How will Maryland Commodity Agriculture Respond to Climate Change? Identifying Challenges and Opportunities from Interviews with Farmers and Farm Advisors

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Summary of findings: Climate change's acceleration of extreme weather events is expected to challenge Maryland farmers' capacity to produce crops efficiently and profitably. At the same time, the agricultural carbon market could offer a new revenue stream and further enable conservation practice adoption. Our research explored how Maryland farmers and farm advisors view and are responding to these climate change related challenges and opportunities. Qualitative interviews with 30 Maryland commodity crop farmers and 14 farm advisors (Extension, private sector) from across the state revealed a few key points.

Most respondents from each group believed climate change was happening regardless of its cause. Farmers reported relatively high adoption rates of practices that provide climate resilience, though they were adopted primarily to achieve non-climate benefits. Experiencing climate related impacts, such as flooding or drought, was or had led farmers to change or expand the use of some practices. Adaptions tended to focus on soil health related practices, drainage/water management, or crop type/variety shifts, rather than fertilizer management. Many interviewed farmers were already using progressive nitrogen fertilizer management approaches, but opportunities to increase the efficiency and resilience of nitrogen use exist.

Farmers discussed their adaptation as part of a "normal" process of dealing with weather and these practices' non-climate co-benefits remained important to farmers' adoption decisions. Farmers' comments suggest they felt capable of adapting to climate risks through reactive, incremental management adjustments, and in general interviewees did not express significant concern about the potential increased risks posed by future climate events. Farmers reported that to become more resilient, they most needed more information about climate risks and mitigation techniques, as well as technical support to implement these practices. These needs may be a reflection of limited concern though—more information and support were needed to justify further attention and time to adaptation efforts rather than to enable action given existing concern. Fertilizer dealer affiliated salespeople were the most reported source of information for general decisions, but universities and University Extension were seen as the most trusted source of information related to climate change and resilience moving forward.

Farmers had generally heard about the carbon market for agriculture, but only one producer had sold carbon market credits in the past. Farmers reported that high adoption rates of cover crops and no-tillage practices prevented them from enrolling in the carbon market given a preference for new practice adoption. Beyond perceived limited potential to participate, farmers also expressed serious doubts about the market. These included concerns about the ethics of carbon offsets as a solution to environmental challenges, low payment levels, and the need for more science and unbiased structuring of the market, among others.

Our work points to several needs moving forward. Future research should consider if current levels of practice adoption are sufficient to achieve resilience to near-term climate threats, as well as what else can be done. Adaptation scenarios, based on social data, should also be considered in future modeling of climate scenarios, including especially the environmental consequences of climate change. Further, research may benefit from considering what barriers are constraining farmers from adopting more advanced fertilizer management practices. Finally, to determine and improve the value of the carbon market for Maryland agriculture, science on the carbon practice's potential environmental benefits is needed, as is engagement efforts to provide agricultural stakeholders a voice in its structure.

HIGHLIGHTED RESULTS

1. 83% of interviewed farmers and 86% of interviewed advisors believed that climate change was occurring, regardless of its cause.
2. Farmers and advisors were generally not deeply concerned about the threat of climate change on agriculture. Economic and social challenges were perceived as much more pressing threats than the potential for accelerating climate extremes.
3. Fertilizer dealer affiliated agronomists/salespeople were the most used source of management information for the whole farmer sample, but this varied by farm size.
4. Extension and university-based sources were primarily trusted by farmers to provide future information on climate related issues.
5. Extension Agent interviewees reported primarily trusting Extension and university-based sources for climate information.
6. Private sector advisors reported trusting a wider variety of sources for climate information, with the two most reported sources being Extension and their own company's data. Other trusted sources were farm organizations, the Intergovernmental Panel on Climate Change (IPCC), multiple sources for validity, and Bloomberg News.
7. More information on climate impacts and technical support for practice adoption were farmers' most reported needs to enable enhanced resilience to climate.
8. Most producer interviewees noted barriers to participation in the carbon market for agriculture: that widespread existing use of cover crops and no tillage methods disqualified them from many carbon programs focused on new practice adoption; that they felt there was insufficient science to support a fair and effective carbon trading approach; and that a high percentage of rented ground added complexity to their consideration of participation.

HIGHLIGHTED RECOMMENDATIONS

1. Efforts to engage farm and farm advisors around climate change must recognize that other, more proximate issues are currently seen by these populations as more pressing. Climate-focused outreach, engagement, and research must account for this reality.
2. Research is needed to establish the resiliency of Maryland grain farms given existing adaptive management practice and to determine future potential approaches.
3. Longitudinal social science survey research should be done to assess the generalizability of this study's findings and to understand farmers' adaptive management overtime.
4. More research should be done to understand what barriers farmers face to adopting cutting edge fertilizer management practices. The role of the current nutrient management plan structure should be considered, exploring opportunities to advance a plan structure and outcome goal that enables greater innovation.
5. University Extension should increase outreach to farmers related to climate resilience and carbon markets. More effort should be put into Agent training related to these topics. Outreach on these topics must account for Recommendation #1.
6. Different farmers use different information sources for their management operation. Future "teach the teacher" efforts, aimed at influencing farm advisors' behavior to influence farmers, should target specific advisor types to reach specific types of grain farmers.

INTRODUCTION

Climate change is expected to present significant challenges to Maryland farmers. While growing seasons may get longer, extreme events like heavy rainfalls and droughts are expected to occur at a greater frequency and intensity (Dupigny-Giroux et al. 2018). These events can limit farmers capacity to enter fields during critical management periods, harm yields, and are likely to increase environmental challenges associated with crop production (Wolfe et al. 2018). For instance, the growing impact of heavy rains are alone predicted to increase nitrogen loss to the Chesapeake Bay by 28%, potentially harming farmers' profitability while also accelerating water quality degradation (Sinha et al. 2017; Robertson et al. 2013).

