An Accelerating Treadmill and Overlooked Contradiction in Industrial Agriculture: Climate Change and Nitrogen Fertilizer

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Abstract: In this article we explore if and why farmers are responding to the impacts of climate change with practices that increase greenhouse gas emissions. Our examination focuses on heavy rainfall events and midwestern corn farmers' nitrogen fertilizer management. Due to climate change, the frequency and intensity of heavy rain events is increasing across the Midwest. These events increase nitrogen loss to the environment and introduces economic risks to farmers. Drawing from a theoretical framework that merges O'Connor's Second Contradiction of Capitalism and Schnaiberg's Treadmill of Production, we argue farmers' responses to these events reflect the second contradiction, increasing contributions to climate change, and are shaped by treadmill-like political-economic pressures. We examine this using a qualitative sample of 154 farmers across Indiana, Iowa, and Michigan. Given profit-imperatives, adapting farmers in our sample primarily used increased nitrogen application rates to reduce their vulnerability to heavy rains. As nitrogen rate is directly associated with nitrous oxide emissions, this adaptive strategy is effective, but increases agricultural contributions to climate change. This preliminarily suggests that the political-economic structure encourages farmers to respond to climate change in ways that accelerates the environmental contradictions of industrial agriculture.

Keywords: Political-Economy; Climate Change; Agriculture; Adaptation; Nitrogen; Mal-Adaptation

INTRODUCTION

Industrial agricultural production both contributes to and is increasingly threatened by global climate change (Weis, 2010). Agriculture emits carbon dioxide, methane, and nitrous oxide, accounting for 10-15 percent of global anthropogenic greenhouse gas (GHG) emissions and is the sector with the largest contribution to non-carbon dioxide emissions (CCPSWG, 2011; IPCC, 2007). In terms of impacts, it is widely expected that climate change will dramatically alter the conditions for crop growth, presenting significant challenges (Lal et al., 2011). Given these realities, it is critical that agriculture transitions to a system that is both less vulnerable to climatic impacts and that contributes less to the GHG emissions driving climate change (Weis, 2010).

This transition will involve the widespread adoption of management practices that both reduce GHG emissions and vulnerability to the impacts of climate change (Howden et al., 2007). We refer to these practices as conservation adaptive practices. In the United States (US), most of these practices are outlined in guidelines provided by the US Department of Agriculture's Natural Resource Conservation District as well as other conservation groups that work closely with farmers to reduce environmental impacts. These practices include changes in tillage as well as residue and fertilizer management (NRCS, 2018). For example, cover crops store more carbon and reduce soil erosion and nutrient loss– serving to both reduce vulnerability and GHG emissions. These benefits can be realized in both the short and long-term.

In contrast, quick-fix adaptive practices refer to agricultural practices that reduce vulnerability to climate impacts but may increase GHG emissions or other sources of environmental degradation. There is a long history in modern agriculture of addressing environmental threats to production through quick-fixes that increase environmental degradation (Clark & York, 2010; Weis, 2010). See for instance Clark and Foster's (2009) history detailing how using Peruvian guano (bird droppings rich in nutrient) to overcome declining soil fertility in 18th century English agriculture increased nutrient pollution and led to the geographical expansion of soil fertility issues.

In this study, we examine how, similar to 18th century farmers, today's farmers responses to challenges related to climate change ultimately increase the environmental contradictions of capitalist, industrial agriculture. We focus on row-crop farmers in the US Midwest and their adaptive responses to the increasing intensity and frequency of heavy rain events and their impact on nitrogen fertilizer use given structural conditions (see below for specific research questions). Nitrogen (N) fertilizer application releases nitrous oxide gas (N_2O), a GHG that is approximately 300 times more effective at heating the atmosphere than carbon dioxide. In the US, agricultural fertilizer use is the primary source of N_2O emissions (EPA, 2015).

Our analysis draws from over 150 personal interviews with Midwestern corn farmers and is guided by a theoretical framework that combines and develops the insights of O'Connor's (1988, 1998) "second contradiction of capitalism" and Schnaiberg's (1980) "treadmill of production." Using these theories, we ask 1) do farmers respond to threats to production imposed by climate change through actions that ultimately further threaten production via increased GHG emissions (illustrating the second contradiction of capitalism), and 2) why do farmers respond this way and what is the role of prioritizing short-term profitability (treadmill of production)?

In this paper, we use interview data to empirically explore these questions among Midwestern corn farmers. To begin, we provide the necessary background on N use, climate change, and management practices. We then present our theoretical approach, research methods, and a discussion of our findings.

BACKGROUND

Nitrogen use, corn and heavy rainfall events

Today, agricultural crop's N needs are primarily met through the production and application of synthetic N fertilizers (Smil, 2002). Corn receives about 50% of all N fertilizer applied in the US, with the majority of this N being applied in the midwestern "corn-belt" states (ERS, 2018; Ribaudo et al., 2011). About half of all N applied in corn production will be lost to the environment through air or water (Cassman et al., 2002). Applied N fertilizer results in the release of N_2O, the powerful GHG that is the focus of our analysis. N_2O is by far the dominant agricultural GHG emitted in the Midwest (Larsen et al., 2007). Approximately 70 percent of all US N_2O emissions come from agriculture (EPA, 2019). To illustrate the significance of corn production for N_2O emissions, we provide some statistics from Iowa, the top corn producing state. While agriculture is responsible for 9% of all US GHG emissions (EPA, 2019), in Iowa agriculture is responsible for 30% of all state emissions and 93% of N_2O emissions, and over 55% of all agricultural GHG emissions are from N_2O (DNR, 2017). Because the amount of N_2O released is directly related to the quantity of N fertilizer applied (Robertson et al., 2013), reducing N fertilizer application is one of the most effective climate change mitigation strategy in agriculture (Kanter, 2018; Millar et al., 2010), especially in the Midwest.

Climate change has and will continue to present a number of challenges to agricultural N management (Davidson et al., 2012). In this paper we focus on farmers' adaptive responses to N loss associated with heavy rain events. Heavy rainfall 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 and intensity of heavy precipitation events has increased across the Midwest (Pryor et al., 2014). Relative to the heaviest 1% of all rainfall events from the 1951-1980 reference period, the frequency of heavy storms occurrence in the region had increased by

23.6% and the amount of precipitation falling in those storms increased by 20.2% between 1981-2010 (GLISA, No date). The trend of increasing frequency and intensity of heavy precipitation across the Midwest is expected to continue in the future (Janssen et al., 2014).

The increased occurrence of heavy rain events has presented and will continue to present challenges to agricultural N management. Heavy rain events increase surface runoff and leaching of N and can further emissions of N_2O from agricultural soils (Davidson et al., 2012; Robertson et al., 2013). The occurrence of heavy rainfall events not only increases the loss of agricultural N (Mitsch et al., 2001), but in doing so poses economic risks. N loss increases the chance that yields will suffer due to N deficiency (Robertson et al., 2013). Across the Midwest, 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). In short, heavy rainfall events present substantial challenges to agricultural producers' N management.

