SOCIAL ATTRACTORS IN AGRO-ECOLOGICAL SYSTEMS: AN ENHANCED PERSPECTIVE ON THE RESILIENCE OF NITROGEN FERTILIZER POLLUTION

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ABSTRACT

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The most significant contributor to excess environmental nitrogen (N) in the US is agricultural fertilizer application. Using a mixed methods approach, this study identifies social processes that drive Michigan corn farmers' application of nitrogen in excess of crop demand. We use Hatt's (2013) recently developed social attractors framework to conceptualize excess N application as a resilient practice actively reinforced by ongoing structural and organizational influences. The social attractors framework significantly improves resilience theory's conceptualization of social systems and may facilitate social scientists' capacity to engage in coupled systems research. Despite its analytical potential, the social attractors framework has yet to be applied empirically. This work contributes to the agricultural pollution mitigation literature, as well as explores the usefulness of social attractors for social-ecological systems (SES) research. Our findings indicate that the greater number of acres planted, more reliance on personal experience in nitrogen application decisions, and being unaware that nitrous oxide is a greenhouse gas all increase the likelihood of applying nitrogen in excess of crop demand. The social attractor framework proved useful in identifying these influential processes, theorizing their relationship to broad social values, organizations and social structures and conceptually framing N rate as an actively resilient practice in an nonlinear SES feedback system.

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KEY TO ABBREVATIONS

BMP=Best Management Practices

GHG=Greenhouse Gas

N_2O=Nitrous Oxide

N=Nitrogen

NPS=Non-point Source

SES=Social-Ecological Systems

INTRODUCTION

In 1973, resilience theory was debuted by C.S. Holling in his seminal paper *Resilience and Stability of Ecological Systems.* Resilience theory's concept of ecological systems that do not achieve peak equilibrium of function but rather fluctuate between different ecological attractors or stable domains of ecological processes radically altered ecological thought (Curtin and Parker 2014). Resilience theory has since been used by multiple disciplines to understand ecological as well as social-ecological systems (SES) (Folke 2006)[1]. However, applications of resilience theory to social systems (e.g. Adjer 2000; Gunderson and Holling 2001) have been critiqued for failing to capture the influence of individual/collective agency, social structural power and offering an overly functionalist, or mechanical, depiction of society (Cote and Nightingale 2012; Davidson 2010; Hatt 2013; Hornborg 2009). In response to these critiques, Hatt (2013) developed the concept of social attractors. Functioning similarly to ecological attractors, social attractors are intended to enhance resilience theory's ability to conceptualize the influence of power and agency within social systems.

We apply Hatt's (2013) framework to Michigan corn farmers' use of nitrogen (N) fertilizer. Agricultural N fertilizer pollution, a form of nonpoint source (NPS) pollution, significantly degrades environmental quality and poses health risks to humans. It is estimated that nearly all freshwater and coastal zones in the US are degraded by N pollution (Baron et al. 2012) and that 20% of drinking water in agricultural regions contains N levels beyond the safe drinking limit (Agrawal et al. 1999). Though numerous nonpoint source (NPS) pollution mitigation strategies and policies have been attempted,

[1] Social-Ecological Systems is also often referred to as *Coupled Human and Natural*

their success has proven difficult to evaluate (Knowler and Bradshaw 2007; Sergerson and Walker 2002). The inability to reduce the prevalence of agricultural nutrient runoff leads Morton and Brown (2010) to argue that more attention needs to be paid to “the persistent and difficult problem of nonpoint source pollution” (3).

This persistence may be better understood through further investigation of social factors that motivate farmers to continue inefficient nutrient management practices. In this paper the determinants of applying nitrogen in excess of crop demand, which is often considered the leading cause of nitrogen leaching and oxidization[2] (Broadbent and Rauschkolb 1977; Grant et al. 2006; Halvorson et al. 2008; Hoben et al. 2011; McSwiney and Robertson 2005; Miller et al. 2009; Robertson et al. 2013), is inspected using Hatt’s (2013) social attractors framework. The social-ecological features of agricultural N application and pollution is recognized through the social attractors framework, as are the social forces that actively compel, constrain or justify farmers’ decisions.

This exploration of the social determinants of a farmer’s N application decisions contributes to agro-food studies and may serve to guide policies and programs aimed at reducing nitrogen fertilizer pollution. Further, as Hatt’s (2013) social attractors approach to understanding resilience in SESs has not yet been empirically applied, our research will begin to explore the usefulness of this concept for SES research. It is our aim to suggest the framework’s potential to (1) enrich the understanding of social drivers of ecologically impactful behavior (2) provide a means for more social scientists to engage in SES or coupled systems research and (3) reveal how individual-level decisions and

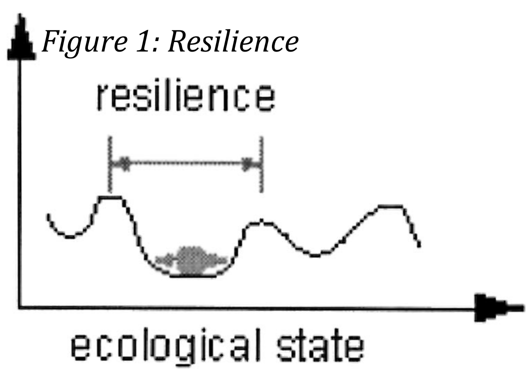
[2] See Snyder (2009) for a full review

behavior are embedded and thus partially determined by contextual factors at multiple levels.

RESILIENCE THEORY

C.S. Holling's (1973) resilience theory altered the traditional notion of an ecological system that could attain a peak equilibrium, or single "climax" stable state of biophysical processes. Instead, it "illustrated the existence of multiple stability domains or multiple basins of attraction in natural systems and how they relate to ecological processes, random events (e.g. disturbances) and heterogeneity of temporal and spatial scales" (Folke 2006, 252). In resilience theory's conception of ecosystems, *resilience* refers to the capacity of a system to undergo disturbances, yet still maintain its current set of functions before shifting to a new stable state, with new processes and functions (Holling 1973). Resilience in ecosystems is often illustrated using a ball in a basin (see *Figure 1*), which represents a system in a stable state, placed between empty adjacent basins representing potential new stable states. In each basin, various social or ecological variables known as attractors can cause the ball, which signifies the ecosystem, to shift into a neighboring steady state. The width or steepness of each basin represents an ecosystem's *resilience.*

Figure 1: Resilience



Adapted from Peterson (2000, 326)

In 1993, an interdisciplinary research group at the Beijer Institute developed a framework to understand the linkages between social and ecological approaches titled *Social and Ecological Systems*, or SES (Curtin and Parker 2014), using it to examine a number of topics (see Folke 2006 for a brief review). The SES framework emphasizes the mutual exchanges between humans and the ecosystems in which they are embedded (Gunderson and Holling 2002; Holling 1973). This concept has led to a fuller recognition within the scientific community of interactions between social and natural systems (Cote and Nightingale 2012).

