was just flying and looked at some of these crops, it was night and day difference" (MI18). Others in Indiana and Iowa commented similarly (see Table 10).

Table 10: Farmers discussing the use of strategic insurance N use
"We've actually slowly increased [N rate] a little bit. Part of that is due to the fact that we're raising better corn and higher yields and the other part of its we've had a lot wilder weather the last few years" (IA34).

Table 10 (cont'd).
"Unless I happen to decide we're going to have weird weather years all the time, which would lead me to put on more nitrogen probably" (IA10).
"[For the last 6 or so years] we have been pretty wet in May and June. And just the amount of rain we've had have made us add an additional 50 pounds of sidedress, just because the rain flushes it down the system" (IA02).

Insurance N use reflects an anticipation of N loss given expected in-season precipitation events. But this was not the only "timing" of the increased N rate as adaptive strategy. Some farmers "responsively" increased N application rate, actually using multiple application timings as a response to precipitation's effect on their applied N levels. As I noted above, best practice calls for multiple applications to spread out a minimum amount of N to reduce N's volatility to climatic events and thereby reduce pollution and improve yields (Robertson et al., 2013). Farmers in this sample, however, used multiple-application timings to enable the application of *more* N in response to in-season heavy precipitation events. Some farmers' spoke generally about this method: "I don't know if it was an advantage or not, but some of the guys were thinking they had to come back in with a later application of nitrogen because of all the rains" (IN50). Others mentioned specifically the use of in-season application equipment like sidedress, to allow them to increase N rates after heavy rainfall events lead to loss of previously applied N. As one Iowa farmer commented: "But, you know, year to year it's different. If you get 10-12 inches of rain in May or June, [and] you don't have enough nitrogen out there, you need to sidedress again" (IA16). Others commented similarly (see Table 11).

Table 11: Farmers using in-season application equipment to increase N rates
"This year after planting we had over 10 inches of rain, so I increased the sidedress [rate by] 15 pounds. I probably didn't need to do that. I showed no nitrogen deficiency finishing corn, everything was dark green" (MI35). "Like last year we had a super wet spring and I had some spring liquid [N] put on with anhydrous in the fall and we had so much rain that I sidedressed [more N] also." (IA54) "I think some years you can get by with less nitrogen and some years even what you put on isn't enough. I think this year we're going to see some denitrification in the real low ground [due to rainfall events] and maybe we'll wish we'd gone through and sprayed a little bit [more N] on top" (IN22). "And, like I said, the other nice part about the sidedress is you can kinda, you have a plan of what you're gonna put on, you can adjust that knowing that you probably didn't loose any, or lost some. Adjust the rate to make up for those issues that we deal with on managing nitrogen" (IA03). "[N is a] very mobile nutrient and it can get flushed out of the system. Last summer, no not last year, you go back two years and then probably 4-5-6 years have been pretty wet May and June. And just the amount of rain we've had have made us add an additional 50 pounds of sidedress, just because the rain flushes it down the system" (IA02).

In line with this adaptive strategy, farmers explained how late-season application equipment, called "Hagies," were being used to apply more N in response to precipitation events resulting in N loss (see Figure 6). For instance: "And in recent years, I don't know if you're familiar with Hagie manufacturing, [they] makes a tool bar…These are high clearance sprayers to sidedress [over tall, late season corn]. Some farmers in recent years have used it as, well, they put an extra 40-50 pounds [of N] on because they felt they lost [applied N] with wet springs. That is the way most people utilize it" (IA01). Another farmer similarly commented, using the term "top-dressing" to refer to the late season application a "Hagie" can perform: "Last year was really wet and we had difficulty getting across the field, because after we got planted it just became extremely wet, so that's when we got top dressing, and that co-op had the equipment to do it" (IN32). Most farmers were not using Hagie-like equipment to apply more N late-season.

But it was a practice more farmers were becoming interested in given the number of heavy rains and amount of N loss they had recently experienced.

While the exact strategy varied, this discussion suggest that a portion of farmers are responding to heavy rain events' impacts on their N use through increasing N application rate, either as insurance N in anticipation of heavy rain events and N loss, or as a reactive response where in-season application equipment is used to apply more N when an event is perceived to have caused loss. While a number of interviewed farmers undertook best management adaptive practices, the majority of this sample responded to climatic events causing N loss through increasing N rate. Not reported in these figures are those farmers who described N rate decisions to be fundamentally based on seasonal weather variations. For instance: "If you knew what the weather was gonna be you could go out and apply that amount of nitrogen right there" (IA02). Comments like these suggest that adjusting N application rate in response to weather events is a common practice for some farmers. When N loss occurs due to heavy rain events, it is likely these farmers also apply more N. As this indicates, it may be that increasing N rate, either in anticipation of or in reaction to perceived N loss from heavy rain events, is a prominent adaptive behavior among Midwestern corn farmers in response to heavy rain events and N loss.

Environmental science research related to human populations broadly indicates that human response to climate change may have a more significant environmental consequence than the direct effects of climate change, (Paterson et al., 2008; Turner et al., 2010; Watson & Segan, 2013). Farmers' use of increased N application rates may be another adaptive response that at least increases the environmental consequences of climate change. Best management adaptive practices are recommended because they help protect against the negative effects of climatic events while reducing further agricultural contributions to climate change. Increased N rate accomplishes the former—protecting against the impacts of climatic events—but at the expense of the latter. N is often the most limiting nutrient in agricultural production, meaning that N loss can result in diminished yields and profitability (Robertson & Vitousek, 1997). Increased application rates help ensure N is not deficient and therefore that the corn crop is able to access adequate N to maximize yield potentials. However, all forms of N pollution, especially emission of the greenhouse gas N_2O, are positively associated with the amount of N applied to agricultural fields (Hoben et al., 2011; Ribaudo et al., 2011). In consequence, this adaptive strategy reduces the impacts of climatic events, but the end result of this strategy is likely increased agricultural N contribution to climate change via increased N_2O emissions, as well as other forms of N pollution.

Figure 6: A Hagie toolbar being used to apply N over later season corn

Motivations for adaptive behavior: Profits and political economic context

Given the environmental consequences of increased N rates in response to heavy rainfall events, what lead farmers to pursue this adaptive strategy? I above outlined how the social-economic system of capitalist is a key structural context in which US farmers' make management practice decisions. This structure makes the pursuit of profits an imperative and has been shown to compel farmers to prioritize profitability over environmental concerns in their decisions regarding management practice adoption (Magdoff et al., 2000). Reflecting the constraining influence of this structural context, Marxist ESPE theory suggests that farmers will necessarily pursue the adaptive practices they perceive to be most profitable, even if environmental quality is known to be being sacrificed. Broadly speaking, farmers' comments as to why they used increased N rates, rather than best N adaptive management practices, confirm this literature's central premise: economic, rather than environmental considerations drive decision making in capitalist production and in consequence, farmers act in ways harmful to the environment. However, some variations from this theoretical framework did emerge in the data. I provide evidence of these variations below.

That profit maximization drove farmers' preference for increased N emerges most strongly in relationship to N stabilizer use. The fundamental issue many farmers expressed with N stabilizers as an adaptive measure was their high costs. N stabilizers were recognized to be at least somewhat effective at reducing N loss from heavy rains. But increased N rate achieves the same goals, ensuring N deficiencies do not reduce yield and in 2014, the year of the interviews, many farmers believed increased N rates did so at a lower cost. In consequence, they preferred adding more N, rather than spending the higher costs on stabilizers: "Yeah, it's cost [that discourage my use of stabilizers]…I guess I look at it [like this]: instead of using stabilizer I'd probably put more units [of N] on to start with" (MI21). Others implied that given the greater financial gains associated with yields higher, higher N rates are economically rational decisions to ensure N deficiencies do not occur from N loss: "I'd rather over apply then under apply nitrogen and fertilizer, because I mean, over apply you're not going to hurt yourself much, but under applying, boy, you can hurt yourself" (IN09). In short, it appeared that farmers considered stabilizers to achieve the same end as increased N rate as an adaptive strategy, but to be associated with higher costs. Others commented similarly (see Table 12).

Table 12: Farmers' reported issues with stabilizers
"How you get it to stay in the soil, you know, and I was … as I alluded to earlier we're not a big advocate of those additives [i.e. stabilizers] to keep it bonded to the soil. Do they work? Maybe. Are they worth the money? I don't know. I just want bang for my buck and I like to kind of see [the results of the money I spend]" (MI17).
"Oh, like that ESN and things that tie up the nitrogen [stabilizers], they seem to be awfully expensive for what you get" (IN01).
"N serve can help a little [reduce N loss], but you know its maybe only 30% effective a lot of times. Which is, for your money, I don't know" (IA11).

While profit maximization led to a preference for increased N rates over stabilizer use, a slightly different economic consideration appeared to discourage more widespread use of in-season application and cover crops as an adaptive measure to heavy rain and N loss. Farmers in general felt that cover crops and in-season 'sidedress' application had high potentials for producing optimal economic and environment outcomes and many expressed the desire to continue to pursue these strategies. However, in terms of their effectiveness as an adaptive strategy to heavy rain events and N loss, farmers perceived a number of issues related to their dependability in producing profitable results. In particular, both strategies were seen to suffer from the consequence of inconsistent results. Cover crops and in-season application are both vulnerable to seasonal variations, meaning that in some years they worked effectively as adaptive strategy, but in others they could be largely ineffective.

Though cover crops are frequently noted to have substantial benefits, both as a general practice and as an adaptive measure (e.g. Blesh, 2018), only between 3-7% of US farmers are using them to some degree on their operation (Borchers, Truex-Powell, Wallander, & Nickerson, 2014). This is likely in part because cover crops suffer from economic barriers to implementation, such as increased costs at planting (Roesch-McNally et al., 2017). Most relevant to my argument is that there is significant seasonal uncertainty that cover crops will provide any agronomic benefits (Bergtold, Duffy, Hite, & Raper, 2012). Cover crops are an organic adaptive strategy. As a live organism, the benefits derived from cover crops depend on successful growth and development—something that is itself vulnerable to seasonal fluctuations just like N loss. Farmers' noted how cover crops, because of their organic nature, had a fundamental "hit or miss" quality in their adaptive benefits: "I like cover crops; it's just they're kind of hit and miss, sometimes I have very good luck with cover crops as far as establishment in the fall and sometimes it's pretty scattered; that's the biggest problem with cover crops" (IN40). Uncertain results led some to pass on using cover crops, while others used cover crops, but changed no other part of their N management practices: "I'm not planning on using less nitrogen fertilizer next year because I'm going to use cover crops this year" (IA28).

In-season application via sidedress, though a technical adaptive strategy, appears to suffers similar seasonal variations in effectiveness as an adaptive strategy. In-season sidedress application has not been as widely studied as cover crop usage. Across this sample, it was a very common practice, with 108 out of 154 of farmers we interviewed using it to apply N. Clearly, many farmers in this sample have access to sidedress equipment and use in-season application as a general agricultural management practice. However, it was not widely discussed as an effective means to reduce N loss from heavy rain events. One reason for this may be that in-season application depends on being able to get equipment into the field. Heavy rain events can saturate soils and prevent access during critical times for in season application (Robertson et al., 2013). In consequence, there is the potential that in-season application could not occur at all. Heavy rains can result in the loss of N already applied; if farmers cannot access fields to apply at all, they will likely be left with far less N in the fields. Farmers noted facing this issue and that is discouraged their use of in-season application as an adaptive strategy, even if it was seen to have economic benefits: “I’ve seen rainy years where the rain sets in, and it was a little bit this year the rain set in, and some guys [who use sidedress] didn’t get all their N on… I really think sidedress is the most economical, but in my situation I can always get around to getting side dressing done” (IN24). See Appendix C for more details on the impact of rain events on in-season application use.

The number of farmers using sidedress application in this sample indicates that the inability to access wet fields is only a minor factor discouraging the use of in-season sidedress application as an adaptive management practice. A more serious barrier may be that even if sidedress application can occur, N loss from rain events is still possible after in-season application. While this practice can minimize this potential (Robertson et al., 2013), it was not uncommon for farmers to perceive that significant N loss from rains had occurred post-sidedress and these losses threatened their profitability via yield loss. For instance, one farmer explained how rain events post sidedress lead to N loss: “Last year, I was putting all the nitrogen on at the sidedress time. And ended up with 7 inches of rain in the week after I put it on. And I was like, ‘ok, we’ll see what happens’. And so when I got my corn stalk nitrate test, I could see it said that the nitrogen got away” (IA04). As N loss is commonly associated with yield loss, these loss events post-sidedress put farmers at risk of profit loss.

Compared to these best management adaptive strategies, increased N rate sacrifices maximum profitability for maximum dependability of achieving at least some profits. In other words, farmers relied on increased N rates because given the relative price of corn compared to N, particularly in much of the 2014 season, this strategy can ensure profits to the extent that they can be given seasonal variable conditions. Farmers' comments illustrate that they perceive N to be a key means to boosting yield: "…seems like [adding extra N is] the most controllable and readily available way for the farmers to boost yield" (IA13). Others emphasized how increased N rates can save a "crop" or ensure yields remain profitable even after N loss events: "If it keeps raining and it's warm we're going to lose nitrogen, big time lose nitrogen, and that's when you've got to come back in and put some more on or you're going to lose the crop, and there's 'why did you lose the crop?' when with another 10 to 15 gallons of 28% [N] you can fix it" (IN14). Importantly, the benefits of increased N rate—ensured yield—come at the expense that some money is necessary wasted on N applied that is lost to the environment. Farmers' comments indicate that at least a portion are likely aware that N loss equates to money wasted: "[Heavy rain events can cause us to] lose our nitrogen that we all spend money to put out there, it's not cheap" (IA49). This suggests that increased N rates may be undertaken as a primary adaptive strategy not because they are perceived as the most profitable means, but rather because they are more capable of ensuring a dependable, though not maximum, level of profitability given seasonal variations in heavy rain events, among other forms of climatic events. See Table 8 for a comparative list of the benefits of best management adaptive practices versus increased N rates.

Whether pursuing maximum or consistent profitability, the prioritization of economic over environmental outcomes is the result. Importantly, evidence would indicate that lack of knowledge of the environmental consequences of increased N rates is not the factor that drove this decision. Rather, as other studies have indicated, interviewed farmers were well aware of the environmental consequences of N loss and higher N rates (Stuart et al., 2012). However, farmers emphasized that profitability was the primary concern in farm management decision making. For instance, an Indiana farmer commented on how profit consideration determines his decision regarding the adoption of new practices in saying: “If it’s a positive return on your money, then that’s what we’ll do” (IN15). A Michigan farmer confirmed this perspective in responding to a question about management practice decision making with the statement: “You know, you want to get the most return on your investment” (MI3). The consequence of this profit orientation was that farmers ultimately prioritized profitability in N management decisions, even if the environmental consequences of this decision was recognized. This profit-first motive would explain the preference of increased N rates, despite recognizing the environmental consequences associated with them. Some farmers’ explicitly discussed how they ultimately prioritized profitability over environmental outcomes: “You know, you don’t have guys out here that completely want to ignore the environment, you know; we might not always think about it first, but we aren’t trying to just screw things up either. We’re trying to make money first, hate to say it but that’s … We’re in a capitalist society, that’s part of it” (IN23).

Marxist ESPE theory indicates that this motive is not a simple choice by farmers. Rather, political economic forces reflecting the structural condition of capitalist production abound in the US agricultural system and these forces—monopolized markets, mono- or di-cultural production, consolidation of and competition for agricultural land and rising debt burdens—make profits an imperative goal as they introduce risks into production (Blesh & Wolf, 2014; MacDonald et al., 2018; NASS, 2012; Schewe & Stuart, 2017). While empirical evidence reveals that these macro-level forces exist and theory indicates how they will lead to profit imperatives, few farmers explicitly commented about how these forces coerced prioritization of profits over environmental outcomes. This may be because profit orientation and the political-economic forces that drive it are so ubiquitous in capitalist societies and the agricultural system specifically that they are assumed factors and thus do not deem explicit acknowledgment by farmers (Gunderson, 2015; Magdoff et al., 2000). Despite this context, some farmers did indicate that they were aware of how these macro-level political economic forces were compelling them to make profit oriented decisions, specifically the continued use of increased N rates. One farmer commented on how competition was occurring for land in their area between neighbors and that this competition led them to use higher N rates:

> "I wouldn't be cutting fertilizer [rate] to save the spotted toad or something like that, if it's going to cost [yield]… Especially when every neighbor around you isn't doing [it]… I mean, everybody around here is […] driving an economic train and it's very competitive and you gotta be right there with it, and that's how you've got to make decisions" (IN16).

Another noted how higher N rates protected them against the threat of debt burdens, enabling them to consistently make payments on this debt:

> "Those who want us to use fewer units, those who want us to do it in a more timely manner, and there are people everywhere who do that, I know that, then what kind of safeguard do you have for me from an economic reality? Do you go off my balance sheet and where I have debt, and it shows I need to service that debt, do you guarantee me that I'm going to get enough corn production to substantiate that? I mean, it's great to sit here

> in your ivory towers, and a lot of people do, and tell us how the world should be run, but how do you bring it down to where I am?" (IN44).