Adaptive practices

A range of practices are available to farmers that can effectively reduce their vulnerability to heavy rain events (among other climate change impacts). We divide these measures into two categories: (1) conservation adaptive responses and (2) quick-fix adaptive responses. Conservation adaptation involves practices that balance economic and environmental concerns by reducing vulnerability to climatic events without increasing environmental harms in the short and long term. Related to N management and heavy rainfall, these practices can 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 (injection of N); applying N at the times of the season when the crop's N demand peaks (in-season application); and using N products or formulations that make N more resistant to climate variability (N-inhibitors or "stabilizers") (Robertson et al., 2013).[1]

Farmers may alternatively (or additionally) undertake management practices that reduce vulnerability to heavy rains, but at the expense of increasing environmental degradation, particularly with regards to climate change. Noted above, we refer to these practices as quick-fix adaptive responses. Related to N use, N application rates in excess of crops needs are sometimes called "insurance N," a strategy to ensure (i.e. "insure") maximum yields given seasonally variable weather patterns (Sheriff, 2005; Stuart et al., 2012). The logic of this strategy in response to heavy rain events is that applying extra N means that a little extra N is left behind to support crop growth after a rain event diminishes N levels in the soil. More N directly replaces lost N and thus is highly effective at reducing N deficiencies. Because N is often much cheaper than corn, this practice of adding more N is also profitable (Robertson, 1997). In this way, increased N rates reduce vulnerability to seasonally variable weather, such as the occurrence of heavy rain events. However, as N_2O emissions are linked to the rate at which N is applied this response, if widely adopted, could dramatically increase agricultural contributions to climate change in addition to other forms of pollution related to N, as even modest increases in N rates can dramatically increase contributions to climate change (Hoben et al., 2011; McSwiney & Robertson, 2005; Millar et al., 2010).

As this discussion suggests, it is possible that farmers are responding to the impacts of climate change, specifically heavy rain events, in ways that increase GHG emissions from

[1] 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).

agriculture. Despite the significance of this potential feedback loop, little empirical work has explored if farmers use quick fix adaptation practices,[2] if they use increased N rates to mitigate weather-related risks (Arbuckle & Rosman, 2014) and overall we currently know little about whether farmers are implementing practices in response to climate risks (Mase et al., 2017) as the majority of the literature on adaptation practice adoption has examined behavioral intentions or supportive attitudes toward conservation adaptive practices (e.g. Arbuckle et al., 2013a, 2013b; Roesch-McNally et al., 2017).

To build on this prior work, we examine the potential that political-economic context does not just discourage the use of conservation adaptive practices as other studies have suggested (Blesh & Wolf, 2014; Roesch-McNally et al., 2018b), but may encourage some farmers to use quick-fix responses. In other words, are farmers adopting quick fixes that ultimately increase future threats to production and if so, why? In particular, how do social-structural conditions influence these decisions? Below, we combine O'Connor's (1988) second contradiction of capitalism with Schnaiberg's (1980) treadmill of production thesis to examine how farmers adapt to heavy rain events given the political-economic structure of industrial agriculture and N fertilizer's central role in this structure.

CONCEPTUAL BACKGROUND

We examine if corn farmers responses to heavy rain events will largely follow O'Connor's (1988) second contradiction of capitalism thesis. In contrast to much of the political-economy literature in environmental sociology, O'Connor's (1988) second-contradiction theory has direct implications for how environmental changes caused by production may influence production.

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[2]As one exception, Roesch-McNally and colleagues (2017) find that some farmers are dealing with weather variability and extremes by using increased tillage, which would increase carbon dioxide emissions. Their analysis and discussion generally focus on farmers using conservation management practices though.

O'Connor argues that in a perpetual search for greater profits, capitalism does not just undermine the consumer base necessary for generating demand (the first contradiction), it also undermines the environmental conditions necessary for production (the second contradiction).

O'Connor (1988, 1998) argues that environmental degradation caused by production is a growing barrier to further production. Specifically, environmental degradation increases the costs of production in a number of ways—e.g. more resources must be used as production efficiency declines, or resources become more expensive as they are degraded/made scarce. In response to lower profits, individual firms respond in ways that aim to restore profits, but ultimately further environmental degradation as these externalities are not directly considered in the decision-making process. As O'Connor (1998: 162) states, individual firms, "defend or restore profits by strategies that degrade or fail to maintain over time the material conditions of their own production," thereby causing further environmental degradation. Referring to this as a "cost-side crises," O'Connor (1988) sees this cycle of production-degradation-and profit-loss to be a fundamental (second) contradiction of capitalism, as in the long-term it will undermine firms' capacity to achieve profit-imperatives in addition to causing increased environmental degradation.

Much of O'Connor's position is already well documented in the context of agriculture. The concentration of agricultural lands and capital intensity of agricultural production has rapidly grown over the last three decades (MacDonald et al., 2018) and a number of scholars have pointed to how this process is accelerating environmental changes, like climate change, that threaten the system's very capacity to function (e.g. Hendrickson et al. 2019; Weis, 2010). For our purposes, the second contradiction of capitalism thesis has at least one key implication. It suggests that the dominant adaptive response farmers implement will further environmental degradation, or in our terms, it will be quick-fix adaptation, thus ultimately undermining the long-term environmental and economic viability of agricultural production.

To explain why farmers are making decisions that could undermine production in the future, we draw from the Treadmill of Production (ToP) theory to understand the drivers in the capitalist industrial agricultural system. ToP theory presents a structural perspective on the relationships between production and the environment within capitalist society (Schnaiberg 1980; Schnaiberg & Gould, 1994). ToP depicts production in capitalist society as operating in an ever-expanding cycle (i.e. treadmill), with growing environmental consequences. Given the structural production/profit imperatives in the ToP, each firm (or farmer in our case) competes to increase production and lower costs in order to capture a larger portion of the market than competitors. The treadmill involves the adoption of strategies to increase production and profits, and when producers do not accelerate fast enough on the treadmill, they can be forced out of business due to competition.

From past work, it is clear that a variety of drivers create ToP conditions, including capital investment, competition, federal subsidies, crop-insurance policies, advertisement and recommendations from fertilizer dealers and seed companies, and models for yield maximization. These and other processes pressure farmers to increase production and seek profits in a ToP pattern (Hendrickson & James, 2005; Magdoff et al., 2000; Levins & Cochrane, 1996; Reosch-McNally et al., 2018b; Stuart et al., 2012; Stuart & Houser, 2018). In our application of this theoretical model, we strive to understand how farmers respond to the impacts of climate change given their highly constrained position within the agricultural ToP. While O’Connor (1988) describes the role of the profit incentives, the ToP emphasizes how systemic drivers place significant pressures on individuals that can restrict decision-making to prioritize profits. The ToP, especially in terms of constrained choice, helps us to explain why we might see a situation that resemble the second contradiction of capitalism.