At the same time, climate change presents financial opportunities to Maryland agriculture in the form of the emerging carbon market. Toward addressing climate change, a growing number of companies have pledged to achieve "net zero" carbon emissions through a varying mixture of reducing their emissions and "offsetting" emissions through paying for carbon capture or reduction in other arenas, such as agriculture (Plastina & Wongpiyabovorn 2021). Research suggests that agricultural lands have a significant *capacity* to sequester atmospheric carbon, and mitigation practices, such as more efficient nitrogen fertilizer use, can reduce emissions lost from agricultural production (National Academies of Sciences 2019; Millar et al. 2010). However, there is a growing recognition that market claims have exceeded our scientific understanding of the benefits of these practices (Davidson 2022). And regardless of the potential of these practices, whether that potential is ever realized depends on farmers' willingness to participate in the carbon market. At this point, the research on the social dimensions of the carbon market is extremely limited, and there is a recognized need to better document farmer interest in and capacity to participate in the carbon market (Davidson 2022; Buck and Palumbo-Compton 2022).

Table 1: Regional breakdown of interviews

Region	Farmers	Farm Advisors			
		Chemical dealer affiliated advisor	Independent consultant	Seed dealer	Extension Educator
Western/Central Maryland	4	2	0	1	1
Southern Maryland	6	1	0	0	0
Lower Shore	10	0	1	1	2
Upper/Mid Shore	10	1	0	2	2
Totals	30	4	1	4	5

How are and will Maryland producers respond to the challenges and opportunities climate change presents? Farmers' choices are key to shaping the impact of climate change on agriculture, the extent to which growing extremes increase agriculture's environmental impact, and the potential of the carbon market in Maryland. These decisions will not be solely on their shoulders, as we know that producers typically rely on a network of "farm advisors", such as University Extension Educators, private sector agronomists and seed dealers, among others

(Stuart et al. 2018; Houser et al. 2019). These information sources are often trusted and influential in farmer decision-making (Beethem et al. 2022; Weber and McCann 2015).

It is likely these sources will also play a role in how Maryland farmers' respond to climate change, and therefore it is key to understand their views on these issues and opportunities as well.

Table 2. Farmer sample characteristics

	Average	Western/Central Maryland	Southern Maryland	Lower Shore	Upper/Mid Shore
Average farm size (acres)	1,557[a]	831	880	1,520	2,400[b]
Average percent of rented ground	52%	82%	47%	47%	51%
Percent using cover crops *at all*	80%	75%	66%	70%	100%
Average percent of ground in winter cover crops (includes non-adopters)	49%**	50%	22%*	48%^	65%*
Average percent of operation under no till***	66%	99%	71%	66%	52%
Percent of farmers with low lying, flood prone land	40%	0%	67%	50%	30%

[a] After excluding one outlier. Sample average is 1,913ac with outlier.
[b] After excluding one outlier. Sample average is 3,360ac with outlier.
*Excludes 1 producers who noted inconsistent annual use
** Excludes 5 producers who noted inconsistent annual use
^Excludes 2 producers who noted inconsistent annual use
*** Excludes six producers whose answers were unclear

OUR STUDY

Understanding farmers' and farm advisors' thinking on the topic of climate resilience and carbon markets is a key first step to identifying the type of support that is needed to build resiliency in Maryland's agricultural system. The Nature Conservancy's Chesapeake Bay Agriculture Program, The University of Maryland Center for Environmental Science Horn Point Laboratory, and The Maryland Grain Producers partnered to conduct an information gathering study to address this need, giving voice to farmers and farm advisors current views, concerns, and expressed needs. Specifically, we aim to offer key introductory insight into farmers' and farm advisors' views on climate change, climate change adaptation decision-making, and perspectives on the carbon market. Given the prominence of commodity crop production in Maryland—corn, soy, wheat—both in terms of land size, economic production, and environmental implications, we focus on understanding the views of commodity crop farmers and the farm advisors for this sector.

METHODS

To understand Maryland farmers' and farm advisors' views, we conducted a series of semi-structure interviews. Interviews are a considered an ideal way to understand little studied topics, and especially toward generating new, unexpected insights (Doll et al. 2017; Prokopy et al. 2011). Interviews took place between June 2022 and May 2023. In total, 44 interviews were completed, 30 of these being with farmers and 14 with farm advisors. Most interviews were completed one-on-one over the phone with a member of the research team. Farmers and advisor contacts were generated through the Maryland Grain Producers' extensive contact list, with a small number of interview contacts being made via snowball sampling (Obilor 2023), where a current interviewee would recommend that we speak to another potential interviewee.

Our interviewees spanned the state's geography to account for the potentially divergent views of agricultural stakeholders across Maryland. Two distinct, but parallel semi-structured interview guides were used for farmers and farm advisors, focused on their climate change views, approaches to resilience, and perspectives on the carbon market. On average, interviews lasted 31 minutes.

Farmer interviewees' operations well represented Maryland commodity producers (see Table 2). In general, farmer interviews were operating relatively large operations in line with commodity crop production. Interviewees rented over half their crop acres, in line with the national average (Bigelow et al. 2016), and 83% of participating farmers reported using cover crops to any extent; a figure that accords with generalizable Maryland survey data (MDA 2005). Farmers in this sample reported use of cover crops on their acres at a proportion (49%) that approximates generalizable samples in Maryland (approx. 50%) (Thieme et al. 2020). Most interviewed farmers used rye, wheat, radishes, or some combination of these as their cover crops. Approximately 55% of commodity crop acres in Maryland is "no tilled" (Claassen 2018). Our sample exceeded this percentage, with approximately 66% of acres being no tilled. This may suggest a slight bias toward more conservation-minded producers.