As these comments suggest, even though a number of farmers recognized the environmental costs associated with higher N rates, economic decision making, like using increased N rates, may be compelled by political-economic forces reflecting the structural context of capitalist production. Related specifically to the adaptive practices of increased N use, this imperative to ensure profits on a yearly basis means that even if farmers knew increased N rates resulted in environmental harm and wanted to avoid this consequence, they were compelled to undertake this strategy:

> "Anytime there is adverse weather, [N rate] becomes a difficult decision, cause you don't want to be bad to the environment and just, 'Ok I'll just throw on 250 300 pounds [of N on] every year, that way it won't run out'…But I think most farmers are thinking more about the environment…We want the rest of the people to think we're trying to do a good job and most people are trying to do a good job and apply what is needed, not to throw on a little extra [N] just so we don't run out. And so that is why it makes it more difficult, *if weather changes you have to add more [N] than you plan*" (IA08 [emphasis added]).

Another commented similarly with regard to insurance N rates. He stated that, "you never know what's going to happen from the time you apply [N] to the time the crop needs it [with regard to rain events]. While we don't like to see [N] get into the water supply, how do you know what to change it to?," the consequence of this unknown being a necessary preference for increased N rates, which he saw as "a type of insurance" (IN03).

To summarize, my data suggest how practice use that prioritizes economic considerations in adaptive practice use is not necessarily a voluntary preference for farmers. Structural political-economic forces are commonly argued to exist in the agricultural systems, and compel farmers to pursue economic over environmental outcomes in decision making. Here, they appeared to drive the use of increased N rate as an adaptive practice. The environmental consequences of increased N rates were known and undesirable to farmers, but a substantial portion of farmers used increased rates to adapt to heavy rainfall events and associated N loss because increased N rate was seen as more cost-effective or the more dependable in producing profits than a number of best management adaptive practices. As this suggests, it may be that farmers' adaptive practice use in response to heavy rain events is constrained by the structural profit imperatives of the capitalist agricultural system. In consequence, at least a portion of Midwestern corn farmers may feel compelled to adopt adaptive practices that achieve economic outcomes at the expense of long-term environmental quality.

Table 13: Pros and cons of using best management adaptive strategy versus benefits of increased N rates to address N loss from heavy rain events

Pros and Cons of stabilizers

- Stabilizers must be used before rain events; if weather is ideal, money is wasted
- At time of the interview, farmers noted stabilizer use was more expensive than adding more N
- Reduces N loss, thus can reduce N deficient and yield loss

How increased N rate is equal or is better

- Higher N rates can be used before rain events, but also used only if needed
- At the time of the interviews, N was less expensive than stabilizer products
- Reduces N deficiency caused by N loss and thus ensures maximum yield

Pros and Cons of cover crops

- Expensive and potential for reduced yield/profits in short term
- Farmers noted lack of consistent benefits
- Reduces N loss and can provide organic N, thus reducing N deficiency and yield loss

How increased N rate is equal or better

- Increased N rates provide immediate, yearly, yield benefits
- Increased N rates have consistent economic benefit

Table 13 (cont'd).

- Reduces N deficiency caused by N loss and thus ensures maximum yield

Pros and cons of in-season application:

- Reduces N loss as crops uptake more N, without spending more on N or other products (once equipment has been purchased)
- Rain events can delay or prevent in-season application
- Rain events can still cause N loss after spring in-season application

How increased N rate is equal or better

- Increased N rates ensure sufficient N remains after heavy rain events at any time
- Increased N rates can be used pre-,in- and late-season in anticipation of or in reaction to N loss from rain events
- Reduces N deficiency caused by N loss and thus ensures maximum yield

DISCUSSION/CONCLUSION

Marxist environmental-sociological political-economy literature argues that due to the profit-imperatives of the capitalist socio-economic system, environmental degradation cannot be effectively addressed in this system and that any environmental barriers to production will be overcome in ways that prioritize economic outcomes and thus maintain or expand the environmental consequences of production (Foster, 2000; Foster et al., 2010). In this study, I extended this theoretical perspective to examine farmers' adaptive practice adoption in response to climate change. My analysis focused on heavy rain events, a climatic event that is increasingly occurring in the Midwestern US region as a result of climate change, and their impact on N loss, a key input and source of pollution from the modern agricultural system (Davidson et al., 2017; Wolf & Buttel, 1997). To this point, individual-level factors, such as risk perception, values and attitudes, have largely been examined as the key predictors of farmers' adaptive behavior in empirical studies (e.g. Mase et al., 2017; Niles et al., 2016; Wheeler et al., 2013). Following the theoretical foundations of the Marxist environmental-sociological political-economy literature, I focused on examining how the structural context of capitalist production, which is widely considered to be prominent in the agricultural sector (e.g. Weis, 2010), constrained farmers' adaptive practice adoption at the individual-level.

My results show that economic considerations were ultimately prioritized over environmental ones in adaptation practice use adoption by farmers in my sample. Specifically, the majority of farmers who reported an adaptive response to N loss from heavy rain events used increased N rates to ensure seasonal yields. This practice is associated with greater levels of environmental consequences, but compared to best management adaptive strategies better achieves economic outcomes. Importantly, some farmers' comments illustrated how they recognized that higher N rates were associated with N pollution levels and that they did wish to harm the environment, but that they ultimately were compelled to prioritize profitability. I suggested that political-economic circumstances, specifically competition and debt burdens, may have been forces constraining this decision. Generally speaking, this finding reflects the limited amount of past research exploring how political-economic factors influence farmers' adaptive practice adoption: that even when farmers acknowledge the environmental benefits of these practices, political-economic concerns can prevent the use of best management adaptive strategies (Blesh & Drinkwater, 2013; Roesch-McNally et al., 2017, 2018).

Absolute profitability, or the cost-benefit ratio, appeared to motivate interviewed farmers' use of increased N rate over stabilizers, but results suggest that farmers preferred higher N rates to cover crops and in season application because of the former achieved more dependable, though not necessarily always higher, profits. Political economic theory would suggest the results of stabilizer: that absolute profitability is the driving goal of production decisions and thus stabilizers, being perceived to be not as cost effective as higher rates would not be used. What would drive preference for consistent, though not necessarily maximally profitable, decision making? Most prior research has looked at how competition, along with other political-economic factors, drives the behavior of firms or entire sectors of production (i.e. the agricultural sector) (e.g. Foster, 1999; York, 2017; Schnaiberg, 1980). Little work has focused on the individual-level. Farmers, acting at this micro-level, may be subject to much more powerful actors themselves, like the agricultural input supply companies, meaning that they may face a double-layer of economic risk in decision making. By this “double-layer” I mean that farmers are both subject to the forces exerted by large and powerful corporate agri-business firms and the forces exerted by other farmers. Agri-business firms, what others have called “anti-market players”, are themselves playing the capitalist game with other anti-market players (Carolan, 2005). As a result of their competitive profit seeking behavior, anti-market players attempt to extract the greatest amounts of profits from each “customer,”[36] in this case farmers, and in consequence may threaten farmers’ continued economic viability (Heffernan, 1998; Stuart & Houser, 2018).[37] Indeed, that firms pursue profitability to the point of undercutting their own viability, in this case through bankrupting their customer base, is a well-established dimension in the Marxist political economy literature (O’Connor, 1988). At the same time, each individual farmer is putting economic pressure on one another, as they individually strive to expand production through land acquisitions to maintain profitability (Levins & Cochrane, 1996). Together, these pressures may create a double-layer of economic risk for farmers, as they face price squeezes by the anti-market

[36] Customer seems to be a potentially misleading term to describe farmers’ interaction with agribusiness. When only a handful of companies control a significant amount of the capital inputs needed for agricultural production, there is really little choice in who to interact with. Thus farmers in many ways resemble *subjects* more than customers.

[37] Marx, in considering the nature of wage labor, argued that in capitalism, firms strive to maximize profitability through extracting the most work at the least expense from their employees and that this ultimately undercut the. A similar, but opposite, principle may apply to farmers as customers of monopolized firms: anti-market players benefit most when their customers are using the most services and products they can and paying the most possible for each services. Given the competitive pressure of firm against firm, one way each anti-market player may strive to stay competitive in through increasing the number of services and costs of those services used by farmers, particularly as the farming population is decreasing. It is in some ways a variation on the first contradiction of capital.

players from above and competition for land by neighboring farmers. This double-layer (if indeed it is occurring) reflects farmers' unique class position within capitalism (Mooney, 1983). For the purposes of this study, the consequences are that farmers have a heightened level of economic risk and that in terms of adaptive decision making, this may lead farmers to undertake practices to manage this risk, ensuring consistent, though not necessarily maximum, profitability given seasonal fluctuations. In this case of this study, it led to the use of high or increased N rates over best management adaptive practices.

Importantly, this finding may be time bound. Corn to N price ratios have been shown to influence farmers' N rate decisions (Ribaudo et al., 2012), with higher rates being used when the ratio strongly favors corn. At the time of the interviews, 2014, this was certainly the case, particularly early in the season. Since this time, corn prices have dropped and thus the noted economic benefits of higher N rate may not currently be existent. Moreover, as the occurrence of heavy rain events increases in the future, it may be that as Midwestern farmers experience the effects of climate change, best management strategies will increasingly result in net profits gains and thus be utilized. Whether this profit driven conservation behavior would last, however, is questionable at best given the noted consequences of market fluctuations on N decisions. Future work should continue to examine farmers' use of increased N rates as an adaptive strategy, considering longitudinal fluctuations in contextual social, economic and biophysical conditions.

With that said, my current results, like other studies of farmers' management behavior generally and farmers' N use specifically, suggest that the political-economy of agriculture structures adaptive management behaviors to at least a degree (Hendrickson & James, 2005; Levins & Cochrane, 1996; Schewe & Stuart, 2018; Stuart, 2009). While some work has argued environmental feedbacks will lead to behavioral change that disrupts the social-economic structures that cause environmental degradation (Beck, 1992), at this point it appears that this political-economic structure has remained unquestioned and instead, because of this structure's stability and continued influence, climate change may be motivating further increases in the cycle of overconsumption and pollution of our natural environment. Given the small sample size, this study should be considered to offer only preliminary insight into farmers' adaptive behavior and the influence of the political-economy of agriculture on this dimension of farmer management. Future work should build on these results and seek to better understand how farmers' adaptive decisions are tied to the political-economy of agriculture, along with a more careful and expansive consideration of the role that biophysical processes play in adaptive decision making related to N use (Basso et al., 2015; Stuart et al., 2015). In particular, greater insight about the relationship between biophysical climatic events in a geographic area and farmers' adaptive responses could be garnered through a quantitative approach that combines biophysical, social and economic data to comprehend farmers past or current changes in their management practices. This type of work will be important moving forward as we attempt to better understand if the more frequent occurrence of extreme weather in the Midwest will drive farmers further into a cycle of overuse of production inputs like N, or increase the adoption rates of recommended strategies given their relative profitability. In either case, to ensure longer-term use and greater adoption rates, policy that makes recommended adaptation strategies more profitable to adopt should be implemented to further encourage their use (Roesch-McNally et al., 2018).

APPENDIX

Addition information on perceived climatic events

Table 14: Perceived impact on N Use by type of event		
Event type	*Impact*	*n reporting impact*
Heavy rainfall events (n=50)	Perceived nutrient loss	35
	Potential for nutrient loss	2
	Increased difficulty of timely N application	7
	General Challenge	4
Spring precipitation events, including heavy rainfall and total rainfall in the spring (n=21)	Increased difficulty of timely N application	9
	Perceived nutrient loss	6
	Potential nutrient loss	4
	Yield loss	2
Variability of recent weather (general) (n=18)	Uncertainty about N loss/N application rate	8
	Variability timing window for spring management	5
	General challenge	5

Table 15: Farmer adaptive response to heavy/spring rain events' impact on accessibility for spring N application	
Adaptive Strategy used	*n*
Increased N rates	6
Increased use of in-season application (more app timings used)	3
Increased use of in-season application (more N applied at one time—often fall or pre-plant)	2
No adaptive practice reported	5

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CHAPTER IV— Another False Promise? Preliminary Results Suggest the Adoption of Agricultural Nitrogen Best Management Practices May Increase N Pollution

INTRODUCTION

Production technologies[38], such as synthetic fertilizers, pesticides and highly capitalized equipment (like tractors with base prices in excess of $350,000[39]), have enable the industrial agriculture system to dramatically increase the amount of food commodities a single farmer can produce throughout the second half of the 20th century. These technologies have also had significant environmental impacts. Agriculture in the United States (US) is a primary contributor to ground and surface water pollution across the country and emits a non-trivial amount of the nation's total greenhouse gas (GHG) emissions (EPA, 2015). "Green" agricultural technologies, in the form of what has commonly been referred to as "best management agricultural practices," have been developed in response to these issues. These practices include: devices, tests and equipment that enable farmers to more efficiently manage their inputs and thereby significantly reduce or eliminate any unnecessary contributions to environmental harms. This approach to reducing pollution from agriculture is driven by a core assumption: the environmental inefficiencies of agricultural production are primarily a technical problem, solvable through technical solutions.[40]

This assumption requires interrogation or is in need of further empirical inspection. A vein of environmental sociology research, the political economy of technology literature, has shown that while technical solutions like agricultural best management practices may be capable of addressing environmental issues, their actual effects are highly dependent on their

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[38]Technology, for the purposes of this paper, can be defined as the application of scientific knowledge for practical purposes, including both production and conservation.
[39] See the lineup of the John Deere model 09A0RW at: https://www.deere.com/en/tractors/4wd-track-tractors/
[40] This technical approach can be said to be shared across the best management practice adoption literature's efforts regarding knowledge/information/education treatments to encourage farmers' conservation practice use.

implementation. Social contexts, like political economic structure (i.e. profit imperatives), can encourage continual increases in production, meaning that more environmentally efficient technologies are often deployed to increase profits, rather than conserve resources (York, 2017). Because of this, it is frequently observed that there are few environmental benefits from the adoption of more environmentally efficient technologies (York & McGee, 2016). As York and Clark (2010) illustrate: "The adoption of alternative fuels, such as agrofuels, does not necessarily displace the burning of fossil fuels, given the ongoing increase in energy consumption to support economic growth" (p. 218; citing York, 2006, 2007). Given evidence of the significance of political economic factors in motivating profit-oriented agricultural production (Schewe & Stuart, 2018; Stuart & Houser, 2018; Weis, 2010), it is possible that the adoption of "best management" technologies (technologies and practices are used interchangeably hereafter) will *not* lead to improvements in the environmental efficiency of agricultural production.

In this paper, I explore the relationship between technology use and the environmental efficiency of agricultural production through a study of corn farmers in four Midwestern states: Illinois, Indiana, Michigan and Ohio. I focus specifically on the use of nitrogen (N) fertilizer in this context. Moving beyond predicting the adoption of N best management practices, I use quantitative data from a sample of 3,280 Midwestern corn farmers to analyze how the adoption of three recommended best management practices influences the rate at which N is applied at the farm level, where application rate is the dimension of N use most predictive of the levels of N pollution in multiple forms (Hoben et al., 2011; Ribaudo et al., 2011). In this way, this study explores whether the environmental gains promised by best management practice adoption is realized in a reduction of farmers' fertilizer rate, a key proxy of agricultural N pollution level (Millar et al., 2010).

Through this analysis, I contribute empirically and theoretically to at least two veins of scholarship. First, I theoretically enhance the best management practice adoption literature through incorporating an environmental sociological approach to technology. In doing so, I empirically contribute insight into how agricultural technologies influence the rate at which N is applied—a topic little explored to this point in the agricultural N use literature. Second, empirical analysis of the environmental sociological literature's 'technology hypothesis' has primarily occurred at a macro-level (e.g. Sellen & Harper, 2002; York, 2017; York & McGee, 2016). My farmer focused analysis brings this theoretical perspective to the individual-level, exploring the limited potentials of 'green technologies' observed at the macro-level and the extent to which this extends to individuals in an agricultural context. I begin by discussing the context of N use, best management practices, a form of technical solutions to environmental issues, and Midwestern corn farming.

NITROGEN, CORN AND BEST MANAGEMENT PRACTICES

Nitrogen (N) fertilizer is an essential agriculture input (Robertson & Vitousek, 2009), contributing to crop yield increases that supply an estimated 40% of the global population with its nutritional needs (Smil, 2002). Agricultural N fertilizer is also the primary cause of a number of pressing environmental issues (Vitousek et al., 1997). N levels that exceed normal biophysical levels contribute to water and air pollution. This includes hypoxia in surface water, most notably it is the primary pollutant causing the 7,000 square mile 'dead-zone' in the Gulf of Mexico (Ribaudo, 2006). It also contaminates ground-water sources, causing such ailments as blue-baby syndrome (Townsend et al., 2003). And finally, when in its nitrous oxide (N_2O) gaseous form, excess N contributes to climate change as a greenhouse gas that is 300 times more effective at heating the atmosphere than carbon dioxide (EPA, 2015).