Applied to our case, the ToP framework suggests: (1) ToP pressures will drive farmers to protect and pursue expanded production/profits[3] in their N use decision making and (2) because of these ToP pressures, farmers will adapt to N loss using the practice that ensures maximized production/profits responses to heavy rain events, even if this adaptation choice is known to increase the environmental consequences of agricultural production. In other words, how much room do farmers have to respond to heavy rains with conservation adaptation practices when the ToP pressures them to conform to the profit imperative in order to stay in business? While the ToP influence may not drive all of farmers decisions, we posit that it has a significant influence. Also, if some farmers have the ability to adopt conservation adaptation practices, what makes that possible?

Using our novel theoretical framework that combines O'Connor's (1988) second contradiction thesis with Schnaiberg's (1980) ToP framework, we can suggest not only how farmers are responding to climate change (in ways that accelerate their contributions to climate change), but why they are doing so, with specific attention to the role of the political-economy of agriculture in shaping their decision-making toward greater environmental destruction and thus barriers to production in the long-term. We draw from over 150 personal interviews with Midwest farmers to examine explicitly what factors drive farmers responses.

METHODS

[3] As one anonymous reviewer pointed out, production and profits are not always empirically linked. Though the two are not absolutely connected and interviewees recognized this, farmers generally "rationally" strove to expand production in a manner that achieved more profits. Our use of the term "production/profits" signifies these intended linked ends.

To explore if farmers are responding to heavy rain events through quick-fixes and specifically why they are doing so, we used 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. 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 (Cresswell & Plano Clark, 2011), 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 gathered, we used snowball sampling, where preliminary contacts are used to gain access to additional respondents, 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.

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[4] and extension organized field days). Farm sizes of interviewed farmers ranged from 170 to 14,000 acres, with an average acreage operated of 1,615. All farmers were white-

[4] 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

males, operated family-owned farms and identified themselves as primary management decision-makers. Interviewees were not asked about their age, but the vast majority appeared to be around middle-age, with only a few having just started farming and or beginning to consider retirement. More information is provided in Table 1.

Table 1: Sample Characteristics	
Characteristic	n
Primary Rotation Type:	
Corn-soy	95
Corn-corn	13
Corn-soy-other (e.g. corn-soy wheat; corn-corn-soy)	9
Misc (e.g. corn, soy, oats, wheat, etc.)	32
Practice use (general):	
Cover crop use	29
In-season application	101
Multiple applications of N	144
Stabilizer use	52
Total n	154

As most contacts were identified through University Extension, farmers in this sample may be more familiar with conservation adaptation strategies. The bias this may introduce to our sample is ultimately not an undesirable one. Since farmers in our sample may have greater knowledge/current use of conservation practices, our work can assess how political-economic conditions shape farmers' adaptation decisions among farmers who are knowledgeable about conservation practices.

A semi-structured interview guide focused on farmers' N use decisions and the various factors, like climate impacts, that shaped these decisions. Interviews lasted between 22 minutes and 2.5 hours. Upon completion, interviews were transcribed and analyzed using NVivo software. 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.[5]

To identify adaptation practices and farmers' justifications for adaptation, we followed 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) adaptation strategies and justifications (Charmaz, 2006). The lead author undertook preliminary coding of farmer responses. In a second round of coding, each adaptation coding was reviewed by the co-author, and any disagreements in coding theme were discussed and settled between the two authors to determine final coding categories and counts.

Importantly, considering the coding of farmers' adaptive practice use, responses were coded 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, farmers were coded to be using an adaptive practice *only* when it was reported that this practice was adopted or used because it was perceived to reduce their vulnerability to heavy rain events and potential to loss N loss 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.

We use our data to examine: 1) How are farmers adapting to increased rain events, especially in terms of adjusting their rates of N fertilizer application? 2) What factors are influencing these decisions, particularly how do structural conditions shape farmers' N

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[5] 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.

application? For the first question we seek to understand if farmers are responding to heavy rain events and N loss in ways that undermine agricultural production in the long term (via increasing greenhouse gas emissions), in line with the second contradiction of capitalism. For the second questions, we seek to understand what influences these choices and, focusing on how profit-imperatives and competition lead to a treadmill-like model of N use that may constrain farmers' responses toward short-term economic goals, rather than long-term sustainability.

HOW ARE FARMERS ADAPTING TO HEAVY RAINS? THE SECOND CONTRADICTION

O'Connor's (1988) second contradiction predicts that barriers to production will be responded to in ways that accelerate environmental destruction. In our case, this suggests farmers will adapt to N loss from heavy rain events, a climate change impact, in a way that accelerates agricultural contributions to climate change, what we call "quick-fixes." We explore this possibility in the first results section.

Interviewed farmers reported increasingly experiencing the impacts of heavy rain events. As one Iowa farmer described: "We've had some wild extreme [weather] here these last 5–7 years […] Where we used to get a half inch to an inch of rain, now it's common to get 2–3-inch rains (IA16)." Across all three states in our sample, 69 (of 154) farmers commented their N use had been impacted by heavy rain events or "extreme weather," which commonly indicated heavy rains. The majority of these farmers (58/69) reported experiencing N loss or were concerned about N loss as a result of heavy rain events in recent years, this number varying across states, possibly a result of actual geographic variations in experiences with rain events (see Table 2).

Given the consequences of heavy rains events for N/yield loss (noted above), farmers were highly motivated to adapt to these impacts. The majority of farmers in our sample who described perceiving N loss from heavy rain events also reported adopting an adaptive practice to address this issue (45 of 58). But variations existed in the types of practices farmers adopted, as shown in Table 2.

Table 2: N loss from heavy rains and adaptation by type and state				
State	Reported N loss from heavy rain	Reported adapting	Conservation practice adaptation	Quick-fix adaptation
IN	18	15	4	11
IA	27	20	4	16
MI	18	9	4	5
Total n	58	44	12	32

Table 3: Adaptation by category		
Farm sizes (ac):	**Using Conservation Practices**	**Using Quick-Fixes**
Mean	1310	2427
Std. Dev.	646	2493
Range	220-2000	200-14,000
Median	1500	1750
Total n	12	32

As shown in Table 2, many interviewed farmers were responding to the impact of heavy rain events with some form of conservation adaptation practice. For instance, one farmer who used multiple, in-season applications justified this practice in saying: “We feel that we can control it better that way because you put it all on at planting time and get a bunch of rain and you would lose some of it and I guess I’m too cheap” (MI19). Beyond using multiple, in-season applications, others adapted via using stabilizers, injecting N under the soil, or through planting cover crops (21% of farmers experiencing heavy rain).[6]

[6] While most farmers reported using only one of these practices at a time (n=7), some used multiple simultaneously (n=5).