Farm advisors represent a broad range of advisor types—fertilizer dealer affiliated salespeople/agronomists, independent consultants, seed dealers, and extension educators. Primarily, advisor interviewees worked directly with producers to advise them on practices, though three of our advisor interviewees represent more management-level advisor roles, where they supervised larger networks of on-the-ground advisors and salespeople. We group our advisors under the regional categories follow from where they were primarily based, though depending on the position they may work at a much larger geographical scale. On average, advisors reported working with 161 farmer "clients," excluding two management-level advisors who reported on their company wide network.

RESULTS

Views on climate change

Farmers and advisors were asked about their views on climate change. Of our 30 farmers, 25 (83%) believed that climate change was occurring, regardless of its cause. This percentage approximates those found in other recent qualitative studies of producers in other regions (Houser 2018; Houser et al. 2017; Fletcher et al. 2019). For advisors, 12 of the 14 (86%) felt climate change was occurring, with two being unsure rather than skeptical. While science-based

sources were mentioned by some, farmers and advisors largely based on their views on direct experience with shifting weather patterns (see Table 3).

Table 3: Farmers and advisors views on climate change happening	
Farmers Illustrative Quotes	Advisor Illustrative Quotes
"What I see most is spring isn't spring anymore and fall isn't fall anymore. When I say that, we used to plant corn in April and now it's May, but December's not wintertime anymore. It's January until it's wintertime. So it's just like it's pushed back" (MD02) "We don't tend to get these small rain events anymore […] And it just seems to, the climate's definitely changing" (MD22). "I think the one concern that really stands out to me is just, it's not so much rising temperatures, it's just the extreme variation." (MD31).	"I think, in general, everyone recognizes that climate is changing" (MD35) "[Over the last] 20 years, it feels like the seasons have shifted a little bit. Like the Springs are later and the falls are later. I think we do get a little more extreme weather patterns" (MD13). "We're seeing, I feel like there are stronger storms, or more storms. I don't know that that's data driven or just, it's what it seems like. Maybe I'm more aware of it. But there's a lot of talk about just these more extreme type events that are happening" (MD21).

Belief that climate change is occurring does not necessary translate to belief it is anthropogenic. Interviews were not directly asked about humans' causal role in climate change, but in discussing their views on climate change, this belief or lack thereof was often volunteered. Of the 30 interviewed farmers, 10 expressed the attitude that humans played at least some causal role in climate change (33%), while five of the 14 advisors (35%) noted this same opinion. It is possible this is undercounting to some extent, though it should be noted the percentage of farmers found here believing in anthropogenic climate change is much higher than previous studies done in other US regions (Arbuckle et al. 2013; Houser et al. 2017).[1]

Many farmers and advisors did express the feeling that climate change—regardless of what causes it—is impacting agricultural production. Some of the farmers who say climate change as occurring (5/25) felt that these impacts were primarily *beneficial*—longer growing seasons, warmer weather, and more rainfall. As one farmer put it:

> "Climate-wise, the climate change has really helped at farming, especially here in Maryland up until this year. With the warmer temperatures, the more rainfall, our crop yields have increased a lot. Some of its genetics also. Some of its fertilizer, but a lot of it has to do with a longer growing season, a hotter growing season, and plenty of water there" (MD43).

[1] Research on advisors' climate change views is extremely limited, making comparison difficult.

Most farmers who thought climate change was occurring considered the local impacts as harmful (14/25), noting the growing occurrence of experienced extreme events—rainfall, droughts, pest pressure, and flooding—as a challenge to agriculture. For instance:

> "So climate change is a big issue for us, in a number of ways. Even with the corn and soybeans, before we started this, we have been seeing a drastic change in weather patterns. Where May, about every other year, is just incredibly wet. It was hard to get the crops in. We had one year, back in 2018 I think it was, where it rained every single day of May. I mean, you couldn't plant anything for the entire month" (MD36).

Other farmers (6/25) did not consider climate change to have made a significant impact on their operation as of yet, or focused on other aspects of climate change's threat (e.g., the potential for additional regulations).

Even among those who were concerned about the impacts, in general climate change's risks ranked low compared to other threats to their operation. Farmers and advisors were both asked to reflect upon major issues facing the agricultural industry and their own operations. Opinions on these topics coalesced generally around a few issues. Most notably, farmers and advisors primarily expressed concern about the rising cost of production given recent inflation. These rising costs—from inputs, to land, to labor, had dramatically increased the economic risk associated with farming, and made operating business more difficult as well. As one farmer succinctly put it:

> "Right now it's just inflation and input cost. That's just got everybody by the throat. I'm looking at ... My operating loan is double what it was last year, right now, and we're not even finished. Close to it. But that and regulation, certain regulations coming up and what we've been dealing with" (MD09).

While essentially every interviewee was concerned about rising input costs, other issues came up, as this above quote illustrates: fear of regulation, perceive public distaste for commodity agriculture, and the loss of agricultural land to development, and even deer pressure. Only 5 of the 30 interviewed farmers and 1 of the 14 advisors mentioned challenges related to weather and extreme events as a "major issue" facing them now. These economic and even social challenges were perceived as much more pressing threats than the potential for accelerating climate extremes.