Agriculture N pollution levels are determined by the amount of N lost from agricultural fields to the surrounding environment, either through leaching, runoff or dentirification processes. Corn is both the primary receiver of agriculturally applied N in the US and the crop that loses the higher percentage of N that is applied to it. About 50 percent of all N applied in the US is applied to corn (ERS, 2017) and approximately 50 percent of N applied to corn is lost to the environment as pollution (Cassman et al., 2002). In the US, most corn is grown in the states appropriately referred to as "corn belt" states in the Midwestern region (Arbuckle et al., 2013; USDA-NASS, 2015). Reflecting the prominence of corn production here and the crop's relationship with N use, the Midwestern states are key sources of and deeply affected by multiple forms of N related pollution (Larsen et al., 2007; USGS, 2010; Ribaudo, 2006).

N is considered a vital input for the contemporary agricultural system (Wolf & Buttel, 1996), making strategies to reduce N like legal restrictions and taxes of interest to researchers and to society writ large. Immediately addressing agricultural N pollution then requires implementing strategies that increase the efficiency of N use; efficiency being used here as a measure of the amount of applied N taken up by the crop and thus not available to be lost to the environment (Robertson et al., 2013). Of the multiple practices to achieve this goal, the rate at which N is applied is considered the practice that most determines the environmental efficiency of agricultural N use and thus the amount of N related pollution all forms (Blesh & Drinkwater, 2013; Ribaudo et al., 2011; Robertson et al., 2013; Sawyer & Randall, 2008). Application at rates that exceed crop yield potential are particularly problematic in terms of level of N pollution (Hoben et al., 2011). This is particularly true regarding N_2O emissions. However, the primary focus on this study is total N application rate. Even when N application rate does not exceed crop yield potentials, increases in total rate lead to increased levels of N related pollution. Again, this particularly applies to N_2O emission, which have been widely found have a positive correlation with the application rate of N fertilizer (McSwiney & Robertson, 2005; Mosier et al., 2006; Dusenbury et al., 2008; Halvorson, Grosso, & Reule, 2008). This relationship between N rate and N_2O is established to the point that N rate has been argued to be a proxy measure for agricultural N_2O emissions (Millar et al., 2010). Given the significance of N rate in determining pollution levels of N, reducing N application rates is a step of vital importance in reducing N pollution levels, particularly as N relates to climate change (Robertson et al., 2013).

A number of management strategies or practices exist that are capable of facilitating lower N application rates (Fils, 2017; Roberts, 2009). These strategies improve N use efficiency and through increasing the impact of what N is applied, they enable less N to be applied. These strategies include applying N fertilizer at the *right time*, in the *right type*, in the *right place.* General practices to accomplish these strategies include: 1) spreading N applications over multiple times, particularly in the growing season (*right time*); 2) applying N near the crop and/or under the surface of the soil, for instance by banding or injecting N in the row (*right place*); and 3) applying a type of N that is not easily lost from the field to the environment (*right type*). A range of agricultural technologies and equipment exist to enable the implementation of these strategies. Application equipment, such as sidedress toolbars for tractors, allow farmers to apply N at the *right time,* while injection or banding applicator equipment places N near crops and under the soil, accomplishing *right place.* The use of N stabilizers with one's N, such as "N-stinct," accomplishes *right type* by reducing the chances applied N is lost from fields. Each of these practices can independently reduce the potential amount of N lost to the environment. However, given the significant environmental impact of N application rate, the central benefit of these N best management practices in principle is that they enable farmers to reduce N rates to appropriate levels through improving the efficiency of applied N. Alongside these equipment and application technologies are a suite of information 'decision aid' technologies: soil tests, tissue samples and pre-sidedress nitrogen tests (PSNT). These decision aids are a means to better understand N needs. In this way, they can facilitate lower application rates, as farmers can better determine their corn crop's actual need for N (Weber & McCann, 2015).

As discussed above, agricultural N use is a key input in the modern agricultural system, but has significant environmental costs associated with inefficient use. The rate at which N is applied is a key predictor of the efficiency of N use and therefore agricultural N pollution levels, particularly related to the powerful greenhouse gas of N_2O. If implemented on the farm scale, management based methods could enable more efficient N use and thereby facilitate a reduction in farmers' N application rate. Because of the potential benefits of these agricultural N best management practices, the current topical literature has focused particularly on what factors lead farmers to adopt these strategies. Practices explored in past literature generally reflect those discussed above (Baumgart-Getz et al., 2012; Prokopy et al., 2008). These include: soil and/or tissue testing, or "decision aids" (Bosch, Cook, & Fuglie, 1995; Khanna, 2001; Lambert, Sullivan, Claasen, & Foreman, 2007; Weber & McCann, 2015); efficient equipment, such as variable rate or precision application equipment (Daberkow & McBridge, 2003; Lambert et al., 2007); and use of N stabilizers (Weber & McCann, 2015).

The challenge commonly seen with these practices is that too few farmers adopt them. This is reflected in the well-developed and ever expanding literature—often referred to as the agricultural best management practice adoption literature—which primarily addresses the question of why these N management practices are not more widely utilized by farmers and what can be done to better encourage their adoption (e.g., Baumgart-Getz et al., 2012; Fuglie &

Bosch, 1995; Napier, Camboni, Thraen, 1986; Napier & Camboni, 1988; Weber & McCann, 2015). This work has offered insights into the factors influencing the use of N best management practices, to this point largely examining individual level processes. The most commonly explored factors include: use of information sources (McBride & Daberkow, 2003; Stuart et al., 2012; Weber & McCann, 2015;); farmer value-orientations and risk perceptions (Reimer, Thompson, & Prokopy, 2012; Urlich-Schad et al., 2017); demographic characteristics such as farmer age, education, tenure and income (Lasley et al., 1990; McBride & Daberkow, 2003; Weber & McCann, 2015); and farm characteristics, such as farm size (Caswell et al., 2001; Lasley et al., 1990; Prokopy et al., 2008; Weber & McCann, 2015). This literature has offered important insights into the drivers of N best management practice adoption and in doing so shed light on key focal areas of future policy development.

However, a key research gap currently exists in the best management practice adoption literature. To this point, very few studies have focused on how farmers' actually implement adopted nutrient best management practices (Urlich-Schad et al., 2017). Stated alternatively, little research has actually explored if adopted best management practices are used in ways that lead to a reduction in environmental degradation. The few studies addressing this topic have indicated that even when a practice is adopted, it may not be implemented as intended or even fully utilized (Genshow, 2012; Osmond et al., 2014). For instance, Osmond et al. (2014) find that farmers were not altering their nutrient management in response to provided soil test recommendations and thus there was not environmental benefit from their adoption. As this suggests, it should not be assumed that adoption of a best management practice will result in environmental gains.

Reflecting this broader research gap, whether N best management practice adoption relates to environmental gains has yet to be thoroughly examined. As I noted above, a primary benefit of the discussed N best management practices—N stabilizers (*right type*), precision application equipment use for multiple application timings (*right time*) and undersoil application technologies (*right place*)—is the capacity to use lower N application rates, the key predictor of N pollution levels. If these practices are used in ways that lead to stable or even increased N rates, their promised environmental benefits may be significant diminished or eliminated altogether (e.g. Ribaudo et al., 2011; Robertson et al., 2013; Sawyer & Randall, 2008). Despite the importance of N rate for agricultural pollution levels, very little attention has been given to how the adoption of these practices impacts farmers' N application rate. Indeed, N application rate itself has only rarely been specifically examined, particularly in the last two decades (see Blesh & Drinkwater [2013]; Schewe & Stuart [2018]; Williamson [2011] as exceptions). Empirical evidence that farmers' adoption of best management technologies leads to reduced N application rate is extremely limited and thus whether N best management practice adoption results in improved environmental outcomes related to agricultural N use has yet to be reliably established.

I offer preliminary insight into this research gap in this study by examining how farmers' use of best management practices affects their N application rates. I build on the small amount of prior literature on adoption versus implementation in contending that whether or not N best management technologies leads to reduced N rates is contingent upon its implementation by farmers. However, in this analysis I conceptually extend this prior work through suggesting, via the political-economy of technology literature from environmental sociology, how contextual social-economic factors may influence farmers' implementation of nitrogen best management practices. Below, I present theoretical background to argue that the political-economy of US agricultural production may lead N best management practices to be implemented in ways that result in increased, rather than decreased, levels of N pollution.

THEORETICAL BACKGROUND

The political-economy of technology literature has emerged in environmental sociology to fundamentally challenge the broader assumption about the capacities of green technologies to lead to reduced environmental impacts and a sustainable socio-economic system (York & Clark, 2010; York, 2006; Sellen & Harper, 2002). This work may be best understood in its opposition to what has been referred to as the "techno-optimist" view in recent work (Dentzman, Gunderson & Jussaume, 2016). Techno-optimism can be said to be defined by two interrelated assumptions. The first is that technical solutions are capable of quantitatively reducing the degree of environmental degradation associated with a range of human activities. Or, as stated by York and Clark (2010), techno-optimism assumes that, "technological breakthroughs will serve as the means to address each and every environmental problem that arises, allowing society to overcome natural limits and all socioecological challenges" (p. 481). Embedded within this assumption is another: that because technical means are capable of solving social and environmental issues, a fundamental change in how human behave (e.g. the manner or the degree to which humans interact with the environment) need not be altered. For example, rather than addressing global food insecurity through adjusting how food is distributed globally (i.e. adjusting human behavior), the techno-optimist position is realized in the growing calls to increase in the intensification of agricultural production via further increasing use of agro-chemical input (Alexandratos & Bruinsma, 2012). The promise of technology is then the relative maintenance of the social, cultural and economic status quo, but with reduced or eliminated environmental impacts (Weinerg, 1981; York & Clark, 2010).

As noted by Dentzman and colleagues (2016), variations of techno-optimism can be found throughout environmentally focused social science literature (e.g. Lomborg, 2010). Ecological Modernization Theory (EMT) may best exemplify this position in scholarly practice (Mol, 2001). At the center of the EMT position is the possibility of technical solutions for resolving environmental crisis associated with commodity production (Fisher & Freudenburg, 2001; York & Clark, 2010). Rather than a quantitative reduction in commodity production (i.e. changing human behavior), EMT scholars have argued that "superindustrialization" or the increased use of "green" technologies in commodity production will result in improved environmental outcomes (Mol, 1996; Spaargaren and Mol, 1992).

The techno-optimist position generally captures the assumptions guiding much of the agricultural best management adoption literature. As noted above, the fundamental question driving this literature is what leads to (or prevents) farmers from adopting agricultural best management practices (e.g. Napier et al., 1988; Morris et al., 2000). Best management practices, as forms of technology, are generally assumed to be capable of at least significantly reducing the environmental costs of agricultural production without fundamentally changing the nature of contemporary agricultural production (e.g., Baumgart-Getz et al., 2012; Millar et al., 2010; Weber & McCann, 2015). And while in recent work some consideration has been given to the need for fundamental changes in the structure and function of the US agricultural system (Blesh & Wolf, 2014; Drinkwater & Snapp, 2007; Roesch-McNally et al., 2018), the potential of technological solutions to reduce environmental consequences while maintaining the current structure of the agricultural system is the dominant focus across this literature broadly (e.g.

Prokopy et al., 2008) and that specific to N use (Caswell et al., 2001; Lasely, 1990; McBride & Daberkow, 2003; Weber & McCann, 2015).

The techno-optimist position has been conceptually and empirically challenged by a theoretical perspective emerging from the Marxist political economy environmental sociology literature. The political economy technology literature argues there are a number of problems with the 'techno-optimist" position as it relates to reducing environmental degradation (see Dentzman et al., 2016; York & Clark, 2010; York & McGee, 2016). Broadly stated, the majority of this literature posits that the macro-level influence of the profit imperatives of the capitalist social-economic system lead green technologies to be implemented in ways that favor economic, rather than environmental outcomes (Schnaiberg, 1980; York & McGee, 2016). In consequence, this theoretical framework argues that if efficiency gains are achieved, they will be used to increase profitability and production output, rather than conserve resources. Therefore, "green" technology adoption, such as agricultural best management practices, will either have a null impact on environmental degradation levels or, reflecting the observed relationship between efficiency and resource consumption of the Jevons' paradox[41] (Jevons, 1906), actually increase the consumption of risk-related resources and associated pollution levels (Polimeni, Mayumi, Giampietro, & Alcott, 2008; York & Clark, 2010).

Both of the political-economy of technology literature's positions have been affirmed in empirical studies, which to this point have primarily occurred at the macro-level, particularly focusing on nation state as the unit of analysis (Polimeni et al., 2008; Sellen & Harper, 2002; York, 2017;). For instance, regarding the failure of technical solutions to provide environmental

[41] See York and McGee (2016) for more detail on the Jevons Paradox. In short, this paradox describes the positive relationship between production efficiency and resource consumption, as observed by William Jevons in terms of coal furnace efficiency and coal consumption (Jevons 1906).

benefits, York (2012) finds that in most nations of the world, over the past five decades, the generation of non-fossil fuel energy typically did not effectively displace the use of fossil fuels—non-fossil energy sources were for the most part added to, not used in place of, fossil energy sources. The Jevons paradox has also been empirically demonstrated (Polimeni et al., 2008; York, 2017; York & McGee, 2016). For example, York and McGee (2016), in an analysis at the global level, find that nations with greater levels of energy efficiency tend to have higher rates of growth in electricity and overall energy consumption and carbon dioxide emissions. This literature frequently cites examples of the failure of technical solutions to lead to improved environmental outcomes in the agricultural context, often using the case of pesticides as discussed by Rachel Carson's (2009 [1962]) *Silent Spring* (e.g. York & Clark, 2010; York & McGee, 2016). However, little work to this point has empirically explored the hypotheses of the political economy of technology literature in this context.

Though it has rarely been applied to agriculture, the political economy of technology literature has much to offer research on farmers' N best management practice adoption. The described debate on the potential of technological solutions indicates that rather than the assumed relationship between best practice use and N application rate—best practice use predicting decreased N rates and thus pollution levels—it is also possible that increased N use and therefore pollution is associated with the use of these technical solutions. This is particularly suggested by the evidence of the presence of political economic factors and profit imperatives in US agricultural production (Friedland et al., 1981; Lewotin, 2000; Weis, 2010). These studies reveal that the same structural features argued to prevent 'green' technologies from leading to environmental improvements in the broader literature exist within the context of the US agricultural system. More specifically, a small but growing number of studies have shown how these political economic forces, such of the profit imperatives imposed by agro-business, are driving Midwestern corn farmers to increase, not decrease, N use (Schewe & Stuart, 2018; Stuart & Houser, 2018). In short, given the presence of political economic forces and their observed impact on farmers' N use, the adoption of N best management practices may have no effect on N rate, or even increase it following from Jevons paradox.

The primary objective of this study is to examine this potential. Stated in the terms of the theory discussed above, my analysis focuses on whether the efficiency gains enabled from the adoption of agricultural best management practices lead to reduced N use and therefore environmental pollution from N. Through this focus I advance both the agricultural best management practice literature and the political-economy of technology literature. Related to the former, I address calls for further investigation of how best management practices are actually implemented by examining if their adoption is associated with N use decreases (Ulrich-Schad et al., 2017). Through conceptualizing my analysis and results in terms of the political economy of technology literature, I further integrate this theoretical perspective into the agricultural literature, building on the small amount of work that has previously done so (Dentzman et al., 2016). As noted the political economy literature has focused both theoretically and empirically at the macro-level of the nation state, with little attention to individual-level potential for efficiency gains from technology implementation. Through examining farmers' behavior, this study can begin to indicate how, or if, the political economic structure influences farmers' implementation of green technologies in the same way it has occurred at the macro-level.

DATA AND METHODS

Data for this analysis comes from a 2017 survey of Midwestern row-crop farmers across four states: Illinois, Indiana, Michigan and Ohio. The survey focused on gathering information on farmers' nitrogen fertilizer use, among other dimensions of crop management. The four states were selected to represent a range of social, economic and biophysical factors dispersed across the Midwestern 'corn belt' states. The surveyed states are themselves major producers of corn in the US and thus the farms and farmers within them are key users of N fertilizer. Together, planted acres of corn in these states made up 26% of the total acres planted in the US in 2016[42] (NASS, 2016), and these states are located in the agricultural regions of the US where the greatest amounts of N is applied (Ribaudo et al., 2011).

To reach corn-soy farmers in these states, a list of 10,582 farmer addresses was purchased from a private marketing firm that specialized in agricultural marketing. The percentage of farmers' addresses purchased for each state varied according the state's total row-crop farming population. In this way, the sample better reflects the regional population. To focus on farmers with the largest environmental impact, addresses for only those farmers who grew over 100 acres of corn or soybeans annually were purchased. A stratified random sample design was then used to ensure adequate representation of large farms. Two categories were used, farms of less than 500 acres and farms of more than 500 acres. In mailing surveys to farmers in these states, a modified Dillman approach was used (Dillman, Smyth, & Christian, 2014). In February 2017, farmers were mailed a preliminary notification postcard. Two-weeks post post-card mailing, an initial survey packet was mailed and included a cover letter on Michigan State University Letterhead explaining the study's purpose. The second and final wave followed the first mailing two-weeks later and included another survey packet and cover letter.