Though some farmers were adapting via conservation practice, most interviewed farmers adapted to heavy rains by using quick-fixes either exclusively (45%) or deploying a quick fix strategy alongside a conservation practice (10%). N_2O emissions are directly associated with N rate (Millar et al., 2010; Robertson et al., 2013). Therefore, we view farmers who reported more N use, even alongside a conservation strategy, as adapting using a quick-fix approach per our definition. That a quick quick-fix response is dominant reflects the second-contradiction of capitalism thesis (O'Connor, 1988).

Interviewed farmers used the quick-fix of more N in various ways. In the adaptation literature, "timing" refers to when adaptation takes place, and can include anticipatory (i.e. proactive) and responsive (i.e. reactive) actions (Smit and Skinner, 2002). A minority of the farmers adapting via quick-fixes (9/32) used increased N rates in an anticipatory fashion, where they assumed that N loss from a heavy rain event would occur in season and therefore, they should apply extra N. Some farmers described this generally, suggesting that they built seasonal weather expectations into their N use: "If we knew how much rain we was gonna get, we'd put more [N] out there" (IA15). To this farmer, N rates were fundamentally determined in anticipation of seasonal precipitation events and N loss and more would be used if weather was expected to be more extreme. Other farmers followed a similar approach but described their anticipatory use of N more specifically. As one Iowa farmer commented: "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 […] just to make sure if we have a really wet year . . . we still have some nitrogen left over" (IA09). An Indiana farmer stated similarly: "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). Implicit in these comments is farmers' expectation that some of their N will be lost to rain events but putting extra N ensured they did not experience yield loss. This reflects the commonly discussed practice of “insurance” N application (Sheriff, 2005; Stuart et al., 2012).

The majority of interviewees adapting via quick-fixes (23/32) increased N rates “responsively” (Smit & Skinner, 2002), or in reaction to the occurrence of heavy rain events. These farmers comments reveal how heavy rains can cause N loss at any period during the growing season, even after using recommended strategies to minimize the potential for in-season N loss, like sidedressing. Whenever rain events were perceived to have caused N loss in the season, responsive ‘quick-fixers’ used in-season application equipment to add N back. If N loss occurred earlier in the growing season, equipment for applying N over smaller corn-plants, like “sidedress” equipment, provided an opportunity to add more back to avoid yield loss. As illustrated by one farmer: “This year we sidedressed, oh 300 or so acres [...] We thought with all the rains, we probably lost some nitrogen, the corn was looking yellowish [, a sign of N deficiency]” (IA16). If a heavy rain caused N loss deeper into the season, late season application equipment to apply N over tall corn-plants, like “Hagies” or “highboys,” and aerial application via airplanes was used. Comments illustrating both responsive timings are in Table 4. These quotes indicate an important point we will return to later: even when farmers are using strategies thought to minimize the potential for N loss, like in-season application (Robertson et al., 2013), heavy rain events can still cause loss that farmers feel must be responded to via more N.

Table 4: Farmers’ comments illustrating responsive quick-fix adaptation, in the earlier and late season
“[I adjust my N rate] year to year based on rainfall. That’s the big thing, just because of the nitrate. It’s 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 [the past] 4-5-6 years have been pretty wet [in] May and June. And just the amount of rain we’ve had has made us add an additional 50 pounds of [N at] sidedress, just because the rain flushes it down

the system" (IA02).

"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).

"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 lose any [N, or lost some [N]. Adjust the rate to make up for those issues that we deal with on managing nitrogen" (IA03).

"[I]n recent years, I don't know if you're familiar with Hagie manufacturing, [they] make 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).

"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).

"[We've] had over 11 inches of rain since then, since sidedressing. So that totally changes how much nitrogen [you need to apply]" (IA32).

"And then we'll follow up with [after sidedress], we'll take a test to see how much rainfall we've had to ssee if we need to add any more with the sprayer" (IA34).

"Extreme years like this I suppose… we've got a field or two where we did decide to add a little bit more and that's with the dry urea over the top with like a box, high clearance buggy, so I'd say this year is pretty extreme with that case, and so we did a little bit of that" (IN34).

"We have difference, of course, from season to season with annual rainfall—this year [rainfall] being exceptionally high. When we have that occur, we can anticipate some nitrogen loss. Especially with those that put down a lot of [N] preseason and that can trigger or generate demand for late season nitrogen to try and achieve their yield goals" (IA22).

Toward explaining why, some farmers were not enacting the second contraction of capitalist via quick-fix adaptation, there are substantial differences in the average farm size of those adapting via conservation and quick-fixes, with the latter group being, on average larger farmers (see Table 3). While some outlying farm size values are exaggerating farm size differences between these two groups, what is particularly suggestive of larger farmers being more prone to quick-fix adaptation is the concentration of very large farmers using the quick-fix approach (25% of this sub-group farmed over 2,700 acres, where no conservation-adapting farmer farmed over 2,000 acres) and the concentration of very small farmers in the conservation group (25% of the sub-group farmed under 1,000 acres, where only 10% of the quick-fixes farmed less than 1,000). On the whole, quick-fix farmers in our sample tended to be operating larger farms compared to conservation adaptation farmers. A few farmers suggested that this was because operating larger made it more difficult, cognitively and in terms of time management, to carefully manage N application. For instance, "The bigger you get sometimes the less efficient job you can do" (IA34).

These findings suggest that interviewed farmers operating larger farms are adapting to heavy rain events in a way that accelerates agricultural contributions to climate change (i.e. quick-fix adaptation). Overall, the prevalence of quick-fix adaptation we reveal in this section accords with O'Connor's (1988) second contradiction of capitalism thesis that environmental barriers to production in capitalist sectors will be overcome in a way that accelerates environmental destruction, in this case climate change and the impact of heavy rain events. We now turn to exploring why farmers primarily used these quick-fix strategies. Following our theoretical framework, we examine the role of structural conditions and first explore if we see pressures and outcomes similar to the ToP.

HOW TREADMILL CONDITIONS SHAPE FARMERS' N USE

ToP Pressures and the need for N

The ToP model depicts an agricultural system in which capitalist growth logic and competitive pressures motivate and compel continual efforts to maximize production. Interviewed farmers, speaking at the level of individuals within this system, frequently commented on the political-economic pressures of this system and how they shaped management decisions. These pressures include debt, tight profit-margins and competition for land. The sample of interview responses below illustrates the presence of these pressures and their influence on their decision-making:

> "Most of us have debt, and so I've tried to remember that, […] You want to be really cost-effective" (IN44).
>
> "You know, just concern if it's gonna be enough [production/profits] to get me through [to another season]" (IA03).
>
> "With profits being so small anymore you don't want to change a whole lot because it's going to affect the bottom end" (IN20).
>
> "It's competition. Sure. The thing of it is, it seems like the big guys are getting bigger, the little guys are getting smaller" (IN14).
>
> "That farming community has disappeared because you have less farmers and they are your competition. I don't like sharing a whole lot of information with them because I think they are my competition" (IA20).