Despite this potential, past applications of resilience to the social components of a SES (e.g. Adger 2000; Adger et al. 2005; Gunderson and Holling 2001) have recently been critiqued (Cote and Nightingale 2012; Davidson 2010; Hatt 2013; Hornborg 2009). These critiques focus on the failure to incorporate a nuanced understanding of the multiple social dynamics within a SES that may drive ecologically impactful behaviors or shape the desirability of a given ecological stable state. Influenced heavily by a functionalist perspective, it has been argued that traditional SES applications reify conceptions of society and thus obscure constraining or motivating factors such as power, social norms, ethical standpoints, etc., which drive individuals', communities' or populations' actions (Cote and Nightingale 2012; Hatt 2013; Hornborg 2009). In general, these scholars call for the inclusion of the motivating and/or constraining factors that influence a social behavior and to acknowledge an individual's or a sub-population's agency in consent, dissent, or adaptation to a given action or event.

Social Attractors

In response to these critiques, social scientists have started to further develop resilience theory's conception of society (e.g. Cote and Nightingale 2012; Hatt 2013). Within this effort, Hatt (2013) developed the concept of social attractors. Social attractors function analogously to ecological attractors, but instead are social devices or processes, such as policy, laws or rhetoric, that "persuade, attack, dissuade, justify, or neutralize actions or projects" (34). They are defined as "discursive (i.e. rhetorical) formulations that serve as reference points in social processes associated with the construction, mobilization, establishment, contestation, and resistance of power" (Hatt 2013, 34).

Hatt envisions social attractors operating in a critical realist conceptualization of society. In contrast to a functionalist social system model, critical realism depicts social relations as stratified along three levels: social structure (e.g. capitalism), organization (e.g. the state) and social interactions (e.g. individuals/civil society) (Archer et al. 1998; Bhaskar 1998; Hatt 2013; Joseph 2000, 2002). This model posits that the layers of society are in a dynamic relationship of mutually shaping feedbacks. Organizations and social interactions are embedded within and shaped by social structures. Social structures are in turn reproduced or transformed through organizational and individuals' actions. Social structure's influence on individuals is not direct, but rather mediated through organizations. Organizations, such as the state or institutional policies, shape social activities through laws or normative practices to reproduce social structure. Bill Freudenberg has emphasized the use of middle range theories in environmental sociological research, which are theoretical frameworks that are testable through the integration of empirical analysis (Merton 1949). To achieve this "middle range," this analysis will focus on the individual level, using theory to link observed social attractors at this level to the organizational/structural levels in which it is embedded.

While the influence of social structure and organizations may constrain or compel behaviors, the means through which they exert influence can also enable the contestation of their influence. As Hatt (2013, 36)) notes, "the processes of organizing consent may also create opportunities for constructing [counter] movements and resistance" (citing Carroll 1990). According to Gramsci (1971), diverse techniques exist to organize consent for, or potentially contest, social activities and policies. It is from this notion of Gramsci's that the social attractors concept was inspired. Hatt (2013) depicts them as the social devices, rhetoric, policy, etc., that motivate, coerce or justify individual's actions.

To illustrate the concept of social attractors in a SES, Hatt (2013) uses an anecdotal example of humans living in close proximity to a lake. In this example, *nature*, *property* and *conservation* are identified as three social attractors, along with two traditional ecological attractors. Hatt (2013) argues that through these three discursive constructions, social actors organized either consent or dissent for given practices that affect the lake's biophysical stable state. For example, through reference to *conservation,* individuals justified or opposed the use of powerboats on the lake, which potentially increases pollution. Conservation is a value that has "the status of being a politically correct orientation that cannot be denied without some sense of stigma" (Hatt 2013, 37). While Hatt's example focuses primarily on social attractors that are discursive, the potential for more formally articulated and forceful attractors, such as policy or regulations, is noted. Following from this, our application identifies and uses discursive social attractors but also incorporates other social processes that could potentially drive ecologically impactful social actions.

This approach can contribute to resilience theory's conceptualization of social actions. We argue that its depiction of a layered society frames persistent ecologically harmful actions through a *process* notion of resilience (Darnhofer 2014). Rather than assuming resilience to be a fixed characteristic of a system, a process focused approach conceives of resilience as continually produced through the production of consent for a given action (Darnhofer 2014, 466). A system became and is continuing to become resilient through active and dynamic processes. When the process approach is applied to social actions they can be seen as persistent (i.e. resilient) because they are actively reproduced via the influence of social structures (through the organizational level). This suggests that to discourage actions deemed harmful, the social processes that are reinforcing it must be recognized and altered through interventions at the individual, organizational or structural level. Secondly, many social variables recognize the constraining influence of social structures, institutional policies, or the individual agency of actors to contest these influence. The social attractor contributes to a nuanced depiction of social relations through recognizing that social influences often do both simultaneously. Finally, it offers a framework for conceptualizing a nuanced society within a SES framing. It depicts a layered society driving social actions that are influenced by and influential on ecosystems in a nonlinear feedback loop.

In spite of this framework's analytical potential, it has yet to be formally applied to empirical data. Hatt's (2013) "hypothetical" example suggests that social attractors may offer a more nuanced understanding of social drivers, but the robustness of the framework will only be confirmed through empirical applications.[3] We begin this process through applying the concept of social attractors to understand resilience in agro-ecological systems. More specifically, we use the social attractor framework to better understand how various social processes contribute to the (re)creation of the resilience of agricultural nitrogen (N) pollution in the United States. We examine a sample of Michigan corn farmers and draw from qualitative and quantitative data to establish what social determinants affect N application practices. In the following sections, we briefly review the impacts and causes of N pollution, describe our research methods, present our findings, and discuss what a social attractors framework reveals in this case study.

[3] Though Hatt (2013) uses empirical observations to inform his example, it is anecdotal.

SYNTHETIC NITROGEN'S ENVIRONMENTAL CONSEQUENCES

Excess N fertilizer from agricultural fields escaping through the air, groundwater or surface water has been shown to be a major source of degraded water, human health and environmental quality (Carpenter et al. 1998; Eickhout et al. 2006; Follett & Delgado 2002; Hunt et al. 1999; Millar et al. 2010; Mosier et al. 2002; Ribaudo 2011; Robertson & Groffman 2007). This environmental degradation is both pervasive and severe. N that escapes through surface and groundwater runoff contributes to high nutrient concentrations in surface waters resulting in eutrophication and/or hypoxia, which can potentially disrupt ecosystem processes and harm aquatic communities (Ribaudo 2011). The pervasiveness of this problem is apparent when considering that N runoff from agricultural fields into the Mississippi watershed is responsible for two-thirds of an approximately 7,000 square miles "dead zone" in the Gulf of Mexico, an area equivalent to that of the state of New Jersey (Ribaudo 2006).