In total, 3,280 surveys were returned for a total response of 31%. A portion of these surveys were unusable for a variety of reasons: the respondent did not grow corn, was not the

[42] Percentage of US total acres in each state is as follows: Michigan (2.5%); Indiana (6.5%); Illinois (13.2%); Ohio (3.8%) (NASS, 2016).

primary decision maker on the farm or was deceased. After eliminating unusable surveys, the final usable response rate was 22%. While this response rate is low compared to traditional metrics, it accords well with other recent mail surveys of Midwestern corn farmers (e.g. Arbuckle et al., 2013b; Reimer & Prokopy, 2014; Stuart et al., 2014). These low response rates reflects the general decline in survey response rates specific to farmers (Johansson et al., 2017); a trend that is also reflected in the broader non-farming US population (Czajka & Beyler, 2016; Tourangeau & Plewes, 2013).[43] Over-sampling of large farms led to a high percentage of respondents operating over 1,000 acres (39%). In consequence, this sample may over-represent large farmers in these states. Given my focus on farmers with the largest environmental impact, this is a desirable bias. After dropping missing cases, the total sample sized examined is 798.

The survey questionnaire focused on a range of topics, including crop management practices, farmer social-psychological value orientations and environmental views and demographic and farm characteristics information. The analysis I present in this study draws results from questions regarding farmers' N fertilizer use and best N management practice use on the largest field on which they grew corn in the 2016 growing season. Questions about nutrient use and practice adoption were asked in regard to a specific field. Largest field was emphasized on for two reasons: focusing on a specific management area will increase the ease of responding for farmers and, given that this is the largest field, it is likely representative of the practices farmers may use across the majority of their tillable acres.

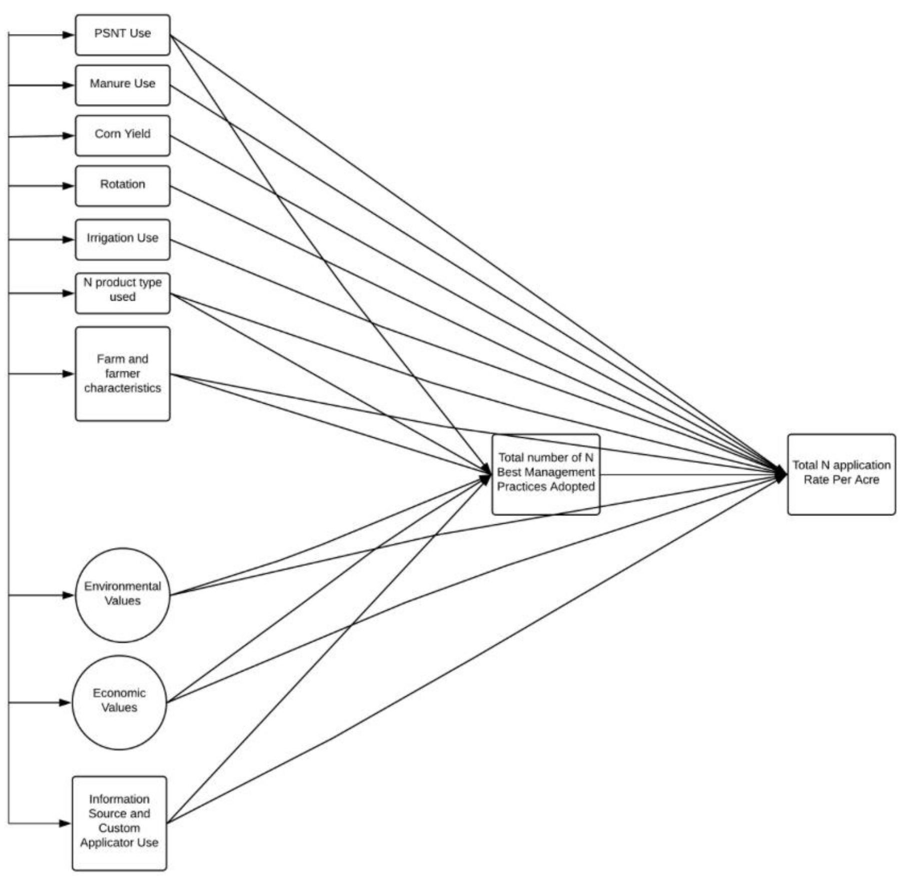
[43] Response rates for long running nationally representative cross-section surveys in the US (e.g. National Health Interview Survey [NHIS]; The General Social Survey [GSS]; The National Household Education Survey [NHES]; The National Immunization Survey [NIS]) have declined considerably over the last two decades (Brick & Williams, 2013). Given this context and that of farmers' declining response rate to surveys, innovative techniques and further methodological approaches will need to be taken to address this serious challenge to a key social science data gathering technique.

I use structural equation modeling with latent variables (SEMLV) to estimate my model (Bollen, 1989; Hoyle, 2012). SEMLV is a multi-equation regression technique that accommodates relations between multiple exogenous and endogenous variables simultaneously and includes both latent and observed variables. A latent construct, also called a latent variable, is an unobserved variable that captures the relations between the multiple observed variables being used to measure it (Bollen, 1989). As is standard practice in SEMLV, I evaluate the fit of each of the two latent variables used as predictors in my model via measurement models (or confirmatory factor analysis (CFA)). I use STATA 14, SAS 9.3 and AMOS 24 for my analyses (Arbuckle, 2010; Long & Freese, 2006; SAS Institute, 2001).

I use two latent variables as exogenous predictors in my model. CFA results provide fit statistics for each measure or component included in the latent variable and the overall fit or quality of the latent construct, both of which need to be examined to comprehensively assess the fit of the latent constructs and evaluate their appropriateness for use in the analysis. The component fit of an acceptable latent variable has standardized and unstandardized factor loadings close to one another (the former above .40 and the latter around 1.00), which taken together with other aspects of component fit show that the included measures are valid and reliable measures of the latent construct. Overall model fit statistics for such a latent variable include a non-significant chi-square value (indicating that the estimated model is not significantly different from the data), fit indices like the Comparative Fit Index (CFI) that are above 0.95, and a Root Mean Square Error of Approximation (RMSEA) that is below 0.05 (West, Taylor, & Wu, 2012). Appendix D provides information about the component and overall model fit for each of the latent variables used in the empirical analyses.

As SEMLV is able to simultaneously analyze multiple relationships between exogenous and endogenous variables, I create a path model that predicts N application rate, working through best management practice use. In consequence, my analysis predicting total N application rate accounts for the indirect effects of variables predicting practice adoption and the direct effect of practice adoption on farmers' N application rate, along with other relevant control variables. I use SEMLV to accurately account for direct and indirect paths as specified in the model shown in Figure 7 below. Given the focus on this study, the remainder of my discussion centers on variables used in the analytical model and results from the equation predicting N application rate. Results for the equation predicting total number of best management practiced predicted are available in Appendix E.

Figure 7: Path model used in analysis



Outcome variables: Total N application rate in lbs./acre

As discussed above, the rate at which N is applied is widely considered the most important factor determining N pollution levels, and N application rate has been argued to be a proxy of various forms of N pollution, particularly N_2O emission (Hoben et al., 2011; McSwiney & Robertson, 2005; Millar et al., 2010). Accordingly, as a proxy measure of the environmental efficiency of their agricultural N use, I use farmers' *N application rate* on their largest field growing corn in 2016 as the outcome variable. Following the biogeochemical literature, N application is measured in lbs./acre (e.g. Hoben et al., 2011). N rate per acre is calculated by aggregating the lbs./acre application rate of all N products used by respondents. When appropriate, N rate by product was recoded to reflect the pounds of actual N applied (rather than the pounds of the total product). After visual inspection of the distribution of the N application rate variable, three responses were dropped. [44] Calculations for this variable's conversions and the N rate survey question can be found in Appendix F and I.

I expect that farmers' N rate per acre on their largest field is generally reflective of the N rates used across farmers' total operation; though future studies should be more specifically attuned to whether and how N rate application varies across farmers' operation. To better ensure the reflectiveness of largest field N rate, the small number of farmers who noted in the table they used variable rate application were dropped from this sample prior to analysis (N=4). Variable rate use indicates that their N application rate on their largest field (if one was included in the response at all) likely does not reflect a general practice across their farm, as variable rate implies that farmers are at least using different rates across fields, if not within fields. Across the

[44] While these outliers were excluded, it should be noted their inclusion did not alter the results of this analysis.

sample, the N application rate ranges from 22 lbs./acre to 383 lbs./acre. The mean rate is 183 lbs./acre. More details on N application rate are presented below.

Independent variables

Farmers' use of N best management practices are the main independent variables of interest in this analysis. The above noted practices argued to enable more efficient N use are included in this analysis (e.g. Robert, 2009; Robertson et al., 2013). To capture the 4-R of *Right time,* I included a variable for *use of multiple N application timings* on the respondent's largest field. This variable is binary, where 1=use of more than one N application timings. Applying N multiple times throughout the season represents the best management approach, as a greater number of application timings can improve N use efficiency and thus reduce N needs. *Use of undersoil application,* where the N product is applied under the soil surface, either incorporated through a form of tillage or injected with a tool, accomplishes "*Right place*." Use of undersoil application is a binary variable, where use is defined by using injection or incorporation to place N under the soil surface (use=1). "Right type" is reflected in the variable *stabilizer use*, which indicates whether a farmer applies their N using a N stabilizer to reduce the chance of leaching or volatilization (Weber & McCann, 2015). Stabilizer use a binary variable (use=1). I combine these three variables in an index measure, *combined practice index,* which creates a measure with a range of 0-3, with zero representing use of no best management practices and three being use of every best management practice. Importantly, for analysis this range was expanded for better prediction (0=0; 1=3.333; 2=6.666; 3=10).

I also include a range of variables that prior literature has found to be significant predictors of farmers' adoption of N best management practices, as they may also drive N application rate decisions. Agricultural information sources are key factors influencing farmers'

N management decisions (Mase et al., 2015), including their N best management practice use (Hoag et al., 2012; Hoag, Luloff, & Osmond, 2012; Osmond et al., 2014; Weber & McCann, 2015). Some past research has suggested that use of information, compared to not using information, is an important factor driving conservation focused N management (Weber & McCann, 2015). I build on this work here by focusing on how intensely a farmer uses agricultural information sources. *Information source use index* measures farmers' total use and trust in agricultural information sources, with higher values being associated with higher total use frequency and trust in the following information sources: campus-based extension faculty, county-based extension educators, chemical dealers, seed dealers, independent agronomists, other farmers and family, agricultural magazines, agricultural websites and smart-phone apps, grower associations, and any other agricultural information sources used. The information source use index variable ranges from 2-9. Also, to reflect the literature's focus on the influence of "decision aid" technologies, a variable for *Pre-Sidedress Test Use (PSNT)* is included (Daberkow & McBride, 2003; Khanna, 2001; Lambert et al., 2007; Weber & McCann, 2015). PSNT tests provide information on current N levels in soils and thus may enable farmers to more accurately determine appropriate (i.e. apply lower) in-season N application rates. PSNT is a binary variable, with use being defined by regular or occasional use of PSNTs in corn years (use=1). I also include two binary variables for *Hired Fertilizer Sampling and Recommendation* (1=hired) and *Hired Fertilizer Application* (1=hired). These variables capture whether or not a farmer did fertilizer sampling and applications themselves, or hired another individual or private contracting company to do them. We might expect farmers who rely on others for these practices to use higher rate of N, as the firms that provide sampling and application services likely also sell fertilizer.

Given expectations from prior literature related to practice adoption, N use may be impacted by farmers' social-psychological characteristics, like the degree to which they are concerned about the environment or their economic value orientations (Baumgart-Getz et al., 2012; Reimer et al., 2012; Ulrich-Schad et al., 2017). '*Environmental values*' is a latent construct that includes four variables gauging values related to how important the items were to being a farmer and managing their operation. These survey items include looking after the environment, passing on the land in good condition, minimizing environmental impacts, and improving the condition of the land on a scale from 1=low importance to 5=high importance. The CFA results and fit statistics shown in Appendix A indicate very good fit of this latent construct. Overall fit statistics are good—the chi-square value is non-significant ($p = 0.074$), and values for the CFI is 0.998, and the RMSEA is 0.0244 (CI=0.00, 0.0488) (West, Taylor, & Wu 2012).

'*Economic values*' is a latent construct that includes six variables capturing the importance of being a successful farmer, especially in economic terms, including being among the best in the industry, building up land and wealth assets, and profit maximization on a scale from 1=low importance to 5=high importance. The CFA results and fit statistics shown in Appendix A indicate good fit of this latent construct. Overall fit statistics are reasonable—the chi-square value is ($p = 0.01$), but other values are good: the CFI is 0.993, and the RMSEA is 0.0507 (CI=0.019, 0.0904) (West, Taylor, & Wu 2012).

Past work has indicated that farmer and farm characteristics may drive practice adoption (Baumgart-Getz, Prokopy, & Floress, 2012; Caswell, 2001; Lasley et al., 1990; Ulrich-Schad et al., 2017; Weber & McCann, 2015). To reflect the variables used in this literature, my model includes measures of education, farming experience, farm size and the percent of household income from farming. *College Education* is a dichotomous measure of whether farmers have attended at least some college (college=1). *Years of farming experience* is a continuous variable, ranging from 1 year to 65 years. I expect farmers with more years of experience may use less N, as they have refined their understanding of their crop's N needs over their farming career. *Farm size* is dummy variable, where large farms (over 1000 acres) and medium farmers (999-500 acres) are compared to small farms under (under 499 acres). *Percent of household income* from farming is also a categorical variable, measuring percent of income from farming in 25 percent increments. This variable is used to determine if farmers' who depend more on their farming income for their livelihoods use more N as a risk management strategy, as suggested by past work (Sherriff, 2005). The state in which the farm was located was also included, with *Ohio*, *Michigan*, *Indiana* and *Illinois* (reference) compared as dummy variables. *Animals on farm* measures whether or not livestock and animal products other than dairy account for 10% or more of farm revenues was also included as a dichotomous variable (1=animals over 10%). Grain farms that also receive a significant portion of their income from animal production may use less N, as more diversified revenue sources minimize economic risks that otherwise would be addressed through increased N rates (Sherriff, 2005).

Finally, a number of variables that may impact N application rate on the largest field were also included as control variables. This includes the binary measures of *irrigation use* (1=use), *manure use* (1=use), and dummy variable for type of N product type used, which includes exclusive *anhydrous ammonia use* (reference), exclusive *UAN use,* exclusive *other N type use*, including urea and ammonia sulfate, and finally *use of multiple N products*. Dummy variables for type of N product are included the control for the price of the N fertilizer product being used to apply N. I expect that lower priced N products, anhydrous ammonia being the historical cheapest form of N (ERS, 2017), could lead to higher N rates as farmers are able to apply more before exceeding profitable N application thresholds. Further, use of multiple N types may also capture N management complexity, where farmers who use multiple types are compared to farmers only using exclusively one type, in this case anhydrous ammonia. I expect that *use of multiple N products* will be associated with higher N use, as it may be more difficult for the farmer to accurately calculate their actual total N application rate. Also, crop rotation on largest field was included as three dummy variables: *corn-corn* rotation, *other crop-corn* and *corn-soy*. Corn-soy is used as the reference category as it is the rotation used by the majority of survey respondents. Finally, and importantly, *the 2014 corn yield* in bushels/acre on the largest field is also included as a continuous variable to capture the effect of expected yield on N application rate.[45] As most farmers were in corn-soy rotation, the 2014 corn yield represents with the majority of sampled farmers had most recently grown corn on their largest field. For those in rotations other than corn-soy, 2016 corn yields were imputed in this variable. In consequence, it accounts for the impact of expected yield, which I anticipate should positively predict N application rate.

RESULTS

Tables 16 through 18 show the descriptive results of variables used in this analysis. Across the sample, the N best management practice most farmers reported using was undersurface application (83%), followed by use of more than one application timing (66%) and a stabilized N product (53%). Some variation in the use of these practices occurred across state context. Use of N stabilizers was notably higher in Illinois than in other states, with 65% of Illinois farmers reporting the use of this practice. Similarly, 80% Indiana farmers reported having used more than one application timing, compared with 70%, 61% and 56% of farmers in Ohio, Illinois and

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[45] Visual inspection of a dotplot of the yield16 variable was used to detect and drop outliers. A total of 8 cases were dropped.

Michigan respectively. Use of undersurface application was fairly evenly and highly used across Illinois, Indiana and Ohio at 85%, 83% and 85% of the sample respectively. A slightly lower percentage (75%) of Michigan farmers used undersurface application. Concerning the combined practice index measure, only 5% of farmers across the sample used no N best management practices, 19% of farmers used 1 practice; 46% used 2 and 31% used all 3.

As displayed in Table 16, of the 798 respondents, approximately 37% resided in Illinois, 30% in Ohio, 18% in Indiana, and 15% in Michigan. The largest category of farm size is large farms above 1,000 acres (38%), followed by medium farms between 999-500 acres (30%). The majority of farmers in the sample derived over 75% of their total household income from farming activities (51%). The average number of years spent farming of respondents was 30, with most farmers having farmed for between 21-40 years (50%). Sixty-one percent of farmers had at least attended some college. Farmers were, on average, fairly intense agricultural information consumers, with an average information source index score of 6.8. Finally, of particular note for characteristics of the largest field is the rotation and yield. The mean reported corn yield across the sample was 189 bushels/acre, and the majority of farmers reported that their largest field was in a soy-corn rotation (78%). See Appendix G for state specific results.