ToP pressures like these farmers describe are engrained at multiple levels, translated from structural goals to practical imperatives by the actions of various institutions and actors across the agricultural system. Federal crop insurance bases insurance-levels on famers' average yields by field. To ensure their potential payments were high, farmers strove to ensure yields are consistently maximized:

> "Yeah, we've been fortunate to have a good proven yield on our farm and we want to maintain that. And it does help our premium on our crop insurance, so I want to grow the best crop I have out there. So, I will try to make sure I feed it [by applying enough nitrogen]" (IA03).

In addition, farmers feel they are locked in by market prices and conditions making it a requirement that they maximize production and cut costs. For example, one Iowa farmer explained: "Everything I buy is retail and I have no control over the pricing of my end product. .

. I have no control over that . . . I cannot build in a margin of profit. I cannot say well I'm gonna mark up my corn 20% to cover my costs here" (IA38).

Agricultural advisors also shape farmers' management practice decision-making and, when associated with fertilizer dealers, are key personal conduits that can encourage farmers to pursue greater and greater levels of production (and N fertilizer use), to the benefit of their own sales (Stuart et al., 2012, 2018). One farmer, IN11, invited his fertilizer-dealer associated advisor to meet with us during his interview and the advisor's comments reveal how he encouraged the farmer to pursue ever greater production:

> "People like [IN11] and other growers are looking… they're looking back and saying 'Hey, we are consistently raising a better crop every year, but mathematically and scientifically to get to this next tier are going to have to have more nitrogen, based on university results and testing.' So that's what we talked about for next year, [we] think we're probably going to have to add about 20 pounds [of N per acre], maybe 30. It's something were going to have to discuss, to next year's program and continue to go from there, because he is wanting to raise his yield goal, he wants to make more money, just like everybody."

The advisor's discussion captures how multiple factors at multiple levels come together to pressure farmers to pursue ever more yield/production: practical, individual rewards, normative materialistic values, instrumental logic that more is better, competitive pressures and debt burdens. But the advisor's own implicit pressure, 'you need to grow more and I can show you how,' is also present.

These comments are not exhaustive, nor are they meant to be. They do reveal how structural pressures of the ToP to maximize production/profits are translated to and reinforced in farmers' decision-making through multiple processes and across multiple levels of influence. Indeed, these pressures are extensive and embedded enough that without prompting, nearly half of all farmers interviewed (44%) explicitly mentioned that their primary goal was to be profitable and maximize production. Given the presence of these pressures, maximizing profitability is a top-priority in agricultural production. The farmer working with this above quoted advisor illustrates this perspective well in saying: "Profit driven, you know, productivity driven, that's the way I think you need to be if you want to be in business" (IN11).

N use is caught up in the pursuit of production and profits in the Midwestern row-crop system. The above comments begin to suggest how the two are intertwined. Sufficient N are a perquisite to maximum yields and, often, adding more N is a key means toward increasing more production. Given political-economic pressures, farmers emphasized that increasing N use, along with implementing other production technologies, is a key means to achieve production and profit imperatives. One farmer, for instance, commented on how he used increased N rates as part of an overall strategy to increase production: "…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 everything lines up again, was nitrogen the determining factor from getting us higher? So bumped [our N rate] up there" (MI20). Similarly, and relatedly, any reduction in N use, particularly on an annual basis, was seen as a production barrier and thus profit-imperatives discouraged considerations of using less N: "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 [through reduced yields/profit]" (IN30). Concern that deficient N levels was a barrier to production was widely held. Across all 154 interviewees, all commented that lower N use, to any extent, would put them at significant risk of not achieving maximum profits on an annual basis (some did hope that future technology would allow them to reduce N use though). This is also well illustrated by one farmer who discussed the consequences of any reduction in N use, saying that if he was to allow N levels to be deficient in his soils: “What kind of safeguard [would] 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?” (IN44). Some even specifically noted how this concern about having enough N is caught up in the structural conditions:

> “I guess you’d be concerned that you’re hurting yourself on the yield. We do need to live with the economic system that we have, but I think, you know, that would be my concern would be if I cut back too much” (IA04).

Additional quotes on the importance of sufficient N to production goals and farmers’ views that even more N is a means to achieve more production are displayed in *Table 5*.

As these quotes suggest, to interviewed farmers it was impossible to withstand the consequences of lower N use, production declines in yield. Our interviews reveal that farmers, facing ToP imperatives, see sufficiently high N levels as necessary in this competitive system and use N as an input to achieve and even increase production/profits in a ToP like-fashion. Having established what kind of system farmers operate and use N within, we now turn to more specifically exploring how because of the profit-imperatives of this system, quick-fixes are a rational adaptation choice for farmers.

Table 5: Farmers’ comments illustrating the use of sufficient/high N to achieve production/profits
“It seems like [nitrogen is] the most controllable and readily available way to the farmers to boost yield” (IA13).
"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” (IN15).
“I’ve been increasing [N rate] a little bit the last couple years” (IA48).
“I’ve probably increased how much nitrogen I’ve put on. I’m probably putting on 60-70 units more than I used to. […] And it paid. My yield went up quite a bit. I know corn needs nitrogen if you’re gonna get good yields out of it. I can see that” (IA39).

[We've] maybe increase the [N] rates a little bit over the past few years [to enable greater] yield potential" (IN39).

"I'd hate to cut back too much because you could lose quite a bit of yield" (IN36).

"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).

"Concern about dropping our economics enough; sacrificing net profit" (IA14).

Am I going to be able to pay my bills with less nitrogen… Is my corn going to be able to produce with less nitrogen to pay the bills? I guess that's what will really influence me" (IN48).

Adaptation decision-making: quick-fixes make sense in the agricultural treadmill

Given ToP pressures, farmers must ensure that heavy rains do not lead to deficient N levels and thus threaten yields/profits. In the following sections, we examine how these pressures and the need to maintain sufficient N shapes farmers' primary use of the quick-fix adaptive approach. Reflecting our second premise from the ToP framework, we expect that due to ToP pressures, (2a) farmers' dominant use of quick-fixes (shown above) is because conservation strategies are perceived to not effectively or profitability ensure maximized production/profits as an adaptive responses to heavy rain events and (2b) they will have employed quick-fixes even if farmers recognize their environmental consequences because of the constraints of profit-prioritization.