In addition to degrading water quality, N fertilizer emissions have atmospheric consequences. Nitrous oxide (N_2O), a greenhouse gas emitted from synthetic N fertilizer application, is 298 times more effective at heating the atmosphere than carbon dioxide (EPA 2009). Agriculture contributes approximately 75% of the nitrous oxide emissions in the United States (EPA 2009).

Environmental N pollution from agricultural systems results from N that has not be captured by crops. Corn, which has particularly low nitrogen use efficiency, needs an excessive amount of N during its intensive growth stage of 6 weeks (Below 2007). [4] As a

[4] Nitrogen use efficiency is more formally defined in Below (2007) from an agronomic perspective as "the yield increase per unit of applied N for a specific portion of the yield N response curve. It is adjusted for

consequence, approximately 50% of fertilizer applied to corn is lost (Smil 1999). Moreover, corn receives 50% of the N applied in the US (ERS 2012). Based on both the amount of N applied to corn nationally, as well as its poor nitrogen use efficiency, corn production systems disproportionately contribute to N pollution. Further, much of the previous nonpoint source (NPS) mitigation literature (e.g. Burton et al. 2008; Dowd et al. 2008; Sergerson and Walker 2002) emphasizes the difficultly in achieving reductions in nutrient pollution via policy. Despite the exploration and recommendation of numerous mitigation approaches related specifically to N (e.g. McDermott 2012; Olson 2013; Millar et al. 2010; Sawyer et al. 2006; Ekman 2005; Fuglie and Bosch 1995; Randir and Lee 1997), agricultural greenhouse gas emissions have increased 19 percent since 1990, spurred on by rising N_2O releases, of which 67% is related to agricultural soil management (USDS 2010). Consequently, there is significant incentive to study potentials for mitigating corn related N pollution.

Farmers could significantly improve nitrogen use efficiency through adopting new application practices. Applying N at the right time (when the crop needs it), the right place (close to the growing plant), the right formula (chemical form of N that is more stable) and most importantly, the right rate (not applying excess N) are all application practices that can significantly increase nitrogen use efficiency (Roberts, 2007; Robertson et al. 2013).

Of all of these means, adopting the right application rate may lead to the most significant reductions. N's negative impacts are predominantly determined by the amount applied (McSwiney and Robertson 2005; Millar et al. 2009; Robertson et al. 2013;

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yield and N uptake without added N, and so it represents the additional yield derived from the fertilizer" (9).

Snyder 2009). Bouwman et al. (2002) generalized across multiple years, sources and cropping systems, concluding that N_2O emissions have a curvilinear relationship with N application rate. A threshold level is suggested to be near the crop demand levels for N. These findings are confirmed by McSwiney and Robertson (2005) and Hoben et al. (2011) in studies of Michigan corn N application rates. These researchers suggest that N application rates above approximately 120 lbs./acres (converted from kg/hectares) led to dramatic increases of N_2O emissions.[5] This leads Hoben et al. (2011,1140) to comment, "N application rate may be the most practical means for achieving decreased N_2O emissions without disrupting crop rotation or general agricultural practices." Many farmers, however, are not using nitrogen conservation strategies and recommendations to reduce application so as to not exceed crop demand are not followed (EPA 2009).

To explore the persistence of the agricultural practices contributing to N pollution, we apply the concept of resilience to Michigan corn farmers' N application practices. Specifically, while a number of application practices offer potentials to increase nitrogen use efficiency, the importance of application rate directs us to focus on the processes that contribute to the resilience of farmers' application at above the threshold rate of 120 lbs./acre.

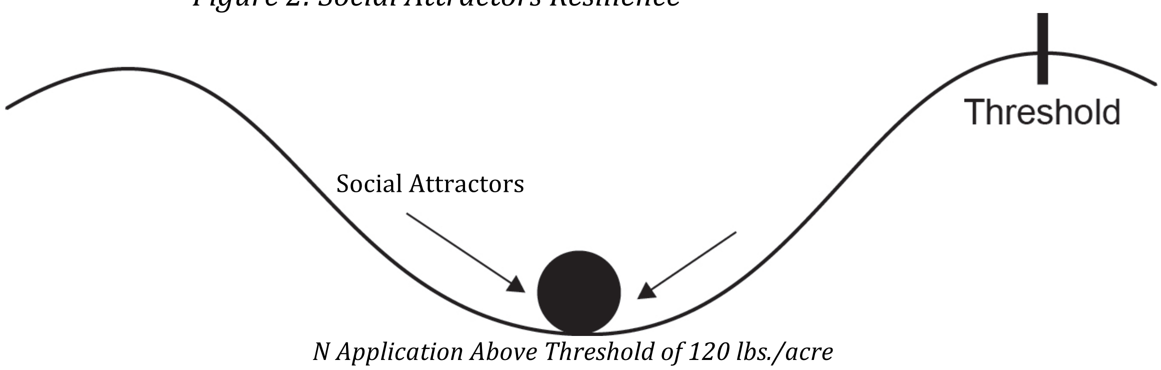
The Resilience of Nitrogen Pollution

Through the resilience framework, excess application can be viewed as situated within a stable state where numerous external 'disturbances', or mitigation programs and strategies in this case, have been unable to encourage a shift to more efficient rates.

[5] "Dramatic increase," is in contrast with Bouwman et al. (2002) finding of exponential increases. While these papers find different relationships with nitrogen application rate and the amount of N_2O emissions, they agree that above nitrogen demand levels pollution output increases at a disproportionately high rate to the amount applied.

Illustrated in *Figure 2*, Farmer's N application rate can be viewed as positioned within a steep basin representing a system of over-application that has remained difficult to alter. Social attractors are the social devices/processes that drive over-application further into a resilient basin or potentially facilitate application practices that disturb the persistence of this practice.

Figure 2: Social Attractors Resilience



Hatt's (2013) social attractor framework is used to identify and frame the social attractors that are contributing to the resilience of applying N in excess. This application will illustrate how resilience is created and maintained in SESs and may highlight previously overlooked dynamics in the N nonpoint source (NPS) pollution literature. Further, it will serve to explore the robustness of the social attractors framework.

MODELS

The SES nature of N pollution demands joint consideration of both social and ecological factors. Based on the need for further understanding of the latter, this study gives priority to conceptualizing social determinants through the social attractors framework. Social attractors are conceptualized as operating in non-linear feedback loops. This study identifies what social attractors are related to N application on corn. To determine this we use qualitative and quantitative data from interviews and surveys of Michigan corn farmers in 2011 along with an extensive review of relevant literature. Survey and interview data are used concurrently in our results section. A mixed methods approach is called for based on the limited amount of relevant prior research. Qualitative analysis, along with a review of relevant literature, will reveal what determinants are important. Following this, we use survey data to construct quantitative variables to represent the determined social attractors and test their effects on the likelihood of over-apply N using logistic regression. This approach tests the applicability of the social attractors determined in qualitative analysis to the wider sample through quantitative methods. Adhering to Hatt's (2013) nonlinear feedback loop conceptualization, water quality and atmospheric conditions are understood to be affected by N application rates which in turn affect social attractors, although the exact effects are not measured in this paper. This intention of this study is to reveal important determinants of behavior related to inefficient nitrogen use. Future work can expand on these findings to include observed effects of ecological factors.