Table 18 displays the average N application rate in lbs. per acre by state. Across the sample, the average rate is 182 lbs./acre. Strict comparison between this study's farmers' N application rates to other studies is difficult, as little research has specifically focused on this topic.[46] Considering that average N rate and yield are relatively equivalent, almost a 1:1 ratio

[46] ERS (2017) offers state level average N rate on corn for the 2016 seasons. As the sample used in this study represents farmers who received a greater percentage of their income from agriculture and have larger operations than the general farming population and are exclusively non-organic, direct comparison between this study and the ERS results is inappropriate. With this said, this study's sample should use higher average rates. This is borne out in comparing state averages of this sample to the ERS sample. ERS state averages are uniformly, though not surprisingly, lower than this sample (format: this study versus ERS): Michigan: 156 compared 122 lbs/acre; Ohio: 183 compared to 167 lbs./acre; Illinois: 193 compared to 169 lbs./acre; Indiana 180 lbs./acre 163 lbs./acre.

(189-182), suggests the reliability of this measure. Use of a 1:1 ratio between corn yield and pounds of N applied is a common (though no longer recommended) rule of thumb for determining appropriate N rates, and Midwestern farmers have been found to report using this ratio (Reimer, Houser, & Marquart-Pyatt, In preparation).

Table 16: Descriptive results

Variables	Results	Standard Dev.	Scale
Attitudes			
Environmental Values	16	2.3	4-20
Economic Values	16.7	2.3	4-20
Information			
Information Use Index	6.8	1.7	2-9
Use of Pre-Sidedress Test[#] (PSNT)	.18	.38	0-1
Hired Fertilizer Sampling and recommendation	.77	.42	0-1
Hired Fertilizer Application	.76	.43	0-1
Largest Field Characteristics			
Irrigation Use	.055	.23	0-1
Other N form Use	.04	.21	0-1
Anhydrous Use	.14	.35	0-1
UAN Use	.23	.42	0-1
Multiple N Type Use	.58	.49	0-1
Manure Use	.11	.31	0-1
Corn-Corn Rotation	.15	.36	0-1
Other Crop-Corn Rotation	.10	.29	0-1
Soy-Corn Rotation	.76	.43	0-1
Corn Yield (2014)	189	32.3	90-275
Individual Farmer and Farm Characteristics			
Farm Size 1000+ Acres	.39	.49	0-1
Farm Size 999-500 Acres	.30	.46	0-1
Farm Size 500 Acres or less	.30	.46	0-1
Years of farming experience	29.7	13.6	1-65
Farmers who attended at least some college	.61	.49	0-1

Table 16 (cont'd).			
Indiana Farmers	.18	.38	0-1
Michigan Farmers	.15	.36	0-1
Ohio Farmers	.30	.46	0-1
Illinois Farmer	.37	.48	0-1
Percent of household income	3.1	1.1	1-4
Animals on farm	.22	.42	0-1
Combined Practice Index	6.7	.27	0-10
Total n	798	--	--

Table 17: Descriptive results for nitrogen (N) best management practice use

State	Use under surface application	Use more than one application timing	Use stabilizer	Combined Practice Index (mean sample values)**	n
Illinois	85%	61%	65%	2.1	294
Indiana	83%	80%	47%	2.1	143
Michigan	74%	56%	44%	1.7	120
Ohio	85%	70%	49%	2.0	241
Total Sample	83%	66%	53%	2	798

*These practices reflect the 4Rs of Right Place, Right Time and Right Type, respectively.
**Range of 0-3.

Table 18: Mean nitrogen (N) application rate per acre across sample

State	Mean lbs. of N applied /acre from sample	n
Illinois	192	294
Indiana	184	143
Michigan	157	120
Ohio	185	241
Total Sample	183	798

Table 19 contains results from my SEMLV equation predicting farmers' total N application rate in pounds per acre, controlling for the model predicting N best management practice adoption (see Appendix H for additional results). While the prediction of farmers' practice adoption has important implications in and of itself, I focus on discussing and interpreting the results related specifically to N application rate. As I have previously indicated, these results can be understood as the effects of each variable controlling for the direct and indirect relationships of variables predicting practice adoption, which are simultaneously modeled though not presented here.

In predicting N application rate, I find that the combined practice index variable significantly and positively predicts N application rate per acre. Average N application rate per acre increases as the number of N best management practices a farmer has adopted increases, controlling for all other co-variates. Specifically, for each best management practice adopted, mean N application rate per acre increases by approximately 2 lbs./acre. Information source use intensity also significantly predicted N application rate. N application rate is reduced by around 2 lbs./acre for each unit gain in farmers' intensity of information source use. Compared to farmers who applied N themselves, farmers who hired a private applier to apply their N had rates that were significantly higher by 9.31 lbs./acre.

A number of significant effects were found related to farm and field management characteristics. As expected, type of fertilizer used had a significant effect on N application rate. Compared to farmers using anhydrous ammonia, farmers using urea and ammonia sulfate (other N sources) had lower rates by just over 50 lbs/acre. Additionally, farmers who used multiple N types, compared to those who used anhydrous ammonia exclusively, applied N around 24 lbs./acre higher. Farm size and rotation also significantly predicted N application rates.

Compared to farmers using a corn-soy rotation, farmers in a corn-corn rotation used N rates that were approximately 12 lbs./acre higher on average. Farmer operating farms that were over 1,000 acres, compared to farmers operating less than 500 acres, applied on average 17 lbs./acre more. Finally, some significant differences in N rate also emerged by state. Compared to Illinois farmers, Ohio farmers applied N at 10 lbs./acre higher on average, while Michigan farmers applied N at rates around 11 lbs./acre lower on average. These variables predict around 30% of the variation in N application rate per acre on largest field. Overall model fit is reasonable. The chi-square value is significant (p = 0.000), but the IFI is 0.942, the CFI is 0.937, the TLI is 0.824, and the RMSEA is 0.041 (CI=0.036, 0.045).

Table 19: SEMLV results for N application in lbs./acre	Unstandardized coeffs (std errors)
Combined Practice Index (*Right Type, Time and Place*)	2.201***
	(0.614)
Values	
Environmental Values	-2.374
	(10.594)
Economic Values	3.661
	(6.23)
Information	
Information Source Use Index	-2.18**
	(1.034)
Hired Fertilizer Sampling and recommendation#	-1.647
	(4.047)
Hired Fertilizer Custom Application#	9.31**
	(3.985)
Use of Pre-Sidedress Test# (PSNT)	-1.852
	(4.11)

Table 19 (cont'd).	
Largest Field Characteristics	
Irrigation use	8.15
	(6.771)
Manure Used#	-8.25
UAN use	-7.287
	(5.463)
Other N use	-52.292***
	(8.679)
Multiple N type use	23.667***
	(0.265)
Anhydrous Use (Reference)	--
	--
Corn-Corn Rotation	11.95***
	(4.706)
Other Crop-Corn Rotation	5.755
	(5.477)
Soy-Corn Rotation (ref)	--
	--
2014 Corn Yield	0.164***
	(0.0540)
Individual Farmer and Farm Characteristics	
Farm Size 1000+ Acres	16.675***
	(4.125)
Farm Size 999-500 Acres	6.587
	(4.109)
Farm Size 499 or less acres (reference)	--
	--
Years Farming	-0.012
	(0.116)
College Education#	-1.121
	(3.443)
Indiana Farmer	2.265
	(4.641)
Michigan Farmer	-11.579**
	(5.561)
Ohio Farmer	10.105**
	(4.262)
Illinois farmer (ref)	--
	--

Table 19 (cont'd).	
Percent of household income	0.237
	(1.486)
Animals on farm#	-5.352
	(4.042)
R-Squared	0.307

DISCUSSION

The application rate of N on agricultural fields is a key proxy measure of the pollution levels from these fields. Research that has accounted for this relationship between N rate and N pollution has accordingly emphasized that a reduction in Midwestern farmers' N application rate must be achieved if the environmental costs of agricultural N use are to be significant reduced (Blesh & Drinkwater, 2013; Hoben et al., 2011; Millar et al., 2010; Ribaudo et al., 2011). Past literature on the topic has primarily examined the predictors of agricultural N best management practice adoption (e.g., Baumgart-Getz et al., 2012; Napier et al., 1986; Napier & Camboni, 1988; Weber & McCann, 2015). This literature has rarely specifically explored how adopted best management practices are implemented and if they result in environmental gains (Ulrich-Schad et al., 2017). Rather, it can be said to have operated under the reasonable guiding assumption that farmers will implement these adopted practices—such as stabilizers, or precision application techniques—in ways that result in decreased agricultural N loss and thus N related environmental consequences. The results of the above presented analyses call this assumed relationship into question.

Using the proxy measure of N application rate for the environmental efficiency of surveyed farmers' N use, my results indicate that best management practice adoption is associated with increased, rather than decreased, potential environmental pollution from agricultural N. The combined practice index variable, which includes stabilizer use, undersoil application and use of multiple application timings, suggests that the more best management practices a farmer adopts, the higher their average N application rate may be.

Importantly, each of the practices included in the practice adoption index are not without their own independent environmental benefits. All three of the practices examined reduce the chances of N loss through leaching and volatilization, and therefore the adoption of these practices may reduce the amount of N lost to the environmental as pollution (Robertson et al., 2013). However, as I noted throughout the manuscript, N application rate is the dominant predictor of all forms of N pollution and particularly so with the powerful greenhouse gas N_2O. Thus, the primary environmental benefits from these practices come from their capacity to enable farmers to lower N application rates without sacrificing yield/profits (Millar et al., 2010). The observed increase in mean application rate therefore likely significantly, if not entirely, offsets the independent environmental benefits of the adoption of these practices. Rather than a reduction in the environmental costs of corn agriculture and N use, adoption of N best management practice may counterintuitively increase the environmental consequences of corn production in the Midwestern agriculture states of Illinois, Indiana, Ohio and Michigan.

Concerning control variables, results are in the expected direction, some with significant relationships. Manure use, though not significant, is associated with lower mean N application rates. Animal manure is a source of organic N and frequently used in combination with synthetic N. Thus, it is expected that use of manure should be associated with lower N application rates. Relatedly, N demand is linked to yield potential and in this study farmers with higher yields had significantly higher N use. Farmers in corn-corn rotations on their largest field apply N at significantly higher rates than those in soy-corn rotations. This difference accords with expectations and recommendations of prior literature for proper N use across different rotational systems (Millar et al., 2010). Finally, consistent with Fuglie and Bosch (1995) farmers using irrigation on their largest field also used higher N rates, though this relationship was not significant in my model. Across these control variables, the direction of their relationship conceptually accords with what we would expect. These results then suggest the reliability of the N rate measure used in this analysis.

A number of other control variables deem brief mention. First, state differences in average N rate appeared for Michigan and Ohio, compared to Illinois. Farmers in Michigan used significantly less N per acre than Illinois farmers. It is possible that biophysical factors, like shorter growing seasons or differences in seasonal climatic conditions, associated with Michigan's northern location relative to the other states, lead to shorter maturity length corn varieties and this process may partly explain Michigan's significantly lower application rates. Ohio farmers used significantly more N per acre than Illinois farmers. This may similarly be a relationship born out of variable biophysical differences, where Ohio can receive grow higher yielding corn varieties that require more N. Future work will need to consider the biophysical environment's role in effecting N rates in more detail. Additionally, farm size significantly and positively impacted N rate in this study. Farmers operating large farms, farms that exceed 1,000 acres, apply more N on average than farmers operating small farms, farms with less than 500 acres. Farm size is often found to positively predict best practice use (Baumgart-Getz et al., 2012). Larger farms may be associated with higher average N rates because farmers who operate more acres are less able to precisely manage inputs across these acres, and therefore higher rates are used to reduce the practical difficulties of operating on more than 1,000 acres of cropland. Reflecting prior work suggesting that information source use is associated with conservation practice use (Weber & McCann, 2015), my results show that higher levels of information source use are associated with lower average N rates. This is likely a result of these farmers being more intense consumers of agricultural information and therefore being more meticulous managers of N. Importantly, while decision aid technologies (i.e. PSNTs) and farmers' value orientation have been a focus of past literature examining practice adoption (Lasley et al., 1990; Reimer & Prokopy, 2014; Weber & McCann, 2015), measures reflecting these factors did not have significant effects on N application rate in this study. Given these results and N rate's relationship to N pollution, it is possible prior literature has overestimated the significance of these variables in effecting the environmental outcomes of production agriculture. However, it is also possible that alternative specifications of these variables are needed to capture their effect. Finally, the type of N being used also mattered for farmers' N application rate. My results show that farmers using other N types, compared to ammonia anhydrous, applied at much lower rates. This is not entirely surprising, as anhydrous is the least expensive form of N and therefore higher rates can be applied before maximum profitable thresholds for application are exceeded. However, I expect that given the substantial coefficient size, which indicates a 52 lbs./acre difference, that this effect is also capturing an effect not included in this analysis. Specifically, as few farmers exclusively use urea, the main N type that made of this category of other N type use, it is probable that rather than price effects alone, some unique characteristic of this group is driving this substantially lower N application rate. Future work will need to examine this in more detail. Further, compared to farmers using anhydrous ammonia, those farmers who used multiple N types in a single growing season used higher N rates per acre. This effect is likely not a function of price difference, but rather may be an effect of a miscalculation. It may be more difficult to accurately determine one's actual N rate when using multiple N product types. Alternatively, farmers who use multiple forms may be more active farm managers who are using more N as part of a combined strategy to increase production and yield outcomes on their ground. Again, future work will need to further examine this.

Returning to the discussion on the effect of N best practice use on N application rate, the observed relationship is the opposite of what the best management practice literature has assumed and what I imagine most scholars in the field would hope to see. However, the premises of the political-economy technology literature are borne out in the observed relationship between N rate and best management practice adoption. This work has commonly argued and empirically demonstrated that there is often a positive relationship between resource consumption and pollution levels and efficient technology adoption (Polimeni et al., 2008; York, 2006, 2007, 2017). To this point, most of this work has occurred at a macro-level, focusing on the national context—for instance, examining how the carbon emissions levels of nations relates to their total carbon efficiency measures (York, Rosa, & Dietz, 2003). Here, my results indicate that this relationship between efficient technology and pollution may occur at the individual level as well. As farmers adopt greater amount of best management practices, their N rate, a key indicator of agricultural N pollution levels, also increases. This finding, like the empirical work of the political-economy technology research, fundamentally questions the guiding assumptions that technical solutions are capable of addressing our contemporary environmental issues, in this case in the agricultural sector.

What might explain this relationship between N rate and best management practice adoption? Controlling for yield and irrigation suggests that higher N use cannot be solely explained by a relationship between farmers who operate on more productive fields, which can receive higher N rates, and also have more management equipment as a result of their increased productivity. Including the control variable for percent of household income from agriculture suggests that relationship between practice adoption and increased N rates does not reflect that farmers who derive more of their income from agriculture use more practices and have higher N rates to ensure profitability. Finally, inclusion of the environmental values variable and the information source variables suggest that the effect of best management practices on N rates is not predicated on access to certain knowledge, nor related to farmers who have more or less concern regarding the environmental impacts of agricultural production. In short, these results indicate the potential for an independent positive relationship between N best management practice adoption and N application rate.

Other than indicating these factors are not driving the observed relationship in my data, I can only suggest what factors may be behind best practice adoption and increased N rates given data limitations and the novelty of this finding. One explanation would be that best practice adoption directly leads to higher N application rates. Use of these practices likely increases farmers' N use efficiency, meaning they may experience a yield and profit increase as more of their applied N is taken up in the corn crop (Millar et al., 2010). Past work has shown that corn farmers apply higher rates of N in search of achieving greater yields (Schewe & Stuart, 2018). In consequence, farmers in this sample seeing a yield increase after practice adoption may increase N rates to try and further increase their yields. Increased N use efficiency could encourage this practice. Farmers using these practices may see that a greater portion of their applied N now contributes to crop growth and seeing this, they may perceive that more N may lead to more yield (and profits). In this way, best management practice adoption, via increased N use efficiency, could directly drive higher N rates and N pollution.

Alternatively, an indirect relationship between best practice adoption and N application rates could exist through risk aversion. Cochrane (1958) and later Levins and Cochrane (1996) depict farmers in the modern agricultural system as indefinitely adopting more novel technologies to further increase production efficiency and further expand production (either to avoid the consequences of ever declining crop prices [Cochrane, 1958] or ever increasing land prices [Levins & Cochrane, 1996]). Those farmers who fail to successfully participate in this "treadmill of technology" (ToT) are, as Levins and Cohrane (1996, p. 550) put it, "lost in the price squeeze", meaning they face the risk of foreclosure and having their land bought out from under them by their "more successful neighbor." In this view, N best management practices are adopted by farmers in their attempts to expand production and thereby avoid this consequence (rather than improve the environmental efficiency of their N use as we might expect). However, not specifically considered in the ToT framework is that the adoption of these agricultural practices comes at significant costs to farmers; particularly the equipment for multiple applications.[47] The purchase of N best management practice equipment, while enabling profit increases, may simultaneously further the risks farmers face through increasing their already high on-average debt burdens (NASS, 2012). In response to these circumstances, farmers use increased N rates to minimize risk and ensure profitability; higher N rates being considered a strategy for risk minimization (Sheriff, 2005). Adopted best management practices, namely the equipment that enables multiple applications, are also a means for farmers to apply *more* N throughout the season (as I show in Chapter III). To summarize, it may be that best management practice adoption increases the risk farmers face, via debt increases, and in response farmers use higher N rates to manage this risk.