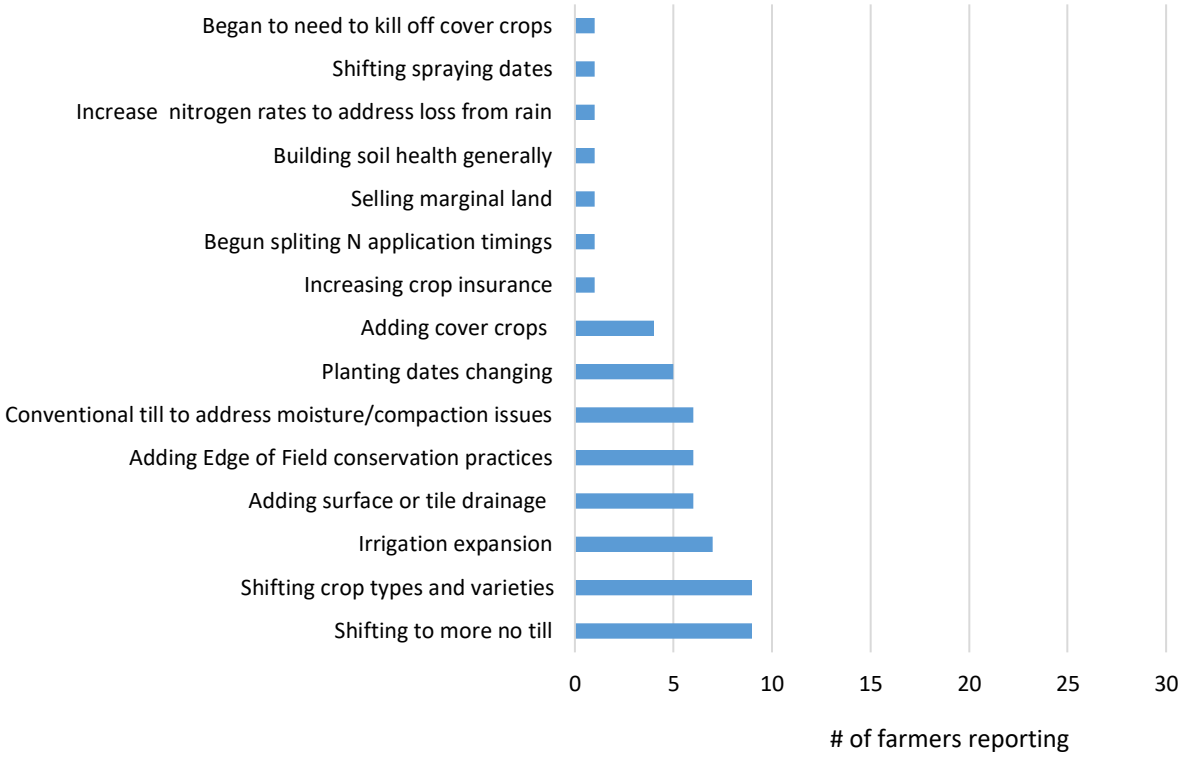
Adaptive management and information use

Adaptation practices

Climate change, and its expression in extreme events and season shifts, is certainly not the most pressing challenge perceived by Maryland farmers and agricultural advisors today. That said, it was notable enough that many farmers reported existing adaptations to climate impacts—or shifts in their management to reduce potential risks from extreme weather or shifts to seasonal norms (Smit and Skinner 2002). As one advisor put it in response to his views on climate change:

"I've answered this differently five years ago [...] There was this feeling that it wasn't that big of a deal, or it was made up or fictional. But I do think that farmers are seeing it. […] And so I think that there is that realization that practices may need to change. Adaptions need to be made." (MD21)