Samples

Qualitative data were gathered from four focus groups and 40 in-person interviews with Michigan corn farmers. Focus groups were conducted in four Michigan counties: Branch, Calhoun, Kalamazoo and St. Joseph. These four counties represented 14% of Michigan's total corn production in 2011 (Kalamazoo (2.9%), St. Joseph (4%), Calhoun (3.5%), Branch (3.7%)) (USDA 2011). Each focus group consisted of participants identified by local Michigan State University Extension (MSUE) agents, recruited at local farm meetings, or invited by another participant. Participation ranged from five to eight farmers in each group. The same list of questions guided each discussion.

Interviews were conducted between January and May 2011. MSUE facilitated initial contacts, and additional participants were recruited through snowball sampling. In total, 11 farmers in Calhoun County, 9 in Kalamazoo County, 12 in St. Joseph County, and 8 in Branch County were interviewed. Of those interviewed, 23 were commercial corn farmers, 11 were strictly seed corn farmers (produce the seeds for commercial corn), and 11 grew both seed and commercial corn. Interviews were conducted on-farm, using an interview guide, and recorded whenever possible. Interview and focus group questions focused on factors influencing fertilizer application, willingness to reduce N fertilizer, and interest in a potential offsets program.

Data for quantitative analyses were collected through a mail survey conducted during the spring of 2011. With the assistance of the *National Agricultural Statistical Service*, 1,000 surveys were mailed to corn farmers in the four southwest Michigan counties mentioned above. Based on acreage, farms were divided into four strata. Different sampling rates were applied to each stratum with the intention that the final sample would adequately represent the different strata. Of the 1,000 mailed surveys, 274 were returned (27.4%). No significant differences exist between this study's respondents' farm size, irrigated acres, age, education, and farm income and that of respondents to a 2008 statewide survey of corn and soy farmers with a 56.4 percent response rate (Jolejoy 2009). Based on response rates related to varieties of corn grown, this analysis applies to un-irrigated commercial corn farmers and thus may not generalize to other varieties (e.g. seed corn farmers).

The social drivers of nitrogen application rates that emerged as common themes are used to construct relevant social attractors. Potential social attractors determined via past literature compliment these. While not all are discursive, those discussed below represent social attractors based on (1) their conception of the potential to simultaneously motivate appropriate or excessive application rates and (2) their theoretical link to social structures or organization. In the section following the construction of social attractors, their quantitative equivalents are outlined along with statistical models.

SOCIAL ATTRACTORS

Individualism/Personal Experience

Interviews indicate that farmers' references to past N application experiences are used to justify rejecting external N rate recommendations (see *Table 1*). Personal experience is conceptually an expression of individualism, which is the widespread American value legitimizing individual choice and personal freedom (Inglehart 1997; Sampson 2001). In centralizing personal autonomy, it justifies the marginalization of other social influences (Oyserman et al. 2002). This was reflected in farmers' comments. For instance, one commented, "I wouldn't say [fertilizer dealers, buyers, other farmers or extension] really influence [our application rate]. I mean they might a little bit, but I guess I know what our ground is capable of and they might think they know."

Survey results show that personal experience is a prominent influence on the application rate for the majority of farmers. Compared to other social sources of information,[6] personal experience was most often cited as somewhat or very important (85%).[7] The prominence of farmers' reliance on personal experience over external information indicates its relationship to individualism. Through its link to individualism, personal experience is conceptualized as a discursive social attractor that is deployed to justify excluding the influence of external information sources on farm management decisions. As it is discursive, the concept of individualism that is embedded within reference to personal experience does not exist at any level of society exclusively. Its deployment by farmers' may reflect influence from sources at the organizational level on N decisions and/or a means to justify a self-determined practice.

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[6] The three following personal experience were (1) fertilizer dealers (53%), (2) universities (48%), (3) other farmers (33%).

[7] Percentages do not equal 100%, as rankings were not mutually exclusive.

Table 1	*Personal Experience*
"I would like to stay where I am at [regarding N fertilizer] because I know it works."	
"All those people influence [my fertilizer decisions] but the main one would be the results that we get from what we do. We are comfortable enough with what we do that we don't do any testing or have any plots, we don't feel the need to do that."	
"We're kind of going from past experience of yield goals."	
"A lot of [our application decision-making] is from past experience for us. An agronomist might lead us a little but more of its just what we found worked."	
"Experience tells us we try to apply as little as we can get by with. We don't necessarily use any formulas you know getting bushels/pound or anything like that."	

Past extension literature has suggested that producer's often develop "a high comfort level with [their] traditional N rate, even though it may be too high for maximum profit" (Sawyer et al. 2006, 13), suggesting that this exclusion could drive application in excess. However, excluding external influences such as fertilizer dealers who serve to benefit from high rates could lead to modest N rates.

Profits

In interviews, farmers referred to the economics of fertilizer-use to justify both the maintenance of their current application rates and the desire to reduce them (See *Table 2*). In response to the question what are the primary reasons why you would want to increase your nitrogen efficiency, three farmers in a focus group responded in sequence, "Costs," "Bottom line" and "Lowest cost producer wins." Survey results revealed that almost 77 percent of respondents indicated that a balance between costs and expected returns was somewhat or very important in determining N rates. References to the pursuit of profit indicate the interplay between the social structure of capitalism and its influence at the level of social relations.

Capitalism is the socioeconomic system reflecting the nature of capital, which is a process of monetary exchange driven by the pursuit of financial profits. The critical realist framework of layered social relations suggests the structural drive of capital is recreated at the individual level. Though potentially accomplished in numerous ways, the discourse of profits is central to generating consent for social actions that recreate capitalism. As Rappaport (1993) argues, the "bottom line" of economics has supplied contemporary "society with its dominant social discourse" (298). Acceptance at the level of social relations reflects its normalization and recreates its presence as a social structure.

At the level of individual social relations the rhetoric of profits functions as social attractor to organize consent for given actions. Related to farmers, the pursuit of profits may motivate or be used to socially justify appropriate N application or maintaining potentially excessive application rates. Though characterized as a rhetorical device, profits are material in their effects on farmers' livelihood as well. We are unable to explore this influence in depth here, based on insufficient data. As a discursive social attractor, profits, like personal experience, are not linked to any level of influence exclusively in this study. The following three social attractors move beyond Hatt's (2013) discursive devices and suggest other mechanism that motivate or justify N application rates, however. Following critical realism's layered society, we trace each attractor's relationship to a given level of social relations to outline where influence is coming from and how it may shape farmers' ecologically impactful actions.