In either case, the broad premise of the political economy technology literature is suggested in these hypotheses and the findings of this study: more efficient technologies will be

[47] For instance, a new sidedress application toolbar from John Deere costs approximately $55,000 dollars. See: https://configure.deere.com/cbyo/#/en_us/products/agriculture/application_equipment

implemented in ways that do not result in environmental gains (Polimeni et al., 2008; York, 2006). Agricultural production in the US has been argued to be fundamentally oriented toward capitalist profit imperatives at a structural level (e.g. Magdoff et al., 2000; Weis, 2010) and political-economic factors have been shown before to impact farmers' N application decisions (Stuart et al., 2012; Stuart & Houser, 2018; Stuart & Schewe, 2016). This suggests that the political economic conditions that have been argued to influence the implementation of adopted efficient technology are present and potentially influential in the agricultural system and farmers' N management decisions; a hypothesis that generally reflect prior work that has examined farmer decision making consider the capitalist structure of agricultural production (Hendrickson & Heffernan, 2007; Stuart, 2009, 2012). While this study does not seek examine the causal role of these processes, these factors may be the potential background context of the preliminarily identified relationship between N rate, pollution, and best management practice use.

CONCLUSION

In the concluding paragraphs of their paper, "Nothing New Under the Sun: The Old False Promise of Technology," York and Clark (2010) bemoan the inadequacies of technological solutions to environmental issues. Having covered the failures of environmentally efficient technologies to truly solve environmental crisis throughout history, they summarize their position on the impossibility that technical solutions can ever provide the potential for environmental sustainability in stating that the, "'new' solutions offered by capitalism are really the same old failed solution" (p. 219). However, much potential a 'green' technology holds, as long as profits are the imperative goal of human activity as they are in the capitalist socio-economic system, these "solutions" will be implemented in ways that prioritize economic over environmental considerations and accordingly they will fail to deliver on their promise of improving the society-environment relationship (Foster et al., 2010; York & Clark, 2010).

At a preliminary degree, this analysis suggests that in the agricultural sector, N best management practices may be yet another false promise of technology. The analysis performed here was intended to explore whether adoption of N best management practices led to a reduction in N related pollution. Using N rate as a proxy for agricultural N related pollution (Hoben et al., 2011; Millar et al., 2010), my results counterintuitively indicate that farmers who had adopted each N best management practice examined—stabilizer use, multiple N application timings, and use of undersoil application—had higher average N application rates than farmers who had not adopted these practices, or had used fewer of these practices. N best management practice did not have the largest effect on N application rate in the model presented here. However, given the expectations that best management practice adoption will lead to reduced resource consumption and pollution, I believe my focus on this variable in this study is theoretically justified.

These results engage with and build on recent work in the agricultural best management practice adoption literature. Recently, calls have emerged for further research to explore how farmers actually implement best practices (Ulrich-Schaad et al., 2017). These calls are in response to research showing that adopted practices may not be used in their intended manner or used at all (Genshow, 2012; Osmond et al., 2014). Like this work, my findings suggest farmers may adopt best management practices, but implement them in ways that increase, rather than decrease pollution levels. Though counterintuitive, this relationship reflects the general perspective of the above discussed political-economy literature (York, 2006, 2007, 2017; York & Clark, 2010): that technical solutions to environmental issues may be associated with more, not less, resource use and consumption. Importantly, my findings here only suggest the association between best management practice use and higher N rates. It does not causally explain why these factors are related. However, I believe these results suggest that more work needs to examine how farmers actually implement N best management practices and that this research should carefully consider how farmers' best management practice use is impacted by the structural confines of the capitalist agricultural production system.

On the topic of future work, further research may benefit from using MRTN threshold rates as a dependent variable, to examine if farmers' who use recommended N management strategies are more likely to exceed maximum profitable N use (Millar et al., 2010; see Houser et al., In preparation). Focusing on exploring N rates across a farm, rather than only on largest fields, may also provide further insights, as the degree to which largest fields are actually representative of general farm-scale practices is still unknown. Additionally, interaction effects are an important next step in this work. For instance, it might be that farmers with higher levels of education use N management practices in different ways. To achieve a more refined understanding of how best practice use effects N pollution than what is presented here, interdisciplinary research that further integrates actual, rather than proxy, measures of N pollution, like the work of Blesh and Drinkwater (2013), should also be undertaken. Finally, qualitative work is likely needed to explain the exact causal mechanisms behind N use increases and N best management use adoption. While more work is needed on the specific topic, this study's conclusions broadly indicate the need for further studies in agricultural literature to focus on practice adoption and implementation (Urlich-Schad et al., 2017). Without doing this type of work, our research runs the risk of promoting technical solutions to problems that require more fundamental changes to the social and ecological organization of agricultural. It may be that rather than using technical means to increase N use efficiency, farms will need to increase rotational diversity to reduce the need for synthetic fertilizer use (Atwell et al., 2010). Recent work has begun to focus on what leads Midwestern farmers to individually undertake these more fundamental shifts in production organization (Blesh & Wolf, 2014; Roesch-McNally et al., 2018) and these results suggest further work on this topic is likely needed. Addressing the environmental impacts of agricultural production through changing the ecological structure of farms to require less supplemental N may be the more difficult solution to pursue. However, it could be a potential solution that is more faithful to its promise of a sustainable future.

APPENDICES

Appendix A: CFA results for econval and envivals

Table 20: Component fit and overall model fit statistics for latent variables

Overall Model Fit	Chi-sq (df)	p	TLI	IFI & CFI	RMSEA (CI)
Environmental Values	6.57 (df=1)	0.010	0.99	0.99	.05 (.02, .09)
Economic Values	6.93 (df=3)	0.074	0.99	0.99	.02 (.00,.04)

Component Fit	Std factor loadings	Unstd factor loadings	Reliability estimates (SMC)
Environmental Values			
Look after the environment	0.656	1.000	0.795
Pass on land in good condition	0.505	0.729	0.255
Have good looking fields	0.479	0.795	0.230
Recreational lands nearby	0.279	0.705	0.078
Economic Values			
Earn a high income	0.749	1.000	0.560
Maximize farm/company profit	0.649	0.702	0.422
Minimize debt	0.446	0.575	0.200
Build up wealth and family assets	0.737	0.948	0.543
Be among the best in the industry	0.483	0.689	0.233

Appendix B: Direct and indirect effects for total N application rate

Table 21: SEMLV results for direct and indirect effects on N best management practice adoption and total N application rate		
Variables:	Unstandardized coeffs (std errors) for Combined Practice Index	Unstandardized coeffs (std errors) for Total N Application Rate
Combined Practice Index (*Right Type, Time and Place*)	--	2.201***
	--	(0.614)
<u>*Values*</u>		
Environmental Values	-0.19	-2.374
	(0.587)	(10.594)
Economic Values	.174	3.661
	(.348)	(6.23)
<u>*Information*</u>		
Information Source Use Index	0.073	-2.18**
	(0.059)	(1.034)
Hired Fertilizer Sampling and recommendation	0.325	-1.647
	(0.233)	(4.047)
Hired Fertilizer Custom Application	0.178	9.31**
	(0.23)	(3.985)
Use of Pre-Sidedress Test[#] (PSNT)	0.507**	-1.852
	(0.237)	(4.11)
<u>*Largest Field Characteristics*</u>		
Irrigation use	--	8.15
	--	(6.771)
Manure use	--	-8.25
	--	(5.636)
UAN use	0.369	-7.287
	(0.312)	(5.463)
Other N use	-1.314**	-52.292***
	(3.793)	(8.679)
Multiple N type use	1.933***	23.667***
	(0.265)	(0.265)
Anhydrous use (Reference)	--	--
	--	--

Table 21 (cont'd).		
Corn-Corn Rotation	--	11.95***
	--	(4.706)
Other Crop-Corn Rotation	--	5.755
	--	(5.477)
Soy-Corn Rotation (ref)	--	--
		--
2014 Corn Yield	--	0.164***
	--	(0.0540)
Individual Farmer and Farm Characteristics		
Farm Size 1000+ Acres	0.378*	16.675***
	(0.234)	(4.125)
Farm Size 999-500 Acres	-0.164	6.587
	(0.237)	(4.109)
Farm Size 499 or less acres (reference)		--
		--
Years Farming		0.001
		(0.007)
College Education	0.142	-1.121
	(0.198)	(3.443)
Indiana Farmer	0.077	2.265
	(0.259)	(4.641)
Michigan Farmer	-0.859**	-11.579**
	(0.295)	(5.561)
Ohio Farmer	0.042	10.105**
	(0.232)	(4.262)
Illinois farmer (ref)	--	--
	--	--
Percent of household income	-0.047	0.237
	(0.085)	(1.486)
Animals on farm	--	-5.352
	--	(4.042)
R-Squared	.186	0.307

$*p < 0.1$; $**p < 0.05$; $***p < 0.01$ (two-tailed)

Appendix C: Descriptions of N rate coding, including calculation for actual N rates

Related to rate, I converted product applied per acre to lbs of relevant nutrient (N, P or K) per acre. In general, these conversions where straight forward, following MSU extension's website to determine percent of nutrients in a product (see http://fieldcrop.msu.edu/uploads/documents/Nitrogen%20Fertilizers.pdf). However, for two fertilizer products—UAN and Ammonia phosphates—farmers were not asked to select a specific nutrient formulation. For both products, possible nutrient formulations are dichotomous. UAN is a liquid solution of nitrogen sources and water, where N percentage is either 28% or 32%. Ammonia phosphate is a dry product containing both N and P, where nutrient content is 18% N, 46% P in DAP (Diammonium phosphate), or 11% N, 52% P in MAP (Monoammonium phosphate). As we did not ask farmers to specify their specific formulation for these products, ERS national fertilizer use reports were used to determine the most appropriate conversation rates to follow for preliminary purposes (see https://www.ers.usda.gov/topics/farm-practices-management/chemical-inputs/fertilizer-use-markets/). For UAN, I averaged across 28% and 32% to treat UAN as 30% N. This follows ERS's treatment of these two UAN formulations. MAP and DAP are examined distinctly by ERS. The only provided use percentage of these products (pounds of product consumed nationally) indicated these products were used approximately evenly across the US. Consequently, like UAN, percentages of nutrient content in used convert to lbs of N and P applied are averages of the two products (14.5% N and 49% P). Moving forward, an ARMS data request will likely be able to provide sufficient detail of percentage use to determine a more exact strategy for determining appropriate nutrient content percentages to use in the conversion of these products.

STATA N rate coding syntax:

```
capture log close
log using "LTER Survey 2 Diss", replace text
clear all
macro drop _all
use "Nrate3_2.dta", clear

tab b11_aa_rate_units1

gen aarate1=((b11_aa_rate_units1*5)*.82)
tab aarate1

recode aarate1 (996.3=243) (1025=250) (1098.8=268) (942=230) (902=220) (922.5=225)
(840.5=205) (820=200) (738=180) (697=170) (902=220) (746/758.5=185) (717.5/721.6=175)
(676.5=165) (656=160) (639.6/647.8=158) (615=150) (594.5=145) (574=140) (533=140)
(799.5=195) (779.5=190) (758.5=185) (717.5=175) (697=170) (492=120) (451=110) (410=100)
recode aarate1 (943=230) (893.8=218) (869.2=212) (779=190) (512.5=125) (500.2=122)
recode aarate1 (1230=300) (984=240) (881.5=215) (861=210) (943=230) (893.8=218)
(869.2=212) (779=190)

tab aarate1
recode aarate1 (.=0)

gen aarate2=b11_aa_rate_units2
tab aarate2
recode aarate2 (.=0)

gen aaratetot=(aarate1+aarate2)
tab aaratetot

gen uanrate1=((b11_uan_rate_units1*10.86)*.30)
tab uanrate1
recode uanrate1 (.=0)
recode uanrate1 (879.66=270) (716.72=220) (651.6=200) (648.342=200) (602.73=185)
(586.44=180) (537.57=165) (521.28=160) (488.7=150) (456.12=140) (452.862=139)
recode uanrate1 (423.54=130) (407.25=125) (390.96=120) (325.8=100) (293.22=90)
(316.026=97)
recode uanrate1 (2704.14=0)

gen uanrate2=b11_uan_rate_units2
tab uanrate2
drop if uanrate2==529
drop if uanrate2==500
drop if uanrate2==350
recode uanrate2 (.=0)
```

```
gen uanratetot=(uanrate1+uanrate2)
tab uanratetot
recode uanratetot (716.76=220)

gen urearate2=(b11_urea_rate_units2*.46)
tab urearate2

drop if urearate2==7021.44
recode urearate2 (.=0)

gen urearate4=b11_urea_rate_units4
tab urearate4
recode urearate4 (.=0)

gen urearate5=b11_urea_rate_units5
tab urearate5
recode urearate5 (.=0)

gen urearatetot=(urearate5+urearate4+urearate2)
tab urearatetot
drop if urearatetot==7021.44
recode urearatetot (7021.44=0)

gen ammitrate2=(b11_ammit_rate_units2*.34)
tab ammitrate2

keep if uanrate1==879.66

tab b11_uan_rate_2

tab b11_aa_rate_2

recode aarate (0/80=1)
drop if aarate==1

tab b11_uan_rate_2

gen uanrate= b11_uan_rate_2

recode uanrate (350=105)

drop if uanrate==601
drop if uanrate==830
drop if uanrate==270
```

```
recode uanrate (500=150)(529=158) (65=211) (70=228) (75=244)

keep if uanrate==70

gen uanrategal==b11_uan_rate_2, for b11_uan_units_2=1

b11_aa_units_2

tab b11_aa_rate_2
gen aagals=((b11_aa_rate_2*5)*.82)
recode aagals (820=200) (738=180) (697=170) (

tab aagals
```

Appendix D: Sample mean values for independent variables by state

Table 22: Sample mean values for independent variables by state

Variables	Illinois	Indiana	Michigan	Ohio	Scale
Values					
Environmental Values	15.9	15.9	16.2	16.6	4-20
Economic Values	16.8	16.6	16.8	16	4-20
Information					
Information Use Index	6.5	7	6.9	7	2-9
Hired Fertilizer Sampling and recommendation	80%	79%	74%	74%	0-1
Hired Fertilizer Application	87%	78%	59%	69%	0-1
Use of Pre-Sidedress Test (PSNT)	17%	18%	29%	14%	0-1
Largest Field Characteristics					
Irrigation Use	4.4%	13%	9%	.4%	0-1
Other N form Use	15%	26.5%	34.6%	39.3%	0-1
Manure Use	4.8%	11.3%	13.9%	17.1%	0-1
Corn-Corn Rotation	18%	20%	17%	7%	0-1
Other Crop-Corn Rotation	2.7%	0%	33%	12%	0-1
Corn-Soy Rotation	79%	80%	51%	81%	0-1
Corn Yield (2014)	205 bu/acre	185 bu/acre	180 bu/acre	179 bu/acre	90-275 bu/acre
Individual Farmer and Farm Characteristics					
Farm Size 1000+ Acres	39%	40%	52%	31%	0-1
Farm Size 999-500 Acres	32%	34%	26%	32%	0-1
Farm Size 500 Acre and below	28%	25%	19%	35%	
Years of Farming Experience	30 years	30 years	28 years	29.8 years	1-65
Farmers who attended at least some college	73%	60%	54%	54%	0-1
% Income from farm	3	3	3.2	2.9	1-4
Animals on farm	18%	22%	28%	25%	0-1
Total n	294	143	120	241	--

Appendix E: Standardized and total effects for path analysis

Table 23: Standardized and total effects for path analysis		
Standardized effects for path analysis	Standardized Effects for Combined Practice Index	Standardized Effects for Total N Application Rate
Combined Practice Index (*Right Type, Time and Place*)	--	0.117
Values		
Environmental Values	-0.054	-0.022
Economic Values	0.059	0.047
Information		
Information Source Use Index	0.047	-0.071
Hired Fertilizer Sampling and recommendation	0.051	-0.013
Hired Fertilizer Custom Application	0.029	0.078
Use of Pre-Sidedress Test# (PSNT)	0.072	-0.014
Largest Field Characteristics		
Irrigation use	--	0.39
Manure Used	--	-0.049
UAN use	0.369	-0.60
Other N use	-0.098	-0.209
Multiple N type use	0.348	0.229
Anhydrous Use (Reference)	--	--
Corn-Corn Rotation	--	0.082
Other Crop-Corn Rotation	--	0.033
Soy-Corn Rotation (ref)	--	--
2014 Corn Yield	--	0.104
Individual Farmer and Farm Characteristics		
Farm Size 1000+ Acres	0.066	0.159
Farm Size 999-500 Acres	-0.028	0.059
Farm Size 499 or less acres (reference)	--	--
Years Farming	0.004	-0.003
College Education	0.142	-0.011
Indiana Farmer	0.012	0.016
Michigan Farmer	-.110	-0.081
Ohio Farmer	0.010	0.089
Illinois farmer (ref)	--	--
Percent of household income	-0.019	0.005
Animals on farm	-0.017	-0.043