Figure 1: Reported adaptation to address climate impacts

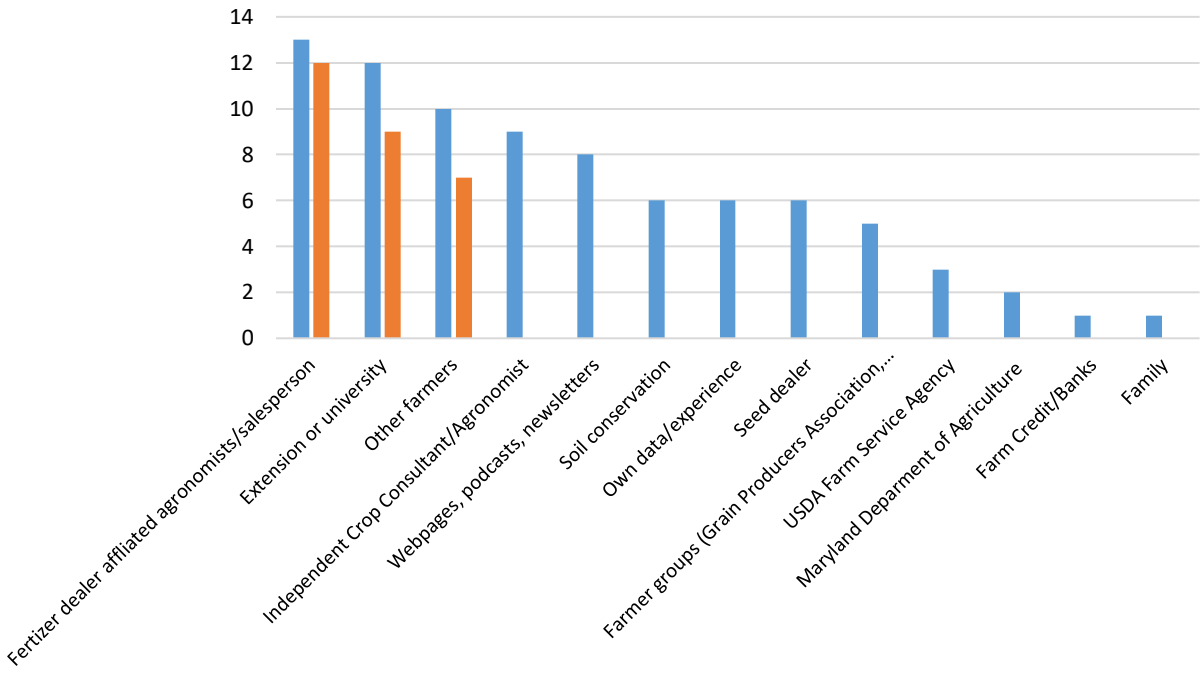


Farmers were asked to describe their current management practices, and in general interviewees reported using numerous approaches that are known to build resilience to climate impacts while also providing other conservation, economic, and agronomic benefits. Cover crops, conservation tillage, as well as fertilizer best management practices can reduce the economic and environmental impact of climate extremes on agricultural production. As shown in Table 2, this sample of farmers had existing, relatively high use of cover crops, as well as no tillage.

Related to fertilizer management, nitrogen fertilizer is especially vulnerable to climate impacts (Robertson et al. 2013). Farmers reported, in general, already using advanced nitrogen management practices. Of our 30 interviewees, 20 reported using "sidedress" or in-season application, a practice that can enable more efficient N management while also reducing the potential for loss from heavy rain events (Ibid).

As this suggests, farmers may adopt practices that provide resilience for a variety of reasons. We explored to what extent climate impacts or expected challenges was promoting practice adoption intended to reduce climate related risks. Figure 1 shows the practices farmers reported to be undertaking given their experience with climate impacts/weather extremes. These counts are not mutually exclusive, as farmers could report multiple practices. Notably, many of these practices will provide agronomic resilience to climate change, while also reducing further contributions to water quality degradation—a critical achievement given the likely impacts of climate change on yield stability and nutrient loss. With that said, some practices could reduce climate related agronomic impacts, but accelerate nutrient loss—such as conventional tillage use and additional drainage. On average, farmers noted the use of 1.74 practices and only four interviewees reported no shifts in their management due to climate risks. This suggests that climate impacts are leading farmers to shift management regimes across the state.

Figure 2: Farmers reported use of management information sources



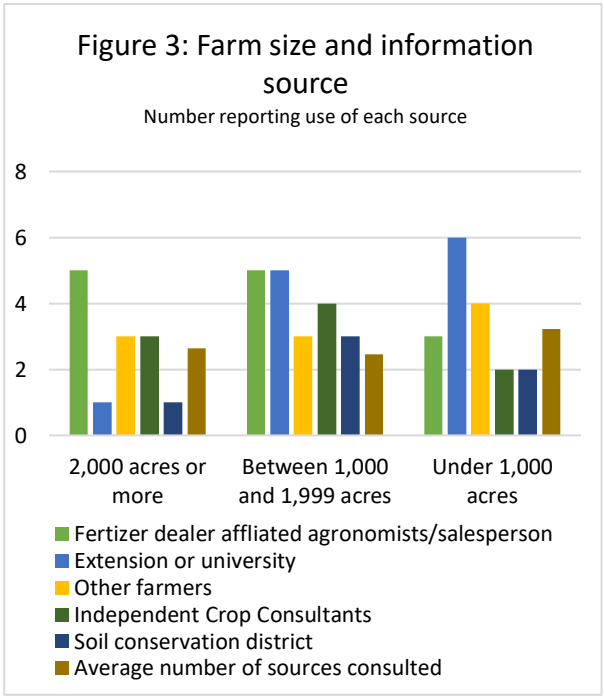
That said, evidence of adaptation should not be interpreted to suggest that climate impacts are leading to a transformational shift in farmers' thinking and management approach. As noted above, many farmers were already using resilience enhancing practices. And when discussing their adoption of "adaptation" practices specifically, farmers framed these practices as extensions of their existing management efforts. Moreover, farmers emphasized that adaptation to climate or "weather" was fundamental to farming, and not a new challenge. As one put it, before describing his recent adaptations:

> "We went to those defensive strategies in the 1970s after the severe drought years in the sixties and it was all a function of the crop rotation, the cover crop planting, winter crops, all that is a function of spreading risk. So everything we did, we were always looking at more from spreading risk issues" (MD05).

While adaptation is occurring in response to climate extremes, it is happening in primarily incremental processes, with minor practice shifts in response to experienced impacts. One farmer summarized this thinking nicely in saying, "We see the way weather is trending and you just slowly over time adapt to it and handle it" (MD01). Farmers comments suggest they felt capable of adapting to climate risks through reactive, incremental management adjustments, and in general interviewees did not express significant concern about the potential increased risks posed by future climate events.

Adapting fertilizer management and N management planning

Fertilizer loss, and especially nitrogen (N) fertilizer loss, is an area of crop systems considered particularly vulnerable to climate change impacts. N fertilizer loss in particular is expected to accelerate given climate change, with some models predicting that nitrogen inputs will need to be further reduced by up to 33% to offset these expected losses potential impact on water quality in the Bay watershed (Sinha et al. 2017). N "best" management practices, such as split application, undersurface application, stabilizers, and variable rate application, can reduce the potential for loss and help support profitable yields (Robertson et al. 2013). However, this is also the potential that increasing rain events may compel farmers to increase N application rates in order to remain profitable. Research in other regions has shown that farmers' use more N to "insure" that higher N loss rates do not contribute to yield loss (Sherriff 2005; Houser and Stuart 2020; Houser 2022), leading to greater environmental impacts (Zhang et al. 2022).