Table 2	*Profits*
"I think in general my rate of application is generally so close to the bottom and I guess usually I don't feel that I could cut a lot [of nitrogen] without significantly reducing my yield."	
As of right now…I'm putting the least amount that I think I can and still getting the max yield for economics…from an economic standpoint it's not feasible [to reduce fertilizer application]."	
"I would love [to reduce fertilizer application] because it saves money—as long as we aren't costing ourselves yield. "	
"If I put fertilizer on and I lose it then it's not economical . . . so I'm going to put it on the most economically friendly way. I don't want to throw my money away."	

Reported Knowledge of Consequences

Overwhelmingly, farmers in focus groups and interviews were unaware of the link between N fertilizer, nitrous oxide (N_2O) and climate change. In contrast, approximately 37% of survey respondents claimed to be aware of N's relationship to N_2O, and nearly 45% knew that N_2O is considered a greenhouse gas (GHG). This departure indicates that reported knowledge may be different from actual knowledge therefore we use the term reported knowledge to make this distinction.

Although it was not evident in farmer's comments, farmers' knowledge of N's consequences represents a potentially significant social attractor. The possession of particular information is a precedent for behaviors. This is not only posited by social-psychological theories such as *Value-Beliefs-Norms Theory* (Stern et al. 1993) and *Theory of Planned Behavior* (Ajzen 1991), but is also reflected in studies of farmers. McGuire et al., (2012) argue that when farmers recognize that their actions negatively affect the environment, they will often adopt conservation practices in order to maintain congruence between a 'good farmer' identity and their actions. Others have not found a relationship. In their meta-analysis, Baumgart-Getz and colleagues (2012) used a variable similar to awareness of N_2O consequences,[8] finding it not significantly predictive of conservation practice adoption. This may be a result of limitations (economic or otherwise) on farmers' ability to adopt conservation practices.

Knowledge related to N_2O may drive behaviors. Its possession is likely determined by information networks in which a farmer is embedded. Information networks, as with other types of organizations, are mediators of social structures influence on individuals. Their influence reflects the structure that supports them, and thus the information they provide may motivate social actions that recreate this structure. What organizations supply this information to farmers is unclear. Though unable to theorize about a particular organizations interest in offering this knowledge, our investigation does indicate what influence this knowledge has at the individual level.

For reported awareness of N_2O as a GHG to act as a significant deterrent, farmers will likely have to believe in anthropogenic climate change. Recent studies of farmers show this might not be the case, however. Surveys of Midwestern corn farmers show that 54% of Iowa (Arbuckle et al. 2013) farmers and 66% of Indiana farmers (Gramig et al. 2013) believe in climate change. However, out of these 54% in Iowa, only 35% perceive human actions to be a cause, and this is even lower in Indiana where a mere 8% of those 66% see this as the current situation. If we can generalize to other farming communities in the Midwest, it is likely that the majority of respondents in our study see climate change to be unassociated with human activities. Thus, awareness that N_2O is a GHG may not affect application, as it does not capture farmers' perceptions of anthropogenic climate change.

[8] Baumgart-Getz, Prokopy and Floress (2012) calls this variable 'cause'. It is also included in research conducted by Esseks and Kraft (1988).

Information Source

We also identified primary sources of information related to N application as a social attractor. Similar to the influence of information networks mentioned above, information from specific organizations or institutions reflects the biases or interests of these organizations and thus function to recreate specific social structures. Fertilizer dealers likely have an economic incentive to recommend high rates, especially compared to sources of information such as university extension educators or literature created in different social arenas. As illustrated in Stuart et al. (2012), many farmers recognize that information provided by fertilizer dealers is biased. Despite this recognition, many farmers in our sample consider fertilizer dealers the most important source for information (27.2%). This was followed by university recommendations with approximately 22% rating it as their most important source.

The source farmers trust will likely direct their final application decisions. Others have shown the importance of farmers' social connections in influencing N decisions (Lubell and Fulton 2008; Prokopy et al. 2008). More generally, in their meta-analysis of conservation adoption literature Baumgart-Getz et al. (2012) find information about best management practices to be the best predictors of practice adoption. We identify primary sources of information about fertilizer application as a social attractor given that they are social processes that shape farmer's actions and likely reflect the interests of organization structures from which they emerge.

Acres of Corn Grown

Though not discussed thoroughly in interviews or focus groups, national changes in farm structure represent a potentially powerful social attractor. The increasing capital intensity (i.e. more machines, inputs, etc.) in agriculture reflects the structural force of capitalism (Lewontin 2000) and has compelled or enabled farmers to manage more land. This is reflected in the growing size of US farms. As of 2007, the midpoint[9] acreage harvested since 1982 has risen 114%, from 500 to 1,071 acres. This is particularly true for Midwestern farms, including Michigan, which have seen the greatest percentage increase in acreage. Additionally, corn's midpoint acreage increased more than any other field crop, jumping 300% (from 200 to 600 acres) between 1987 and 2007 (MacDonald et al. 2013).

This change in American farm structure functions at the organizational level, as it possibly mediates the influence of structure on the individual. Capitalism (a social structure) drives changes to the national farm structure (organizational) and we examine its affects on operators' actions (individual). Larger farms could enable or prevent a reduction in N rates. Some studies have considered acres farmed an indicator of economic capital which is thought to measure the capacity to adopt 'risky' practices such as conservation practices (Baumgetz et al. 2012, Daberkow and Mcbridge 2003). Alternatively, more acres could also result in increased risk related to N application as more crops planted equates to greater potential profit losses in poor years. N over-application is a form of risk management to avoid the potential consequence of unprofitable yields (Sherriff 2005, Stuart et al. 2012), and thus may be a result of changing farm structures. Farm size functions as a social attractor in that it is driven by

[9] Midpoint measurements are a form of medians. As MacDonald et al. (2013) explain, "midpoint acreage is the median of the distribution of acreage by farm size, as opposed to the more commonly reported median of the distribution of farms by farm size" (6). This measure is used to reduce the influence that a recent spike in the number of very small farms have on average acreage.

social structural influence on farming that may compel or motivate individual's appropriate or excessive N application rates.

The social attractors noted above are considered because of their conceptual links to broader social structures/organizations. They function as indirect influences from a social structure, such as acres of corn's link to capitalism or information sources connection to institutions or organizations. Others (e.g. economics and personal experience) also reflect the rhetorical attractors that Hatt (2013) focuses on. Further, all potentially motivate either appropriate or excessive N rates and thus incorporate the nuances of individual agency. If we were applying Hatt's (2013) framework precisely, a theoretical framing of these social attractors' nonlinear feedback relationships to N application would follow. Instead, a quantitative analysis is used to assess the noted social attractors' influence on the likelihood of over-applying N.