Table 24: Total effects for path analysis

Variables	Total Effects for Combined Practice Index	Total Effects for Total N Application Rate
Combined Practice Index (*Right Type, Time and Place*)	--	2.201
<u>Values</u>		
Environmental Values	-0.343	-3.320
Economic Values	0.248	4.292
<u>Information</u>		
Information Source Use Index	0.077	-2.002
Hired Fertilizer Sampling and recommendation	0.329	-0.901
Hired Fertilizer Custom Application	0.184	9.749
Use of Pre-Sidedress Test[#] (PSNT)	0.514	-0.674
<u>Largest Field Characteristics</u>		
Irrigation use	--	8.310
Manure Used	--	-8.154
UAN use	0.377	-6.418
Other N use	-1.305	-55.102
Multiple N type use	1.933	28.020
Anhydrous Use (Reference)	--	--
Corn-Corn Rotation	--	11.864
Other Crop-Corn Rotation	--	5.628
Soy-Corn Rotation (ref)	--	--
2014 Corn Yield	--	0.164
<u>Individual Farmer and Farm Characteristics</u>		
Farm Size 1000+ Acres	0.372	17.499
Farm Size 999-500 Acres	-0.170	6.178
Farm Size 499 or less acres (reference)	--	--
Years Farming	0.001	-0.011
College Education	0.124	-0.928
Indiana Farmer	0.086	2.343
Michigan Farmer	-.842	-13.531
Ohio Farmer	0.057	10.076
Illinois farmer (ref)	--	--
Percent of household income	-0.046	0.142
Animals on farm	-0.113	-5.593

Appendix F: N and corn prices used to calculate MRTN profitable Rates

Table 25: N and corn prices used to calculate MRTN profitable rates

Year	average annual corn price per bushel full year	Average annual anhydrous ammonia price per ton	Average annual anhydrous ammonia price per pound	N-to-corn price ratio
2014	4.16	691	0.42	0.1
2013	5.69	879	0.54	0.09
2012	6.92	846	0.52	0.08
2011	6.8	773	0.47	0.07
2010	4.31	506	0.31	0.07
2009	3.75	808	0.49	0.13

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CHAPTER V— CONCLUSION

The narrative across these chapters is simple. N use in agriculture is necessary given the system's current set of social-environmental relations (Wolf & Buttel, 1996), and more efficient use of N could be achieved that would lead to significant reductions in N related pollution of all forms (Davidson et al., 2012). In response to this possibility, scholars and outreach specialists have increasingly pursued efforts to educate Midwestern corn farmers about the importance of and means to achieve more efficient N use (e.g. McLellan et al., 2018; Doll & Reimer, 2017) and states level policies have been implemented under the intention of encouraging the adoption of practices that achieve this end (e.g. Iowa's Nutrient Reduction Strategy).[48] In spite of this context, my results preliminarily suggest that the environmentally inefficient use of N fertilizer in the Midwestern row-crop agricultural system is likely not improving and may be getting worse. Across my chapters, I focused on examining the factors impact the rate at which N fertilizer is applied, as this determines the amount of all forms of N related pollution from agricultural systems (Davis et al., 2000; Hoben et al., 2011; Millar et al., 2010; Ribaudo et al., 2011). My results show that farmers who are over applying N may not wish to reduce their N application rate, even though it is in their immediate financial interest (Chapter II); the effects of climate change appear to not only be leading to increased N loss (Robertson et al., 2013), but to be encourage greater over-use of N (Chapter III); and the strategies thought to enable less total N use may actually drive, directly or indirectly, increased N use at the field level (Chapter IV). My primary argument is that the structural forces of the political-economy of agriculture are a key factor behind each of the identified specific occurrences of environmentally inefficient N use. Broad conclusions for both the environmental sociology and agricultural practice adoption

[48] See more on Iowa's Nutrient Reduction Strategy at: http://www.nutrientstrategy.iastate.edu/

literature can be drawn from the findings and arguments within and across the chapters of this dissertation.

Implications for environmental sociology

A major concern driving this study has been to examine how macro-level political-economic circumstances influence farmers' behavior at the individual level. To this point, the vast majority of the political-economy literature in environmental sociology has been macro focused, explaining the functioning of structural dimensions of the US agriculture system and how it impacts production practices and their environmental effects generally (e.g. Magdoff et al., 2000). My results indicate that macro-level political-economic factors lead farmers to actively seek or be forced to prioritize profitability over environmental outcomes in their N management decisions. Ideological factors as the mechanisms of this structural influence are the focus of Chapter II, while I emphasize how material political-economic factors at the macro-level level of agricultural production relate to the decision-making and practice implementation of farmers in Chapter III. Chapter IV, while providing no empirical evidence on this point, argues through the political-economy of technology literature that circumstances similar to those identified in Chapters II and III may be preventing farmers from implementing N best management practices in ways that reduce N use. Through this focus, I believe I have offered what others have called for: analyses that account for how farmers' behavior is influenced by macro-level political-economic factors (Stuart & Gillon, 2013), including the role ideology plays in facilitating this influence (Gunderson, 2015). In doing so, this dissertation connected individual-level decisions and behaviors to the structural context of the political-economy, a rarely used approach in studies of the political-economy's influence on environmental outcomes.

My inspection of individual-level actions in a political-economic framework suggests the need for research using this approach to further consider the potential for individual-level deviation from structural patterns of behavior. Though not the analytical focus of this dissertation, the potential for individual agency is indicated particularly in Chapter II. A portion of the total sample was unexamined in this study, as they were not applying N at rates that exceeded maximum profitable thresholds. The political-economy literature, reflecting its macro-level focus, has been quick to diminish the potential for environmental gains in capitalist economies. This minority of farmers[49] suggests that at the individual level some deviation from this structural context can occur. Again, focusing on individual agency was not the expressed intent of this dissertation, but data does imply that the political-economy approach may be currently overly deterministic. It may benefit the political-economy literature to undertake further cross-scale analysis to determine what circumstances, potentially a combination of structural and personal, enable agency of individual actors with regard to environmentally significant behavior.

Further, in applying a cross-scale political-economic approach to understand farmers' N management behaviors, my work has preliminarily suggested a novel hypothesis in need of further conceptual development and application in the political-economy literature specific to agriculture: the double-layer of risk hypothesis. Most past work on the role of the political-economy in environmental behavior has emphasized maximum profits as a driving force (e.g. Foster et al., 2010). Evidence and arguments, presented briefly in the conclusions of Chapter III suggests that many farmers feel compelled to undertake profit oriented decisions, as they face risks from fellow farmers and the increasing pressure and control of monopolistic agri-

[49] In the future, I intended to consider how geographically dispersed this group of farmers is.

businesses. In Chapter 2 (pp. 121-122), I referred to this circumstance as the “double layer” of risk, where farmers face both lateral political-economic pressure (other farmers) and horizontal pressure (more powerful agri-businesses). This circumstance occurs because of farmers’ unique class position within the capitalist system—while they are “capitalists,” in that they own and operate their own means of production, they are also subject to actions of much more powerful capitalist actors, monopolistic firms (Mooney, 1983). This position leads farmers, I argue, to undertake practices that prioritize dependable profits and are willing to sacrifice maximum profitability for dependability. Or stated alternatively, the material risk of significant profit loss, rather the material reward of maximum profit gains, is a key process driving farmers’ management decision, often to the greater detriment of environmental quality. This is explicitly argued in Chapter III, and implicitly suggested in my discussion of the hypothetical role that economic risk plays in connecting best management practice adoption and higher N rates in Chapter IV. As risk rather than reward is the central driver in the hypothesized framework, it may suggest that farmers are more discontent with the current capitalist model of agricultural production than has been thought in previous studies (e.g. Ellis, 2013; Stuart & Houser, 2018). While I discuss future research more below, this is a potential conceptual advancement in the political-economy of agricultural literature and indeed novel in the broader political-economy literature across environmental sociology. The motivating role of maximum profit seeking may be overstated among populations that experience greater levels of economic risk. Instead, their environmentally significant behavior could be driven by the motivating role of the avoidance of the consequence of the failure to make profits, which is a similar but distinction driver of action.

Finally, another intent of this work was to suggest the biophysical environment as a causal process in human behavior within a political-economic framework. This focus was almost exclusively relegated to my consideration of farmers' adaptive practice use in response to heavy rain events in Chapter III. My results suggest that farmers actively respond to experiencing these biophysical processes with changes in their N management; however, the nature of these changes reflects the profit imperatives of agricultural production in the capitalist system. Specifically, rather than using recommended best management practices (which Chapter 3 questions the absolute environmental benefit of), many interviewed farmers increased their N application rates. This method reduces vulnerability to weather events and is cheaper and more economically dependable than other recommended strategies. However, it also leads to higher levels of N pollution from agriculture (Millar et al., 2010). That the method of adapting to heavy rain events is determined by profit concerns at the expense of environmental outcomes suggests the role of political-economic circumstances in influencing how farmers respond to the causal impact of biophysical processes. Or, stated more broadly, while biophysical processes can influence humans' behavior, the exact effect these processes produce are shaped by the social structural context in which they occur. Past environmental sociology literature has predicted that the feedback effects[50] of environmental pollution on society, processes like climate change, will lead humans to alter their behaviors and undertake or pursue a more environmentally sound state of society (Beck, 1992; Polanyi, 1957; Schnaiberg, 1980). While more recent work has shown climate change is not producing environmental actions in the political sphere in the US (McCright & Dunlap, 2010), nor changing the perceptions of at least a significant portion of the US population at the individual level (Dunlap, McCright, & Yarosh, 2016), little empirical work has considered if the material effects of climate change (or other feedback effects of environmental pollution) produce pro-environmental changes in actions of the populations or

[50] I used "feedback" effects in the same sense that it is often used when discussing Urlich Bech's reflexive modernity (1992).

individuals that experience them. The results of my analysis in Chapter III preliminarily indicate that rather than encouraging the predicted pro-environment change in behavior, biophysical factors may drive humans to use further environmentally destructive practices as means to respond to the challenges these new ecological circumstances introduce. This implies the feedback effects of environmental pollution may speed up the destructive environmental consequences of human behavior within the capitalist economic system. Future work in environmental sociology may benefit from further considering this possibility, both in agricultural contexts and among other populations.

Implications for agricultural practice adoption literature

In my intention to contribute to both the environmental sociology and the agriculture practice adoption literature, I now discuss the relevance of this dissertation to the latter vein of research.

The individual-level focus of the agricultural practice adoption literature is mentioned throughout this dissertation. The pervasiveness of this focus, I believe, indicates a voluntarist approach to human behavior is the widely held assumption guiding much of the practice adoption scholarship. Voluntarism can be said to emphasize the capacity of individuals to act freely according to their will (Dillon, 2013). Based on my above discussion, it should be clear that I do not discount the potential for human agency, particularly at the individual level. However, the results of my dissertation certainly indicate that the best management practice adoption literature (or practice adoption literature, used interchangeably hereafter) may assume too great of a potential for farmers to act independently of their social circumstances. The results across my three chapters suggest that farmers' decisions and behaviors are confined by these circumstances to a great degree. This is most clearly empirically suggested in Chapter III, where

I show that farmers' use increased N rates to ensure profitable crops in response to heavy rain evens when they are aware of and concerned about the environmental consequences of increased N application rate. But that even farmers' perceptions of their N management is deeply connected and influenced by their social context is revealed in Chapter II. As this suggests, the role that farmers' knowledge, values or attitudes play in determining behaviors can be quickly overridden by or themselves be produced by factors emerging from the macro-level social-economic context.

Another implication emerges from my work's critique of the voluntarist assumptions of this literature. If the practice adoption literature over-estimates farmers' capacity to voluntarily undertake environmental significant management practices, then it also may be pursuing solutions to the environmental consequences of agricultural production that do not fully address the causes of these issues. As argued in Chapter IV, at the heart of the practice adoption literature is the assumption that technical solutions like management practices have the capacity to significantly reduce the environmental impacts of production agriculture. My analysis in Chapter IV fundamentally questions this assumption. I show increased pollution levels may be associated with increased use of N best management practices. In doing so, this analysis at least suggests that technical means may not be capable of mitigating the environmental consequences of modern agricultural production.

In addition to promoting technical solutions to environmental problems, outreach and education has been a primary solution focused on in this literature (e.g. Church et al., 2018; Eanes et al., 2017; Prokopy et al., 2017). The perspective here follows what has been called the "information deficient model," which assumes that environmentally harmful behavior emerges from lack of knowledge and thus these behaviors will change if the appropriate information is available (Dickson, 2005). Again, it appears from my results, and those of others (Hendrickson & James, 2005; Schewe & Stuart, 2017), that the voluntarist assumption on which this approach is based may be flawed. Structural material or ideological circumstances likely constrain the potential for additional information from leading to significant changes in farmers' environmentally significant behavior.

The conclusions of this dissertation certainly should not stop the exploration of these possible solutions, as my contributions to this literature represents only a small step toward indicating the confined status of farmers' management decisions and behaviors. Rather, this literature may benefit from *also* examining intervention strategies specific to the Midwestern context and that account for variation in social, political-economic and biophysical circumstances in which farmers' act across this region. In particular, the potential of policies that pay for the adoption and implementation of more environmentally efficient practices may enable farmers to better act on information or more effectively use their best management practices to reduce N related pollution. The possibility of encouraging Midwestern row-crop farmers to undertake farm-level restructuring to a more bio-diverse and less input intensive system should also be explored (more on this below). Recent work has shown the potential of more bio-diverse cropping systems to reduce the environmental consequences of agriculture, specifically considering N use (Gardner & Drinkwater, 2009). In response to these benefits, some studies have begun to seek to better understand what enables Midwestern row-crop farmers to undertake farm-scale transformations such as this (Blesh & Wolf, 2014; Roesch-McNally et al., 2018.). In light of my results emphasizing structural constraints that farmers face, the practice adoption literature may benefit from further examining these potential means of addressing agriculturally related pollution, particularly related to N fertilizer use.

Future Research Directions

As a scholar, I am fundamentally interested in examining the barriers to and motivations for environmental significant behavior at the individual-level, focusing on political-economic factors within a broader coupled-system perspective. Throughout my work to date, I ask: What social and biophysical processes constrain or motivate humans' capacity to adopt novel sets of environmental behavior? I specialize in exploring this question as it relates to natural resource users, specifically in the context of managed ecosystems in the Midwestern United States. My work in this area engages with the political-economy of agricultural literature and builds coupled-systems theory, but is practically grounded in my intention to develop the resilience of Midwestern communities, ecosystems and managed ecosystems to environmental change through understanding the barriers to behavioral change and developing effective strategies to respond to these constraints.

My future research agenda will build on the conclusions of this dissertation in ways that reflect these core scholarly interests and intentions. The results of my dissertation have strengthen my resolve that environmental sociology is applicable and beneficial to understanding farmers’ individual level behavior in the agricultural context. I am particularly inspired to further undertake research that captures the role of the political-economic structure in influencing farmers’ behaviors. I discuss my future research intentions here, beginning with how I will further develop a broad conceptual approach to be used across the specific research areas discussed below.

Across this work, I plan to deploy a cross-scale political-economic framework, the potential benefits of which are suggested by my broad conclusions noted above. However, some specific considerations may be able to improve upon this framework. As I note, I strive to address practical research questions such as these, but in ways that deploys and develops sociological and environmental sociological theory. Across my dissertation, I utilized the political economy literature of environmental sociology. My results of Chapter II suggest it is a key context that offers ideological positions to farmers and is influential in their decision making through this medium. Chapters III and IV indicate the role of profit imperatives from the political-economy of agricultural in influencing farmers' N management (as well as other areas of farm management). While the results of these empirical studies are certainly suggestive, I largely rely on theory to connect farmers' profit oriented decision making to the structural context of capitalist agricultural production. Only minor reference is made to the specific material forces that may make these profit orientations an imperative reflecting macro-level forces. For instance, in Chapter III, I use a select number of quotes to indicate the role that competition and debt plays in leading farmers to prefer the more dependably profitable adaptive practice of increased N application rate. More work is needed to empirically identify the specific political-economic factors influencing farmers' decisions and behaviors. As these forces can be difficult to capture in quantitative analysis (York & Clark, 2010), future qualitative studies may benefit from more explicitly questioning farmers about the influences on their management decisions of factors such as competition, monopolistic agri-business companies, input, crop prices and market fluctuations and debt. My observations from personal conservations with numerous Midwestern farmers pre-and post-formal interviews/focus groups suggest that these topics are far from the taboo subjects we might expect them to be in an interview context. Rather, many farmers appear to be eager to discuss these issues and how they are making being a successful farmer more difficult. By explicitly questioning farmers on these topics, research aiming to bring a political-economic approach to the context of agriculture may be able to more tightly connect political economic factors and farmers' decision making.