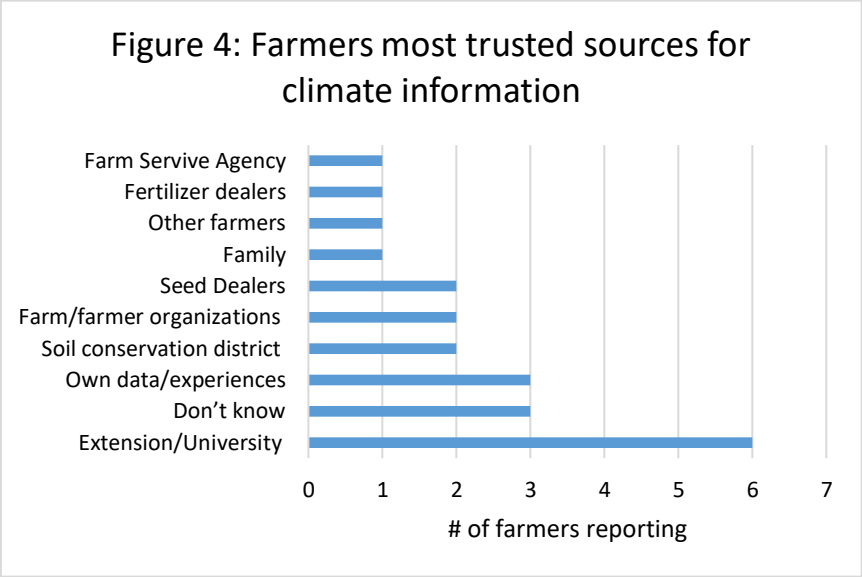


Even considering the incremental nature of farmers' adaptation behavior, farmers' adaptions tended to focus on soil health related practices (e.g., cover crops, no till), drainage/water management (irrigation, tile drainage) or crop shifts (e.g., new seed hybrids). Very few farmers discussed fertilizer management related adjustments—with only one saying they switched to multiple in-season "split" applications to the reduce the risk of fertilizer loss, and another noting increased total N application rates to account for rain-related losses.

Limited consideration of how to advance nitrogen management in the face of climate impacts among our sample may be at least partially attributable to farmers' existing high use of best management practices, especially in-season application. But there is the potential to further mitigate loss potential through additional adoption of other advanced N management approaches, including undersurface application and use of variable rate (VR) application techniques. At least eight of our interviews were still broadcast applying commercial N fertilizer, a technique that puts N on top of the soil leaving it susceptible to loss from rain events. Only two farmers in our sample used VR application, where application rates of N vary across the field to account for differing yield potentials. In short, interviewed farmers were very progressive with their N management approaches, but we know more must be done to meet water quality goals in the Chesapeake Bay Watershed, especially given future expected loss potential due to climate change (Sinha et al. 2017). At the time of our interviews, most farmers in our sample were not actively pursuing these cutting-edge fertilizer management techniques in response to climate risks.

Information sources and climate advice

Interviewed farmers reported using a wide variety of information sources when making general farm-related decisions. The most reported source of information were fertilizer-dealer affiliated agronomists and/or salespeople (Figure 2). This accords with much past research on farmer information source use (Beethem et al. 2022). Also like past research (Houser et al. 2018; 2019), farm size was related to information source selection (Figure 3), with larger farmers primarily using fertilizer dealers, midsize farmers using fertilizer dealers and Extension equally, and smaller farmers primarily using Extension.



Insight into information preferences on climate change is important moving forward. When asked what was needed to enable resilience to climate impacts, additional information on climate risks/predictions and technical support for adaptation was most reported need (16 of the 30 interviewed farmers). This may be in part a reflection of limited concern—more information and support were needed to justify further attention and time to adaptation efforts rather than to enable action given existing concern. Farmers also emphasized new equipment and technologies, especially related to irrigation, drainage, and seed, and some noted they felt "nothing" was needed, as they were deeply unconcerned about growing threats.

Farmers were also asked about their preference for information sources when it comes specifically to climate change and related management practices. Despite the general sample primarily using fertilizer dealer affiliated agronomists/salespeople, the most named group for climate change information was "Extension and/or Universities." Most of these farmers specified University of Maryland and University of Delaware as key sources given their focus on local conditions. Most who mentioned this source, or any source, noted that they would take the recommendations "with a grain of salt" (MD36). One farmer even explicitly emphasized that he felt Extension's message was increasingly too environmentally focused, and but he did appreciate direct connection to researchers/scientists from universities and their information:

> "So there are efforts within all the university systems to co-opt the Extension process to push agendas, whether that be electric vehicle adoption, solar power generation or whatever regenerative ag keyword is the hot point for today. And so that's why I won't say blanket [trust in] University because I'm seeing it within our own university. There are folks that are meddling with the message that are not generators of science, but disseminators of stuff that[…] I can't write it off as being unscientific, but I'm much more likely to trust the researcher that is doing work in irrigation, doing work in nutrient management, or drainage, or whatever field it needs to be and that data, rather than this public policy perception movement that's coming out of the universities too" (MD37).

While Extension and university-based sources were most reported, this comment suggests that there is not "blanket" trust for information from these sources, and consideration of the messenger and messaging is key to providing effective climate-related information to our state's producers in the future.

Advisors and climate change information

Farm advisors, as our farmer interviews suggest, clearly play a role in farmers' management decision-making and likely are shaping farmers' responses to climate change. Advisors were asked if farmers ever actively sought out or asked about climate related information from them. Five of our advisor interviewees noted that this had happened, but even this group emphasized that this was a very limited number of customers. As one advisor illustrated,

> "I would say the times that [farmers] state it as 'climate change', like, 'Hey, I'm concerned about climate change. How can you help me improve?' I would say in the last five years that's happened once or twice."