Though this application flattens the conceptual capacity of attractors to be simultaneously motivators of both excessive and conservative application rates, it provides certain benefits. We are able to verify statistically if a connection exists between influence and actions, as well as make assertions as to the general influence a social attractor has on N application (i.e. does it tend to drive excessive or appropriate rates). Our model remains true to Hatt's (2013) nonlinear feedback loop framework for social attractors, and thus embeds its analysis of social actions within an SES framework. Further, our model pulls from the process approach to social resilience indicated by Hatt's (2013) work, as we attempt to reveal the social processes that reinforce the persistence of N over-application.

QUANTITATIVE METHODS

To investigate the statistical effects of the five identified social attractors on N application rate, logistic regression is used to predict the effect of variables on the probability that farmers applied N above the generalized threshold rate mentioned above (> 120 lbs./acres = 1). In this section, the variables used in this model are outlined. See Table 3 for descriptive results

Dependent Variables

N Rate: The primary dependent variable used in these models is pounds per acre of N fertilizer applied to commercial un-irrigated corn. Respondents were asked to write in their fertilizer application rate in lbs./acre for the most recent year they grew corn. Fertilizer application rate was recoded into a binary variable (> 120 lbs./acres = 1) to reflect the generalized threshold rate at which fertilizer application exceeds crop N demands and N_2O emissions begin to increase substantially (Bouwman et al. 2002; Hoben et al. 2011). Commercial un-irrigated corn fertilizer application rates ranged from 1.5 lbs./acre to 400.[10] The mean, at 136.3 lbs./acre is approximately 14 lbs. above the 2011 Michigan average of 122 lbs./acre (USDA 2012). Of all the farmers in our sample growing un-irrigated commercial corn (152)[11], 61.8 percent applied above the estimated threshold rate (120 lbs./acre). Importantly, Stuart et al. (2012) show that commercial corn farmers apply significantly less N than seed corn farmers.

Awareness of N_2O as a greenhouse gas (GHG). Awareness of N_2O as a GHG measures farmers' knowledge of N_2O to be a greenhouse gas (Yes/No dichotomous response). It is

[10] Five responses of 0 were dropped. Farmers that do not apply nitrogen are an exception and likely represent a minor subgroup of corn farmers (e.g. organic).
[11] Sample sizes were reduced based on missing cases.

used in a linear path model, where an independent awareness variable (discussed below) is used to predict it and then both are used to predict N-rate as the primary dependent variable.

Independent Variables

Personal Experience: Personal experience measures the farmer's self-reported importance of previous farming experience in determining current N rate, with higher scores indicating more importance.

Profit: The motivation of profit is measured using farmers' self reported importance of a balance between costs of returns in determining their N rate. Higher scores indicate more importance.

Information Sources: Three variables are included in the quantitative model. The effect of *fertilizer dealers* as the farmer's most important source is measured against those that use *university recommendations*. *Other sources* (50.4%) is included for the purpose of direct comparison between university recommendations and fertilizer dealers as sources of information.[12] Respondents choose only one most importance source from a list. These are therefore dummy variables.

Reported Knowledge: Reported knowledge of consequences is assessed using two variables in the quantitative analysis: Reported *awareness of* N_2O and reported *awareness of* N_2O *as a greenhouse gas (GHG).* Awareness of N_2O measures farmers' awareness of N_2O's link to nitrogen fertilizer application. *Awareness of* N_2O *as a GHG* measures

[12] Other sources include: Other farmers, magazines, company fieldman, private consultant and a write in category of 'other.'

farmers' knowledge of N_2O to be a greenhouse gas. Both are binary variables (i.e. awareness is measured against being unaware) as the survey questions was a Yes/No response. The effect of a farmer's knowledge of nitrogen's link to N_2O and N_2O as a greenhouse gas are expected to effect application rate in a linear path, where awareness of N_2O precedes and thus predicts awareness of N_2O as a GHG, which are then both used to predict odds of applying in excess.

Acres of Corn: Acres of Corn is constructed from farmers' reported acres of corn grown. Higher values indicate more acres grown. Results will suggest how nationwide changes in farm structure impact farmers' N application rate in our sample. All descriptive information (e.g. range, standard deviation, mean) for variables is available in Table X.

Table 3	*Descriptive Results*		
Variables	Mean	Standard Deviation	Range
Dependent:			
N-Rate	Avg. Rate: 136 lbs./acre	49.93	1.5-400 lbs./acre*
Awareness of N_2O as a greenhouse gas (GHG)	45%	.50	0-1
Independent:			
Personal Experience	3.31	.85	1-4
Profit	2.93	1.14	1-4
Information Sources:	% Used as Main Source:		
1. Fertilizer Dealers	27%	.45	0-1
2. University Recommendations	20%	.40	0-1
3. Other	52%	.50	0-1
Reported Knowledge:	% Aware:		
1. Awareness of N_2O	37%	.48	0-1

Table 3 (cont'd)

2. Awareness of N_2O as a greenhouse gas (GHG)	45%	.50	0-1
Acres of Corn	443 acres	1.33	10-3,700 acres**

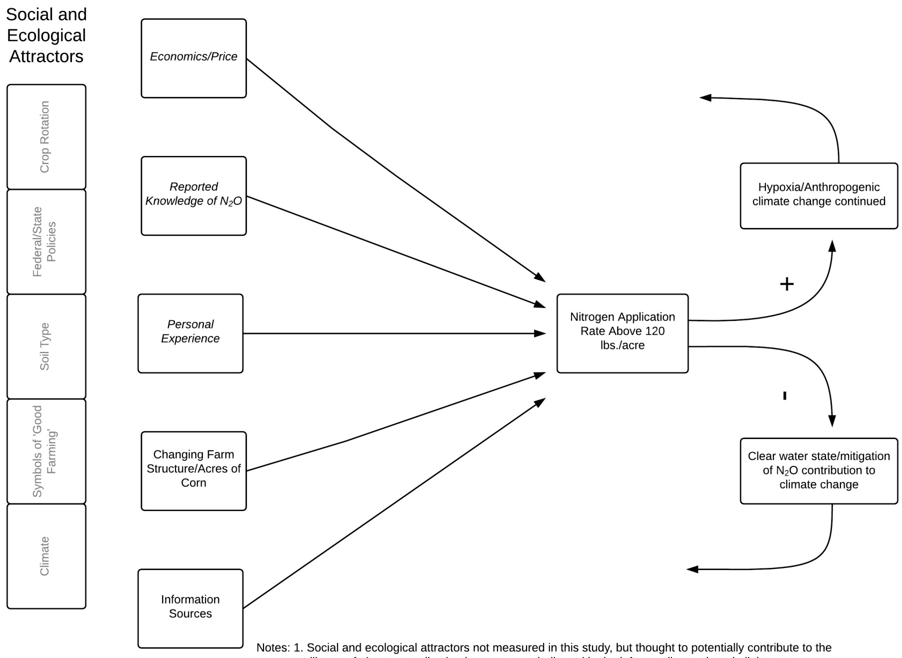
*Recoded to dichotomous variable 0= <120 lbs./acre and 1= >120 lbs./acre,
** Recoded into 5 categories: 10-100=1, 101-225=2, 226-500=3, 501-1400=4, 1450-3700=5, to ensure each cell had sufficient counts (>30).