Ineffectiveness of conservation practices

ToP pressures to ensure sufficient N and maximized profits limited farmers' reliance on conservation practices adaptation practices. Farmers had widely adopted conservation N management strategies as general practices to increase N use efficiency. Of the entire sample, over 74% used at least one conservation N management practice generally, and 39% percent used at least two—these practices aligning with those considered to be conservation adaptation strategies. However, the use of these strategies did not prevent farmers from reporting N loss from heavy rains in recent years—38 of the 58 farmers who reported N loss were using N conservation practices (mostly multiple, in-season applications) as general practices (and not as adaptive practices). Farmers' comments illustrate these experiences and suggest that the unreliability, along with high costs of some conservation adaptation reduced their reliance upon them as adaptive strategies.

In many cases, farmers expressed uncertainty over whether cover crops would provide any reduction in N loss (among other agronomic benefits). As a live organism, the benefits derived from cover crops depend on successful growth and development—something that is, just like N loss, vulnerable to seasonal fluctuations in weather/climate (Bergtold et al., 2012). Farmers noted how cover crops were not reliable: "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). Another farmer similarly said: "I had never done cover crops before. Last year I [enrolled] 500 acres [in a federal program that paid me to plant cover crops, but] I couldn't get [them] planted because it was wet" (IA47). Others noted that cover crops they had used were not, in their view, effectively holding and releasing N: "To say I'm seeing benefit from nitrogen release from the cover crops so far, not really" (IN10), or that they were just unsure of what the benefits of covers had been: "Now I have been using cover crops, and I'm not really sure yet how much nitrogen they are absorbing and providing. It's hard to tell" (IN40). Uncertainty of whether cover crops could be planted or would provide benefits led some farmers to not use cover crops, while others used cover but did not rely on them: "I'm not planning on using less nitrogen fertilizer next year because I'm going to use cover crops this year" (IA28).

Like cover crops, using multiple applications suffers from dependability issues. Across the sample, in-season N application was a very common practice, with 101 out of 154 of farmers interviewed using in-season application methods to apply N and it was generally recognized by farmers to have economic and environmental benefits. But, as we illustrated above (see page 10), using multiple application timings does not ensure N loss will not occur and even when farmers were using multiple timings (e.g. pre-plant, at-planting, sidedress, and/or late-season), heavy rains events could lead to N loss. To affirm this point, one farmer's comment is suggestive: "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 […] when I got my corn stalk nitrate test [results back], I could see it said that the nitrogen got away" (IA04). In short, in-season application does not ensure N loss will not occur. That 20 of the 32 farmers who reported increased N rates were using in-season application exclusively as a general N management practice (and not as an adaptive strategy) maybe best illustrates its ineffectiveness as an adaptive strategy for insuring N loss did not occur from heavy rains.

And as with the other conservation practices, farmers noted consistency issues with N stabilizers, in particular, Michigan farmers:

> "I have [used stabilizers] in the past, but I really didn't see a lot of…a lot of difference" (MI8).
>
> "We've worked a little bit and looked at nitrogen inhibitors [i.e. stabilizers]. Typically, what happens to us here is physical movement of material through these coarse textured soils with excessive water, and that happens even if you put an inhibitor in there" (MI9)
>
> "I've played with [stabilizers in the past] and never seen any difference" (MI34).

Adding to reliability issues was the price of stabilizers. They were seen to be expensive by farmers and some discussed how high costs of stabilizers, combined with unreliability discouraged reliance on this adaptive strategy:

> "I am not sold on… Oh, like that ESN [Environmentally Smart Nitrogen] and things that tie up the nitrogen [stabilizers], they seem to be awfully expensive for what you get and I've found that… We've actually tested them, and I found that, you know, the same amount of nitrogen did just as good [in terms of yield] whether it had that in it or not" (MI17)

> "N serve can help a little, but you know its maybe only 30% effective a lot of times. Which is, for your money, I don't know" (IN11).

> "I have tried [stabilizers] in the past, and had very mixed results, most of the time non-favorable… In a side by side comparison, you know, [my stabilized ground] was 15 bushels an acre less on yield and I think [it was] like around $35 more of cost in the fertility end of it" (MI3).

> "We've experimented with stabilizers, and we actually used some a couple years ago, and it's pretty expensive, and I had absolutely zero difference in yield" (MI38).

In addition to reliability issues, other farmers noted that cost discouraged their use of conservation practices. Some mention of this was made to cover crops: "Cover crops are a great thing but you're going to run into maybe $20 or $30 an acre worth of costs to do it" (MI21). But most farmers who noted cost as an issue were focused on stabilizers: "I was willing to pay that 8 or 10 bucks an acre [for stabilizers, but my fertilizer dealer] didn't feel like it was a definite pay off […] How much more nitrogen could you buy for 10 bucks an acre? More than 10 pounds…" (IN23). Farmers commonly focused on how given the cost of stabilizers, they used more N in an anticipatory fashion instead (see Table 6).

Table 6: Farmers adapting via quick-fixes instead of stabilizers
Yeah, it's cost [that discourages 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). "We utilized Agrotain, NutriSphere and one other [stabilizer…] but [we moved away from them]…it comes down to is it making your money" (MI32). "The cost of the N serve was prohibitive. It's the same cost whether you put on 40 or 180 pounds. We were paying about as much as the nitrogen [per acre]. We decided that was a bad deal!" (IA19). "No, [we don't use stabilizers]. Well, if we sidedress, you can tell where you need to put more [N] on or not, usually" (IN25).

Noted above, ToP pressures drove farmers to feel that sufficient N levels were mandatory to maintain production and profits. Conservation adaptive practices, as we have illustrated here, were perceived as either unreliable and ineffective, or in the case of stabilizers, as more expensive than using more N, which was equally or more effective at ensuring N deficiencies did not occur. In short, these practices could not ensure sufficient N for maximized production as effectively or cheaply as just adding more N (Sherriff 2005). In consequence, farmers could not rely on conservation practices to adapt to heavy rain events, as doing so could lead them to fail to achieve maximized profits and thus to face the consequence of ToP pressures. One farmer, discussing conservation adaptation practices, particularly cover-crops, illustrates how economic pressures influence this decision:

> "And I think most farmers are in tune with wanting to do the right thing for the environment, the right thing for the climate. But we also have to look at that, and our margins are thin enough now that we have to look at these type of changes as, 'Is it something we can add and it's not going to hurt us, not only short-term but long-term,' as far as the financial picture. 'Can we include these types of practices and be [economically] sustainable?'" (IN35).

Indicated by farmers' above noted adaptation via quick-fixes, the answer to this farmer's question was often "no." Instead, most farmers relied on quick-fixes, often using more N, as more N directly replaces N lost from heavy rain events and additional application is relatively inexpensive given the price of N to corn ($1/10^{th}$ the price in the year if the interviews) and consequently results in net profits if it boosts yield (Sherriff 2005; Robertson 1997). As this section suggests, the quick-fix of more N is more widely used because it better enables farmers to meet the ToP demands for maximized production and profitability.