Advisors were also asked if they ever advised farmers on climate related issues. Essentially every advisor interviewee noted that they would never discuss "climate change" by name with farmers, but half of our advisor sample (7 of 14) said they did discuss practices could mitigate climate risks with their clients. The multiple co-benefits of these practices were typically emphasized. As one advisor expressed,

> "I've just found, though, to engage growers, I don't lead with climate. We're talking about it quite a bit, but, again, more through the lens of long-term sustainability, regenerative ag, and soil health. And then we talk about the fact that one of the added benefits is as we do these things, you're protecting yourself against some of the downside risks associated with more extreme weather" (MD35).

Other advisors, of course, felt that climate change was not a significant threat, either because we were not going to experience dramatic risks, or that their clients were already widely practicing key resilience strategies, especially conservation tillage and cover crops.

Regardless of whether the advisor was actively advising their clients on climate related practices, they were asked about their knowledge of how to achieve resilience to climate impacts. By and large, advisors emphasized seed variety choices (7 advisors; especially seed dealers), as well as soil health related practices, specifically cover crops, and conservation tillage (5). Only two of our 14 interviewees mentioned that they encouraged clients to adopt new fertilizer management efforts to address climate related challenges. More than simply quantitative differences, those emphasizing seed and soil management practices tended to discuss these practices benefits related to climate challenges in more detail, and at length, whereas only one of the advisors mentioning fertilizer management offered specific practice strategies they may cover with a client.

As noted, farmers' rarely reported shifts to their nutrient management strategy in response to climate risks, mirroring advisors limited focus on the topics when they are discussing resilience approaches with producers. Conversely, a focus on seed variety and soil health accords with farmers' similar focus in their behavioral shifts. It is not possible to determine the extent to which advisors' focus on specific types of adaptation practices plays a role in farmers' thinking and behavior, but this may be a factor shaping existing responses to climate change in Maryland agriculture. In every case, as above, the co-benefits, rather than the climate benefits, were emphasized in how and why advisors discussed these practices with farmers (Table 4).

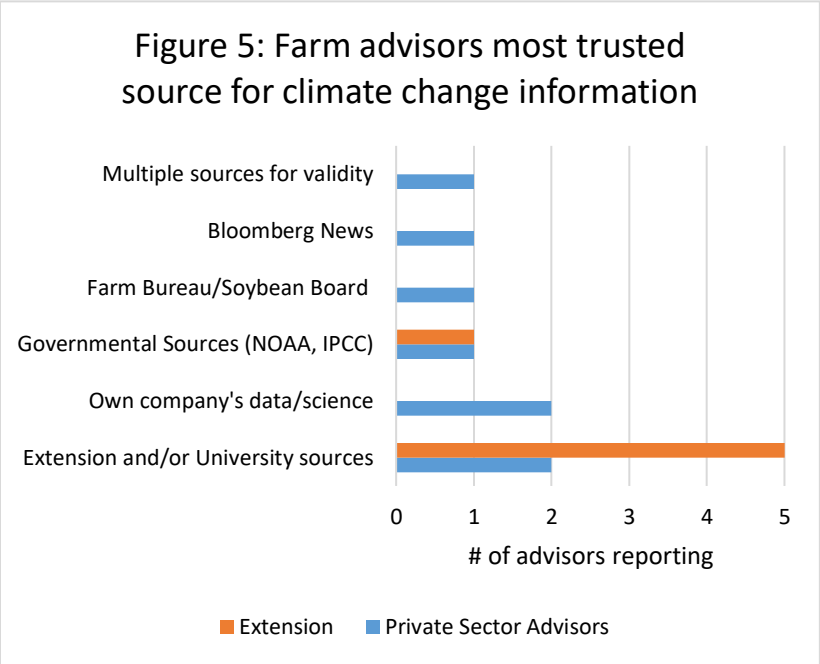
Advisors were asked who they would most trust to provide additional information on

Table 4: Framing the co-benefits of climate adaptation practices

"The short corn ones, people are excited about that because it's not just necessary for them to be safer against hurricanes and stuff. It also gives them more flexibility and capability to be able to go do a fungicide application during the growing season, where they wouldn't have been able to do that with tall, normal size corn. So I think that's an easy example where a change and an adaption is going to work seamlessly because it's a win-win for the farmer" (MD26).
"Yeah. So I think a lot of it is doing with, it gets back to kind of the 4-Rs (a fertilizer best management strategy) and making sure that we're applying […what is…] economically and environmentally reasonable. Economically, you don't want to put something out there that you're not going to get a return on. And environmentally you don't want to put something out there that you're going to lose and cause harm elsewhere" (MD22).

climate change's impact on agriculture in the future. The most noted source was Extension

and/or University sources with seven of the 14 advisors saying this was their most trusted sources. However, advisor's organizational affiliation mattered. Private sector advisors had much more dispersed trust across distinct sources, with the two most named sources being Extension (2 advisors) and their own company's data/science (2 advisors). Overall, most advisors trusted non university/government sources. In contrast, five of the six Extension Educators we interviewed primarily trusted Extension/University sources, with the remaining advisor also trusting a public source (NOAA).



Carbon Market Views

The carbon market for agriculture is rapidly evolving and while there may be a potential to achieve environmental benefits while also supporting farmers' profitability, ultimately whether the market is implemented at all depends on the voluntary decisions of farmers—are they willing to participate? Farmers' views on the carbon market have yet to be thoroughly considered in research, or in the design of the market.

Of the 30 farmers interviewed, 29 had previously heard of the emerging carbon market for agriculture. Sources of information varied with the most reported being emails, publications, potential carbon market aggregators or buyers, such as Perdue and Bayer, as well as other farmers. Beyond simply hearing about the market, half of the interviewed farmers stated that they had been approached about potential participation by companies such as Perdue, Bayer or Nori.