THE SOCIAL ATTRACTORS FRAMEWORK

Social attractors operate in a nonlinear feedback loop where they drive actions that have ecological impacts that in turn affect other social attractors. However, with only one wave of data, the causal connections proposed in this nonlinear feedback loop cannot be assessed. This may be accomplished in future analysis. In *Figure 3*, we depict the social attractor variables driving N application rates to be below or above 120 lbs./acre.

As shown, rates above 120 lbs./acre encourage further changes in aquatic and atmospheric states towards undesirable consequences such as climate change and hypoxia. Application below 120 lbs./acre mitigates the agricultural drivers of these ecosystem changes. These ecological states are considered to impact social attractors in a non-linear feedback loop, although the exact effects are not examined in this study. The social and ecological attractors that may drive application rates but are not measured in our study are depicted at the far left of the figure in gray. Our model, as with all models, is an abstraction from the complexity of reality. We indicate other potential social and ecological attractors not tested in this study to illustrate the larger context and to indicate other variables for future work.

Figure 3: Hypothesized SES Feedback Process



Notes: 1. Social and ecological attractors not measured in this study, but thought to potentially contribute to the resilience of nitrogen application in excess are indicated in the left most line and are in light gray.
2. The + and - symbols indicate positive and negative relationships. For instance, nitrogen application above 120 lbs./acre is negatively related to clear water states and N_2O emissions.

RESULTS

Results of the logistic regression model predicting nitrogen application are shown in Table 3. The social attractors of acres of corn, both reported awareness variables (N_2O and N_2O as a GHG) and personal experience all significantly predicted the likelihood of applying above the N threshold rate. Results indicate that larger farms are more likely to over-apply nitrogen. Further, the odds N will be over-applied increases as farmers rely more on past experience (and rely less on outside sources of information).

As expected, awareness of fertilizer's relationship to N_2O predicted farmers' awareness of N_2O's relationship to climate change.[13] When predicting the odds of applying in excess, both awareness of N_2O and N_2O as a GHG were significant. Farmers who are knowledgeable about N as a GHG are less prone to apply in excess. In contrast, those that reported they were aware that fertilizer is a source of N_2O were actually more likely to over-apply. All results are shown in *Table 1*.

Depicted in *Figure 4*, we use the social attractor framework to comprehend how a farmer's N applications are embedded in a nuanced SES. First, N applications are situated within a layered society that asserts downward pressure to actively reinforce resilience. Farmers' actions are further embedded within a broader ecosystem, the state of which is influenced through their N application rates, among other practices. In turn, in a perpetual non-linear feedback loop ecosystem feedbacks created by environmental N (or lack thereof), such as water or climatic states, operate reflexively to influence farmer's N application practices or the processes reinforcing them (indicated by left facing curved arrows). For instance, states associated with climate change, such as sporadic weather

[13] Results can be found in N_2O model.

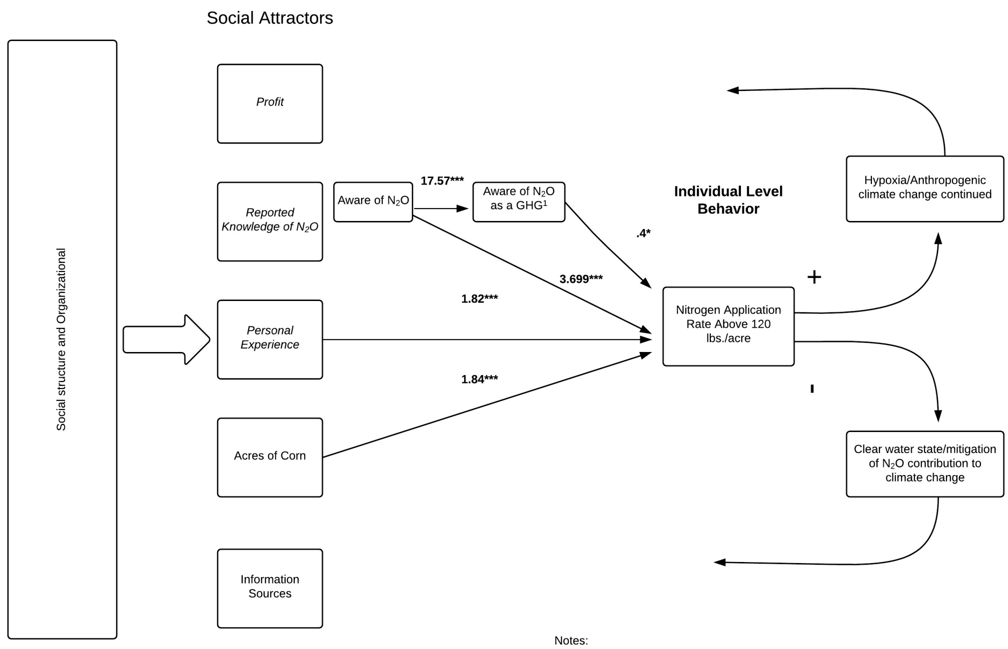
patterns like heavy rainfalls, may increase N rates through causing more leaching. Farmers excess N rates (>120 lbs./acre) are actively reinforced by the increasing farm sizes associated with capitalist production, the widespread social value of individualism, embodied here as personal experience, and their awareness of N_2O. The continuation of this practice feeds excess agricultural N to the environment, thus spurring on the creation of undesirable aquatic and atmospheric states. Awareness of N_2O as a GHG was shown to disrupt excess N application.

Table 4: *Final Model*

Model:	(1)	Final
Social Attractors predicting:	Aware of N2O as a GHG=1	N Application Rate > 120 lbs/acre = 1
Personal Experience		1.821**
		(0.520)
Profits		0.922
		(0.169)
Aware of N_2O	17.57***	3.699**
	(7.684)	(1.959)
Aware of N_2O as GHG		0.398*
		(0.201)
University Recommendations		1.702
		(0.921)
Other Sources		1.701
		(0.742)
Acres of Corn		1.843***
		(0.293)
Constant	0.297***	0.0743***
	(0.0722)	(0.0622)
LR Chi-Squared	56.70***	33.89***
Pseudo R2	.271	.168
N	152	152

*** p<0.01, ** p<0.05, * p<0.1

Figure 4: Final Model



Notes:
1.The + and - symbols indicate positive and negative relationships. For instance, nitrogen application above 120 lbs./acre is negatively related to clear water states and N_2O emissions.
2. GHG stands for greenhouse gas
*** p<0.001, ** p<0.01, * p<0.05

Discussion

Results indicate a number of processes actively maintain the practice of applying N in excess of corn demand. Interviews with farmers identified that personal experience justified ignoring external sources in favor of past history of application. Our results show that farmers who more strongly favored this social value were significantly more likely to apply in excess. Personal experience likely is a rhetorical device used to justify the rejection of outside recommendations that would persuade farmers to apply less. Its successful deployment thus benefits organizations such as the fertilizer industry as demand for fertilizer increases. Future inquires may benefit from tracing the personal experience rhetoric to a specific organizational or cultural source. Related to policy interventions, this finding suggests that methods encouraging farmers to be open to and respond to new information about fertilizer application may persuade them to reevaluate and reduce their application rates.