Quick fixes, the environment and constrained choices

As conservation strategies were seen as ineffective or too expensive, farmers used more N to ensure they are not in jeopardy of suffering at the pressures of the agricultural ToP. Farmers discussed this decision as a constrained choice, noting their desires to minimize agriculture's environmental impacts via N use. Only one farmer recognized that N use contributed to N_2O emissions, but almost all were generally aware of and believed that N use is related, at least in part, to water-pollution (144/154). Farmers commented on how despite their water-quality stewardship concerns, they could not only adapt via conservation strategies, and/or simply withstand the loss of N from heavy rains. Because of the need to annually maximize yields, farmers felt compelled to adapt via more N, even when this ran counter to their environmental ethics. As one illustrated, despite his best intentions, he discussed adding more N as a constrained choice:

> "Anytime there is adverse weather, [N rate] becomes a difficult decision, cause you don't want to be bad to the environment … I think most farmers are thinking more about the environment… 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]).

This farmer represents the responsive users of quick-fixes, and his comment indicates how despite best efforts to minimize N use and the potential for N loss from heavy rains (he used multiple, in season applications), heavy rains still can cause N loss that demand additional N use. Another commented similarly with regard to insurance, or anticipatory N rates. He stated, "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 increased N rates, which he saw as "a type of insurance" (IN03). Similarly, another farmer wished to undertake system-level crop diversification changes to deal with row-crop agriculture's vulnerability to climate change: "I'm more of the mind that we better be diversifying, because nature's best means of survival is diversity. And corn and soybean rotation is not diverse. I don't know if that is contributing to climate change, but if we're gonna survive climate change, it's gonna have to be something different than corn and soybeans," However, if he felt like he had lost N in-season, he ultimately added more N to ensure he did not experience yield loss: "If there has been an exceedingly wet year, like last year, sometimes we'll bump up the rate in a couple spots, if we think the corn will respond to it, if we think we've lost any [N]" (IA13). Even when farmers wish to respond to heavy rains in ways that minimize environmental consequences, like conservation strategies, they feel compelled to prioritize economic-ends and thus to use the quick-fix of more N.

Farmers discussed how political-economic pressures and system-level profit imperatives drove them to be more concerned about profits than environmental outcomes in farm decision-making. In response to a question about what factors shaped his N management decisions, one Indiana farmer stated: "[Y]ou 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 …we're in a capitalist society" (IN23). Others similarly commented on the need to prioritize profitability in agricultural production give ToP profit-imperatives:

> "I mean as much as everything [i.e. the environment] is important, we're still here to make a profit on the farm" (IA08).

> "The water quality has definitely gone down in Iowa over the last 50 years and I think that's, farmers haven't felt that it was their problem, I don't think. I think they feel like, well, this is what I, what the economy is asking me to do. I'm doing what I'm supposed to as a farmer. Produce the most corn that I can" (IA04).

> "I wouldn't be cutting fertilizer [rate] to save the spotted toad or something like that, if it's going to cost [in yields]…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" (IN16).

> "I think a lot of it boils down to the economics of it. It comes right down to we want to be good stewards, but economics drive a lot" (MI45).

Farmers had a limited capacity to make decisions based on environmental concerns, given system-level pressures to achieve short-term profitability. Within this ToP agricultural structure, that demands consist profitability and de-emphasizes environmental concern, adaptation to heavy rain events via conservation adaptive practices did not compare well with the quick-fix response of adding more N. The environmental consequences of these actions, in the long-term are either unknown (climate change) or cannot be considered given the need to maintain profitability in the short-term.

DISCUSSION

Our results closely resemble the two theoretical frameworks we employ—O'Connor's (1988) model of the expanding contradictory nature of capitalism related to its environmental basis for production and Schnaiberg's (1980) Treadmill of Production (ToP). In the first section, we show the majority of adapting farmers responded to heavy rains by using more N fertilizer, which releases more N_2O emissions and thus further contributes to climate change and heavy rain events (Hoben et al., 2011; Millar et al., 2010). Farmers' quick fix adaptive responses to climate change largely accord with the theoretical premise of O'Connor's (1988) second contradiction thesis: environmental barriers to production will be responded to in ways that ultimately further contribute to environmental destruction and thus in the long-term further undermine production.

In contrast to an activity like clear-cutting a forest, that immediately destroys the basis of production, climate change unfolds slowly over time and the specifics of outcomes are unknown. The temporal distance between quick-fix adaptive actions *now* and the impacts of climate change *later,* as well as the uncertainty involved in future impacts, make this case of the second contradiction of capitalism seem less direct and obvious. Nitrous oxide (N_2O) from fertilizer is also only one of many emissions contributing globally to climate change, making agricultural emissions seem spatially diffuse. The impacts to water quality are also spatially distant (e.g., the “dead zone” in the Gulf of Mexico) and therefore less obvious. While these impacts were not the focus of our study and do not contribute to undermining production in the same way that GHG emissions do, water pollution also illustrates the challenge in agriculture of linking environmental impacts to actions given the spatial and temporal scales of the impacts. Despite these differences in scale, the realities of the relationships between N fertilizer and climate change match the trends depicted in O’Connor’s (1988) second contradiction.

In the second section, we focus on how ToP pressures shape farmers’ adaptive decisions. Results indicate that one reason for adding more N in response to heavy rain events is the ToP pressures drive decision-making. Interviewed farmers utilize the production input of N fertilizer in ways that accord with the structural drive to accumulate in capitalism. The system-pressure to maintain/expand production noted by Schnaiberg (1980) were translated to interviewed farmers through various, cross-scale processes, such as competition for land, crop insurance policies and sources of agricultural information and drove them to feel like sufficiently high N levels were mandatory. While few studies have depicted N as a specific component in this treadmill-like system of capitalist agriculture, we are in good company in considering the expansionary system of capitalist agriculture as one that constrains farmers’ decision-making toward prioritizing economic imperatives and ultimately is leading to ever-greater environmental degradation that threatens the viability of the system in the not so long-term (Hendrickson et al., 2019; McMichael, 2009; Weis, 2010). Similar to past work, our interviewees saw conservation adaptation practices, including in-season application, cover crops and stabilizers, as too expensive or unreliable at ensuring heavy rains did not lead to N loss and untenable deficiencies (Basche & Roesch-McNally, 2017; Roesch-McNally et al., 2018c). In contrast, more N directly ensures N deficiencies are not present and can do so in a more cost-effective manner, as has been widely noted (Arbuckle & Rosman, 2014; Sheriff, 2005; Stuart et al., 2012). In short, the "quick-fix" response is better at achieving profit-imperatives demanded by ToP pressures. Even among farmers who strove to minimize their environmental impacts, they expressed the need to use more N due to the need to maximize production and achieve profitability. As this suggested, mal-adaptation is not just a consequence of ignorance, or willful prioritization of short-term rewards. Instead, we cannot (or at least should not) disassociate farmers' use of a quick-fix, contradictory adaptive strategy from the ToP system in which they operate. In a system where N is the "cornerstone" input of production (Wolf and Buttel, 1996), one cannot be without it in sufficient quantities. The ToP of agriculture makes additional N a rational reaction and conservation practices a riskier response. In this way, structural production imperatives constrained farmers' adaptive decision-making in response to heavy rains toward quick-fix strategies, making even those who wish to prioritize long-term environmental goals focus on the short-term economic realities. This suggests that the political-economic structure encourages farmers to respond to the climate impact of heavy rains in ways that accelerates the environmental contradictions of industrial agriculture, reflecting O'Connor's (1988) theoretical premise.