Beyond empirical development, the political-economic approach used in this dissertation would benefit from further conceptual development. Particularly, my "double layer" of risk hypothesis[51] outlined briefly in Chapter III holds analytical promise if further developed (see above for short description). The empirical focus on political-economic factors discussed above could serve as a testing-ground for the reliability of this hypothesis. However, initially a single theoretical article may be used to more fully outline this model and suggest the potential role it plays in influencing farmers' decisions to prioritize dependable, rather than maximum, profits. Specifically, I believe this hypothesis could be turned into a framework if bolstered conceptually through connecting it to the Marxist political-economy literature (e.g. Marx, 1847; Baran & Sweezy, 1966), and the vein of political-economy research specifically focused on agriculture (Magdoff et al., 2000; Levins & Cochrane, 1996), particularly that which identifies the role of powerful agri-businesses on farmers' behaviors (Schewe & Stuart, 2017; Stuart & Schewe, 2016; Stuart & Houser, 2018). For instance, to conceptualize the downward pressure agribusinesses place on farmers, an adapted version of Marx's labor value theory (Marx, 1847) could be combined with empirical work showing that farmers are increasingly economically exploited by seed companies (e.g. Stuart & Houser, 2018). Together, this work conceptualizes the motivations of companies to exploit farmers, shows that this is occurring and further reveals the effects of this process on farmer decision making and practice use. To outline the lateral pressure competitive neighbors place on farmers, I can combine evidence of farm-level consolidation and its consequence for farmers' behavior (Dudley, 2018; MacDonald et al., 2018) with the

[51] In the future, I must consider whether this is "layered" or "multi-dimensional."

Treadmill of Technology framework (Levins & Cochrane, 1996). If well-developed, this framework has the potential to shed new light on the manner in which the political-economic structures influence farmers' N use, among other dimensions of farm management. It also potentially suggests new directions to take in developing and offering best management practices. Practices that conserve resources and minimize economic risk (rather than maximize profitability, such as MRTN does) may be better adopted if the premises of this hypothesized model are realized in the actual sphere of agricultural production.

Using a form of this more developed cross-scale political-economic approach, I plan to undertake a number of further empirical studies that build on the findings of each chapter and the conclusions of the dissertation at large. Here I comment on specific future research directions to which I will apply this cross-scale political-economic approach.

Chapter II: In chapter II, my findings suggest that Midwestern corn farmers who are exceeding the maximum profitable threshold for their N application rates, according to MRTN (Millar et al., 2010), may feel their rates are appropriate and actively not desire to reduce them. Of the potential future research this finding warrants, three main ideas primarily interest me. First, as suggested in the chapter's discussion, material forces may constrain farmers' capacity to lower N application rate. In consequence, these forces may set an artificially high "minimum" rate, which farmers' defend and perceived as appropriately minimum through the identified ideological positions. As shown in Chapter III and argued in Chapter IV, biophysical processes and material political economic factors both could lead farmers to require higher N application rates. In future work, I will examine if the farmers who expressed these ideological positions in defense of their overuse of N also were somehow more subject to these biophysical and political economic forces than farmers who used N at rates seen to be appropriate by the MRTN approach.

Second, quantitative analysis is needed to expand on the results from the qualitative data used here. Though I consider the qualitative sample used in this chapter to be robust[52], greater generalizability could be achieved through use of a quantitative data set. If somewhat adapted, Arbuckle and Rosman's (2014) survey question, discussed at the beginning of this chapter, could serve to measure the perceived appropriateness of farmers' N fertilizer rate.[53] This question, coupled with actual N application rates and latent variables for farmers' ideological positions, could serve to test the generalizability of this chapter's findings across a wider sample of the Midwestern row-crop farming population.

Finally, it is certainly possible that my arguments about the material backdrop to these ideological positions are incorrect. Rather, farmers' who express these positions may simply be mistaken on the most appropriate N rate to use; a hypothesis suggested by the "information deficit model" of the practice adoption literature (Dickson, 2005). If this is the case, then this sample of farmers is ripe for an information treatment. In a future study, I could re-interview these farmers about N use and their perceptions of the appropriateness of their current rate. If application rates still exceed MRTN recommended thresholds, an online MRTN calculator could be presented to a random subset of "over-appliers." Follow up interviews could assess the effects of this information treatment and in this way further inspect the validity of the voluntarist approach and the information deficit model of the practice adoption literature.

[52] An argument for the reliability of qualitative samples of farmers' is currently a discussed paper idea between Riva Denny and myself.

[53] Farmers were asked by Arbuckle and Rosman (2014) to rate the appropriateness of their N fertilizer application rates, with most expressing the "about right" opinion. This question has been regularly asked across waves of the Iowa Farm and Rural Life Survey.

Chapter III: Results from Chapter III indicate that Midwestern row-crop farmers' may be responding to the effects of climate change, but in ways that reduce vulnerability at the expense of increased pollution levels from N use. I intend to initially pursue three primary research ideas emerging from the results of this study.

First, this analysis was fundamentally exploratory, as the topic of increased N use in response to heavy rain events was not a core question asked to the majority of the interviewed farmers that made up the qualitative data set for this study. In consequence, whether this is a primary or only marginally practiced adaptive response to climatic events like heavy rain events cannot be concluded. It can only reasonably be said that at least some Midwestern row-crop farmers are likely using this strategy in response to heavy rain events. To build on this, quantitative research should be employed. In particular, greater insight about the relationship between biophysical climatic events in a geographic area and farmers' adaptive responses could be garnered through a quantitative analysis that combines biophysical county level data, farmers' perceptions of the changing climatic circumstance and the areas of farm management that have changed in recent years. While N specific practices will be my initial focus in this quantitative follow-up work, a second area of research is to explore the broader crop management changes farmers are making in response experiencing these biophysical processes. Very preliminary analysis of a quantitative sample of Michigan farmers suggests row-crop farmers are perceiving changing circumstances and have altered management areas in ways that reflect this chapter's findings and, to a degree, the expectations of the broader adaptation literature and my prior work on farmers' climate change views (e.g. Houser et al., 2017) discussed in it (see Appendix A).

Finally, an interdisciplinary research project will likely be warranted if these quantitative results (from both my survey of Michigan farmers and Wave 2 of the CMSP survey) suggest that farmers who experience the effects of climate change are increasing N application rate. Noted in Chapter III, I only assume that farmers are *perceiving* N loss from heavy rain events. Whether this perception of loss reflects an empirical reality is a matter for future investigation. In-field tests of N levels throughout a growing season could be used to determine the effects of heavy rain events on N loss in actual agricultural conditions across the Midwest. This biophysical science could be combined with a social science perspective that examines farmer's perceptions of the effects of these events on their N use and the farmers' perceived potential for the adoption of more environmentally sound practices that increased resilience to climate change (e.g. cover crops; Gardner & Drinkwater, 2009).

Chapter IV: This chapter's findings may deem the greatest amount of further research. I show that the use N best management practices are associated with higher N application rates, a key proxy for N pollution levels from agriculture. These findings are counterintuitive and challenge the premises of the entire body of practice adoption literature. In consequence, careful further empirical tests are needed to confirm the reliability of the preliminary conclusions of this chapter. It is possible that particular variables and effects not accounted for in this analysis explain some variation in this general finding. For instance, farmers' may implement best management practices differently if they also use particular information sources, such as the MRTN calculator or PSNT tests or have particular value orientations, like holding higher stewardship values. It is also possible that an information treatment shared with a small cohort of farmers might enable them to more effectively utilize their best management practices (particularly when considering variable rate applicators). Further, the hypothesis in Chapter 4 that risk may connect best management practice adoption and higher N rates suggests a relationship between length of practice use and N rates. A greater length of time having used a practice may mean that initial debt burdens from its adoption have been reduced. Thus, the risk associated with this debt burdens will reduce over time, enabling lower N application rates as length of time the practice is used increases. The consequence of these interacting effects may mean that the adoption of N best management practices leads to less total N use (controlling for relevant factors) among certain sub-samples of farmers. Further, the MRTN threshold approach used in Chapter 1 could be brought to an analysis of practice use adoption on N rate. Logistic regression could be used to asses if best management practice adoption leads to greater odds that a farmer does not exceed MRTN maximum profitable thresholds. This analysis would build on the less sophisticated total N rate measure used in this study. Other practices could also be examined. Recent literature has emphasized the benefits of cover crop adoption for reducing N need and loss (Gardner & Drinkwater, 2009; Silva & Moore, 2017). As less total cost is likely associated with their use, adoption of organic practices such as cover crops, rather than technological practices examined here, may enable farmers to actually use less total N. I will examine this potential in future work.

Finally, I was only able to offer a hypothesized relationship between higher N rates and best management practice use in this chapter. If this relationship can be further established in the empirical work I discuss above, then I intend to pursue empirical studies that enable me to better understand why this relationship is present. Qualitative research is particularly suitable to this task, as it enables the exploratory analysis into not well understood research problems. To me, if I am to determine why best management practice adoption leads to greater N use and therefore pollution, the key dimensions to understand are (1) farmer motivations for adopting a new N best management practice and (2) the temporal process of practice implementation (i.e. from the motivations of the initial adoption of the practice to the factors that influence how the practice is actually used on farm). Insight into these areas will shed light on whether farmers want to use these practices for conservation purposes or solely for profits, and, if conservation is a primary intended outcome, what social, economic or biophysical factors may intervene to lead farmers to implement them in in ways that increase N rate. Ethnographies with a small number of farmers in various circumstances who could serve as the methodology to address these questions.

Future research that emerges from across all three chapters

These above directions for future research emerge specifically from each chapter of my dissertation and will provide the basis for the follow-up papers I write to this work. Beyond these directions are those that emerge from the conclusions of this dissertation across all three chapters. I discuss three specific topics I intend to pursue in response to the broad conclusions of this dissertation.

Farmer' N management over time: My efforts to understand farmers' N management in this dissertation reflect the general approach used to understand practice adoption across the vast majority of prior literature: a cross-sectional approach. This snapshot in time provides details into the drivers of farmers' N management behaviors, but it misses how these behaviors and the circumstances that may impact them change throughout the course of time. In particular, it should be expected that the vast majority of the circumstances I and others argue to impact farmers' N use will vary across time, including political-economic conditions (e.g. competition intensity, crop and input prices), biophysical processes like climate change and farmers' views, attitudes, perceptions and farm characteristics. To capture the role of these time-bound processes in driving farmers' N use, future work should employ longitudinal technique to study farmers' N management across time at two scales of analysis: the macro and micro. At the macro, the effect of long-term changes (i.e. years/decades) in biophysical and social-economic conditions on N rate across the Midwestern row-crop system can be determined. Specifically, it is possible to undertake a quantitative longitudinal analysis of N fertilizer rate at the state level across the Midwestern US using publically available ERS data from the years 1964 to the most recent year with available data (see Appendix B for more details).

At the micro-level, greater understanding of how farmers' management decisions occur and practice adoption changes within and across seasons is needed. Chapter 2 suggests that farmers alter their N management decisions in-season in response to climatic events. Further evidence of this is needed, particularly to understand how responsive management shifts, like adaptive practice use, that occurs in one season translates across multiple seasons. Additionally, as I noted above, how practice implementation occurs is not well understood. Longitudinal analysis at the individual level is needed to develop an understanding of this processes and what barriers farmers' face in effectively using these technical solutions. Finally, suggested in multiple chapters, the variations in crop and input prices likely matter for farmers' N management, but very little work has considered the implication of these changing circumstances (see Ribaudo et al. [2012] and Williamson [2011] as exceptions). Specifically, farmers' may vary their N management within and across seasons in response to these price fluctuations. For instance, the tariffs China may impose on US soybeans imports could affect farmers' rotational decisions and/or increase the relative price of corn. This factors, or others that lead to varying seasonal crop and N prices, may influence how N best management practices are implemented or how farmers' respond to the effects of climate change. Pursuing a better understanding of these research gaps could be achieved through analysis of longitudinal survey data from individual farmers and/or be gained by qualitative data from repeated interviews with a small group of farmers within a season and across multiple seasons.

In short, there is a need to empirically address the temporal variation in farmers' N management practice use and how changing circumstance effect this management; a topic that is both relevant at a macro-level and micro-level. Though this dissertation often mentioned the significant of changing circumstance, given data limitations is unable to account for these. I will begin to do this in future work.

Data collection methodologies specific to farmers: Another area for future research to emerge from this dissertation is related to the need for better data collection methods specific to the farming population. This research need is in no way a central component of this dissertation. However, it emerges across the small amount of discussion given to data collection in each chapter's methods section. Farmers, as I note, are a hard to reach population. Snow-ball sampling is required to develop sufficiently large qualitative samples and response rates to surveys were considered normal at around 22-24%. And the total number of farmers is only decreasing (USDA-NASS, 2014). In response to these issues, it appears that the declining number of Midwestern farmers are increasingly pursued for their participation as research subjects across the departments of multiple universities in the Midwestern US.

I believe the potential consequences of this are two-fold and related. First, one detrimental effect is the declining response rates of farmers to mail surveys (Johansson et al., 2017). Over burdened by requests for their time, farmers appear to be increasingly refusing to respond to survey questionnaires, reflecting the trend across the US general public (Czajka & Beyler, 2016; Tourangeau & Plewes, 2013). Unless changes are made to the survey methods we use, it is possible that continued declines in response rates will threaten the usability of our data. The second consequence to me is potentially even more dire. There is growing skepticism among the US general public in the validity of scientists (Gauchat, 2012) and my personal experience alongside some past work (Houser et al., 2017; Houser et al., In Review) suggests that many Midwestern farmers have a growing distrust of university scientists in particular. Given this context, recent work has begun to recognize the threat of farmers' distrust of science to our scholarly endeavors and develop strategies to deal with this threat (Swinton, 2018). However, to this point little work has considered the role that data collection may play in further dismantling (or potentially rebuilding) the trust between university scientists and farmers. As data collection may now be the primary connection university scientists have with farmers, this medium can be a source of growing tension or trust depending on how it is performed. In an attempt to alleviate the growing distrust and encourage higher response rates to university surveys, a research project I intend to pursue from this dissertation is a short methodological book on data collection techniques for the agricultural context. Insight and evidence for this work can be drawn from the multiple surveys, focus groups and interviews I participated in during the data collection process of this dissertation. Work on this topic is needed to continue to conduct high quality research on farmers and to ensure that the scientific recommendations that emerge from this research is heard by a more receptive farming audience.

Transitions to more bio-diverse agriculture at the individual-level: Finally, the collective results of my dissertation suggest that the barriers to reducing N application rate and therefore N pollution levels are many, persistent, and potentially insurmountable. Chapter 3 in particular offers a pessimistic perspective on the capacity to reduce N pollution from row-crop agriculture in the Midwest. It appears N best management practice use may lead to increased N pollution levels. A small amount of prior work has explored what enables Midwestern row-crop farmers to transition their operations to be more biodiverse and less input intensive systems (Blesh & Wolf, 2014; Roesch-McNally et al., 2018). Should the numerous follow-up research projects I propose above confirm the findings of Chapter IV and those of Chapters II and III, it will be time to more seriously consider farm transformations as a potential necessary solution to pursue to the environmental consequences of contemporary agricultural production (as I suggest above as an implication of my research). Two related veins of work would be particularly useful in this efforts. First, following the research of Blesh and Wolf (2014) further research is needed on what factors enable or encourage farmers to shift their operation from the input intensive di-cultural system of the majority of the Midwest to a more bio-diverse, less input driven system that has significantly lower environmental consequences (Gardner & Drinkwater, 2009). Additionally, the material and ideological factors that maintain farmers' practicing the current Midwestern agricultural system must be better understood. Only very little work has considered the factors that keep farmers participating in the current agricultural regime (e.g. Stuart, 2018; Stuart & Houser, 2018). Both veins of research should be further pursued to offer a clearer picture of what social, biophysical and economic factors may bar farmers from or enable them to transition to farming systems that require less N inputs. Given the results of my dissertation, this more dramatic approach to reducing N pollution may be needed if we are to see significant improvements in the environmental relations of agricultural production in the Midwestern United States.

Concluding thoughts

In this dissertation and across these future research plans, I have connected the disciplinary traditions of environmental sociology to that of the agricultural practice adoption literature. I believe addressing our contemporary environmental issues in the agricultural context requires this merging of disciplinary perspectives. For this to occur, more research that is at the nexus of these two perspectives must be done. But continued divides in disciplinary traditions may bar this merger. I believe my work throughout this dissertation suggests that analysis at the individual-level in the agriculture context can contribute insights to the core interests of environmental sociology, particularly the political-economic scholarship. In doing so, I hope my work here builds on past studies to further legitimize agriculture as a realm of environment-society interactions for consideration in environmental sociology.

I seek these broader impacts because I believe that further connection between agriculture and environmental sociology is necessary for practical reasons. Without environmental sociology, I fear the agricultural practice adoption literature will fail to see how farmers' behavior is significantly constrained by macro-level circumstances. In missing this, the outreach efforts promoted by this literature may not only fail to provide adequate solutions to identified issues such as N pollution, it may increasingly alienate farmers as it misses the circumstances they live within. Without the agricultural practice adoption literature, the theoretical insights of environmental sociology, which I find to have significant practically applicability, will likely remain largely cloistered away in academic journals. In combining these literatures in this dissertation, I hope to have at least begun to reveal the potential for these mutual benefits. In particular, I have attempted to suggest that N pollution in the US is without a doubt the result of the collective action of individual farmers like the practice adoption literature suggests. However, these farmers use N in ways that reflect the system in which they live. They are, in my opinion, just trying to make a living in increasingly tough circumstances. They are no guiltier of bad management than I would be in the same circumstances. Farmers don't need to change. I believe the system does. More research must focus on how this change can realistically be achieved.

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