Awareness of N_2O as a GHG also reduced the tendency to over-apply. Exposure to information about GHG emissions and climate change may also influence application decisions. Functioning as a social attractor, this conservation-inducing knowledge likely stems from the organizational level of social relations. Organizations and institutions, such as university extension, may shape farmers actions through education on the environmental impacts of their practices. Farmers are potentially simultaneously exposed to arguments dismissing the anthropogenic causes of climate change (Stuart et al. 2012), which mitigate the potential for knowledge such as this to prompt behavioral change. How these competing visions of farmers' impacts on the environment are negotiated is its own arena of social attractors and in the future should be examined in more detail. It is probable that farmers' perception of and willingness to act on this knowledge is shaped by the influence of peer-groups. An exclusive vertical influence of social attractors (i.e. between levels of social relations) is unrealistic and horizontal pressure is potentially exerted as well (i.e. within a level).

Actors' agency to act on or dismiss information was also revealed. For instance, farmers who reported awareness of N's link to N_2O were significantly more likely to apply in excess. This knowledge may be indicative of farmers who have knowledge of the chemical composition of N, yet are productivist in orientation. Alternatively, the relatively high reported knowledge of N_2O in surveys compared with little awareness stated in interviews and focus groups leads us to question the validity of the survey results. Reported awareness may be exaggerated, potentially a result of farmers wishing to validate their application decisions through displaying expertise. The deviation between qualitative and quantitative results suggests that in future studies of similar populations researchers should be careful in interpreting survey responses related to reported knowledge.

Acres of corn planted also proved to be predictive of application rates. The last 50 years have witnessed a concentration of farmland, leading to fewer producers operating on significantly more land. Our results reveal that farmers who have larger farms are more likely to over-apply. Therefore, a general shift in farm size may be driving inefficient application practices such as excessive N rates. Over-application on large farms may be a means to mitigate risk associated with under-applying. Alternatively, this could be linked to the difficulty of managing the sheer size and complexity of large farms, which leaves less time for decisions on applying precise amounts or an ability to adopt conservation application practices (e.g. sidedress application, cover crops, etc.). The social attractor framework conception of social relations frames this finding in relationship to the structural influence of capitalism. It suggests that as industrial farms have become increasingly capital intensive, specialized and large (MacDonald 2013) under capitalism's drive for production expansion (Lewontin 2000), they have also become inefficient related to N application rates.

Surprisingly, no significant differences were found between farmers that use different sources of information. Insignificant results may signify the importance of multiple and interactive, rather than singular, sources of information (Stuart et al. 2012), or may be linked to the noted declining credibility of university extension educators based on their link to industry (Buttel 1985; Henke 2008; McDowell 2001). This finding is unanticipated and indicates the need for further research. It may be more beneficial to consider

The social attractors framework proved useful in this study and likely for future work as well. In the qualitative analysis, the social attractor concept enabled the identification of social processes or techniques that functioned to compel or enable farmers to consent or contest applying in excess. While this conceptualization revealed the nuances of farmers' potential for agency, the subsequent quantitative analysis allows us to make broader conclusions about the general influence of these processes on N rate. Though quantitative analysis of social attractors precludes the inclusion of the above noted potential for agency in each social influence, the social attractor framework guided our conceptualization of quantitative models. It supported our conception of social actions as persistent based on a process of active reinforcement through structural and organization influences without neglecting opportunities for such influences to disturb the resilience of these actions. Further, the framework's embedding of social actions within an SES nonlinear feedback loop, where actions impact ecosystems that in turn influence social relations in ways that drive actions, allows for a study of the complex social and ecological drivers and consequences of excess N application. While we did not have ecological data to include here this framework offers a means of conceptualizing the complex social and ecological interactions beyond a simple linear path of influence and enables social scientists to theorize how social actions operate in coupled systems. Thus, it may encourage social scientists to engage in more SES research.

Our results apply to un-irrigated commercial corn farmers in Michigan. For further generalization, future studies should take insights from this study and expand their investigation to larger, more diverse samples. While 120 lbs./acre was used as the tipping point at which application exceeds crop demand, this measure is generalized. Each farm, based on soil type, weather conditions, etc. will have its own unique tipping point rate. However, this rate is a likely average point at which N rates have disproportionate effects on the environment and minor influences on yield potential.

Finally, while ecological attractors were identified in this study (*Figure 3*), we did not yet test them based on limited data. Instead we focused only on social attractors. To support a SES focus, future studies should include both social and ecological attractors to explore a comprehensive social-ecological attractors approach. Despite these limitations, this study provides numerous insights into how farmers think about land, profits, and the environment.

CONCLUSION

Though human action may now dominate most ecosystems functions, ecosystems remain dynamic. Their stable states fluctuate as social and ecological disturbance change their processes. These changes often feed back into society, impacting the very social practices that triggered them. This reciprocity is likely significant and should be modeled in future analyses to determine exact effects. Resilience theory's SESs framework has proved fruitful in depicting this process of mutually shaping feedbacks. However, its application has tended to capture the complexity of ecosystem processes in SESs to the detriment of its depiction of society.

Ecologically impactful social actions do not occur in a vacuum devoid of power relations or individual agency. In contrast, they are embedded within social structures, compelled by organizational and institutional policies and motivated by social norms, along with numerous other encouraging or coercive determinants. Furthermore, at each point actors have the ability to contest these influences.

In an attempt to capture a degree of these complex processes that influence farmers' N rate decisions, Hatt's (2013) social attractor framework was used to conceive of N application as a resilient social-ecological action. Using this conception, we have suggested that N application, along with other ecologically harmful social practices, remain persistent based on social processes (structure, organizations, beliefs, knowledge) that actively recreate its resilience to various social and ecological disturbances. The social attractor framework proved useful in building the theoretical capacity of resilience theory to depict a nuanced social dimension of SESs.

In theorizing how these actions are maintained, this framework and research also suggest the sites at which effective social disruptions may be explored and/or introduced to shift farmers' state of application from excessive to conservative. For the development of future disruption strategies, a more specific exploration of the identified drivers of excess N rate may prove fruitful. Until these processes are actively disrupted, agricultural contributions to climate change and degraded water quality will remain resilient and continue to threaten the healthy state of local and global ecosystems as well as the safety of human lives.

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