This finding aligns well with prior work that has revealed how even farmers who intend to undertake conservation practices can be contradicted by their short-term productivity goals (Roesch-McNally et al., 2018b). It also engages with the prior literature emphasizing that adaptive decision making among Midwestern farmers is shaped to a great degree by system-level path-dependencies (Roesch-McNally et al., 2018a), where many farmers are 'locked-in' to the production-oriented practices and thinking of capitalist agriculture (Dentzman & Jussaume, 2017). While this prior research primarily highlights the barriers this system puts in place to conservation adaptation practices, we reveal how it also pushes farmers to use practices that reduce vulnerability to climate change, but ultimately accelerates the rate at which agricultural production contributes to climate change and thus expands its contradictory nature by further undermining the environmental conditions upon which the system depends to function.

Importantly, in terms of acres farmed, some large farmers were capable of using conservation strategies and some small farmers used quick-fixes, but in general our results indicate that smaller farmers in our sample were less likely than larger interviewed farmers to employ quick-fix strategies (see pp. 14). Noted above, a few respondents argued this was a result of smaller farmers being more able to intensively manage their land, and thus less likely to opt for the 'easier' quick-fix approach. Additionally, smaller farmers likely derive a lower percentage of their household income from their farming activities, and thus face less risk from heavy rains events, because they are less dependent on annual profitability and on maintaining the farm for their and their families' livelihoods. In either case, among interviewed farmers in our sample, not all were equally prone to use quick-fix adaptation. Given the qualitative nature of our sample, future quantitative studies using representative samples must assess if this finding is generalizable to the larger population of farmers. This work may also benefit from giving more attention to why some farmers can rely exclusively on conservation practices.

In addition to the political-economic structure we focused on this study, other factors contribute to quick-fix adaptation. In part, this is an issue of who suffers consequences of more N and when those consequences will be experienced. Quick-fixes are a rational choice for any individual farmer. More N both objectively improves and is perceived to improve farm-level adaptive capacity to heavy rain events. However, at greater scales of aggregation (e.g. landscape or regional) and at (relatively) distant points in time, this practice increases all farmers' and indeed society's vulnerability to climate change. As past, adaptation literature has suggested, part of the reason quick-fix practices are employed by individuals or communities is due to the spatially dispersed and temporally distant consequences they sow (Moser & Ekstrom, 2010).

CONCLUSION

Reflecting O'Connor's (1988) second contradiction thesis, this study preliminarily indicates that many farmers in the Midwest are responding to climate change in a 'contradictory manner', that will ultimately increase GHG emissions and the likelihood of future climate related challenges. Building on O'Connor, this paper reveals how farmers are undertaking this practice because the competitive, treadmill-like agriculture system pressures that Schnaiberg (1980) outlines. This system constrained their adaptive choices, leading many to prioritize profitability and use the "quick-fix" of more N because it was the most effective means to achieve this end in response to heavy rain events.

At this point, our findings suggest we should be concerned that many farmers' adaptive practices for N management are potentially contributing to the increased severity of these climate impacts and that there is a need to further explore the extent that farmers are using quick-fix adaptive practices. In particular we feel survey research is needed to better assess the prevalence of quick-fix adaptive strategies and the full range of strategies being employed. In this way, future research can further assess the introductory arguments and findings in this paper. Recent events may be making the occurrence of quick-fixes particularly acute among US corn and soy farmers in the Midwest. President Trump's tariffs have substantially lowered the price of soybeans for US farmers (Higgins, 2019). At the same time, heavy rains and flooding prevented the planting of a significant percentage of agricultural land in the Midwest during 2019, leading corn prices to rise significantly (Kliesen, 2019). The farmers that were able to plant corn will likely be especially intent on ensuring further heavy rains do not limit their corn yields. In short, contemporary farmers may be widely using quick-fixes given these dynamics. Future studies should continue to explore this potential.

Future research in this area would also benefit from exploring the group of farmers this study gave little attention to: Those using conservation practices to reduce their N's vulnerability to climate change. Though political-economic context may constrain farmers, some farmers can act within these circumstances to achieve environmental ends and short-term profit imperatives, as Roesch-McNally and colleagues (2018a) also find in their study of soil conservation focused adaptation efforts. Following examples like Roesch-McNally et al. (2018a), future research on agricultural adaptation should build on our analysis here by giving more empirical and theoretical attention to the interactive role of structural conditions and individual agency.

On the practical side, our results point to the need for more effective policy options to sustain agriculture and reduce GHG emissions. Given the ToP (Schnaiberg 1980) and its impacts on farmer adaptation choice, efforts that continue to focus on environmental education may help but are unlikely to substantially increase the adoption of conservation N adaptation practices. While a thorough review of policy options is beyond the scope of this paper, we conclude by mentioning a few options that should be given consideration. First, N fertilizer remains inexpensive making adding more an easy and economically rational choice; however, eliminating subsidies, increasing N prices, or taxing fertilizer could greatly reduce N application (Hamblin, 2009; Sergerson & Walker, 2002; Stuart & Gillon, 2013). Second, most of the corn grown in the Midwest is not produced for human consumption but for ethanol or cattle feed – both uses that should be reduced or eliminated on the basis of energy efficiency, GHG emissions, and environmental impacts (Crutzen et al., 2016; Donner et al., 2008; Shepon et al., 2016). We acknowledge that these strategies, while likely effective, would face considerable opposition from agribusiness, especially corporations invested in fertilizer, seed, and livestock production (Hauter, 2012). However, they are possible and based on likely effectiveness should be increasingly considered. While the responses to climate change we identified in this study represent quick-fixes that ultimately increase GHG emissions, future responses must be guided by policies that reshape production systems to prioritize mitigation and adaptation along with promoting changes that encourage on-farm and broader landscape-scale resilience.

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