Many existing carbon programs require farmers to implement a *new* practice, and farmers who had been approached about the market generally said they were expected to adopt a new practice (or expand an existing practice) in order to qualify. As has been noted (Table 1), farmers reported relatively high use of typical carbon market practices, such as no till and cover crops. Interviewees commonly reported their current widespread use of these conservation, carbon capturing practices as being a reason they would be unable to participate. As one farmer illustrated, there was a sense of injustice that the market would reward current non-adopters:

> "[Carbon markets are paying for] a lot of what we're already doing through cover cropping and whatnot. So then you run into the issue of early adopters. If you're already doing those practices, are you going to get paid to continue to do them or do you get

penalized in that market for being an early adopter and not eligible to receive payment?" (MD18).

Even if they could participate, farmers held significant reservations about the market. Farmers primarily saw the market through the lens of carbon offsets for direct emissions. A key concern (18 farmers) was the perception that an offset approach to address climate change (or other environmental issues) was ethically flawed. Farmers emphasized that companies that are polluting should strive to reduce their direct emissions, rather than offset them through the market:

> "I'd rather the industrial companies fix their problem rather than just paying us to fix their problem. I just, I don't know. I feel like they're paying us so they can pollute" (MD07).

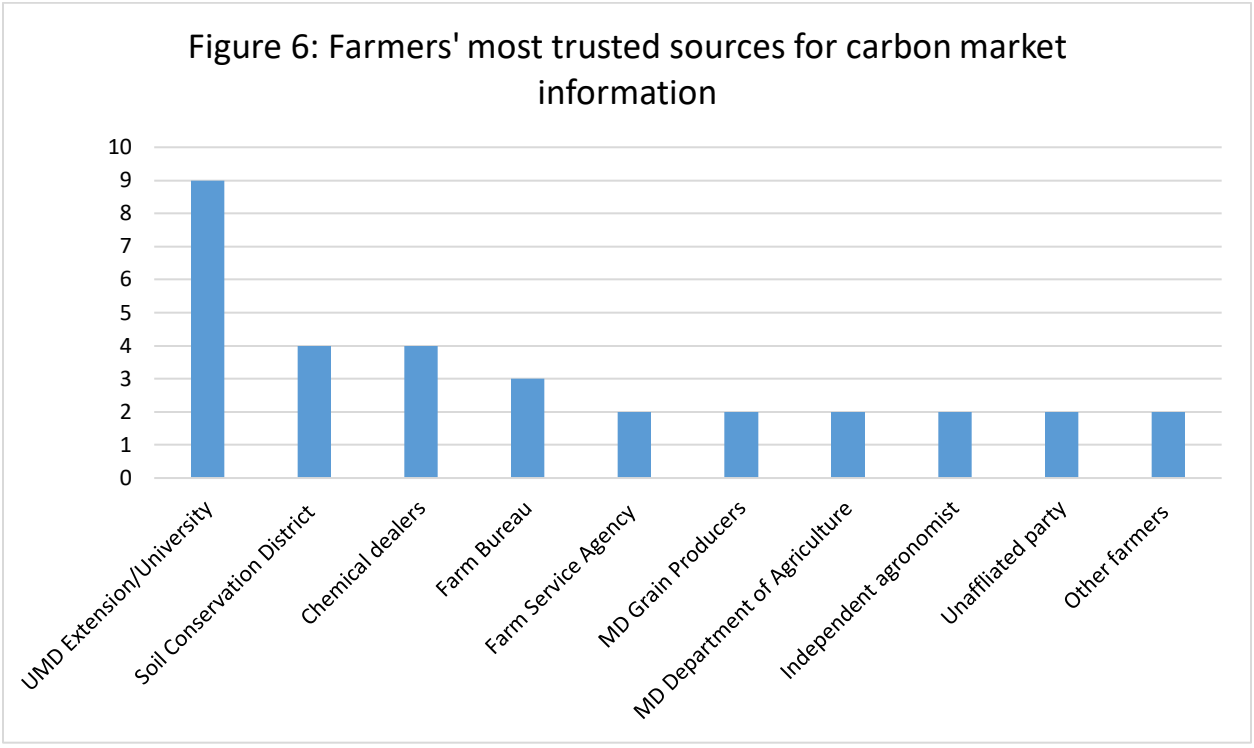
Related to this ethical attribution concern—in other words, who should be responsible for their pollution—some farmers also expressed a belief that this was ultimately a greenwashing effort. Companies could continue to pollute, carbon market aggregators would make money, and farmers' economic benefits would be minimal, while their effort would greatest. This was often cited as another reason companies should address their own direct emissions:

> "There's a strong possibility that the brokers in carbon credits will be the ones to make money, and the farmers will get paid a mere pittance to do their work" (MD18).

Other top thematic concerns about participation revolved around low payment prices, potentially inflexible contract stipulations, and a lack of scientific basis to understand carbon sequestration amounts. The need for increased compensation for carbon credits to encourage enrollment was noted by 16 farmers. Additionally, 19 of the 30 interviewees were concerned about being locked into a certain practice for an extended period due to potentially lengthy and/or inflexible contracts. The main practice of concern was no-till with the worry of not being able to properly repair fields after a potentially wet fall harvest. Finally, nine farmers raised concern regarding the lack of science to back the carbon market, with the main worry being finding a basis to measure carbon sequestration that is fair to all parties.

Despite these concerns, most interviewed farmers thought the carbon market *could be* beneficial, primarily because it could serve as an additional revenue source. Thinking about future carbon market engagement, farmers responded that their most trusted sources to consult with about the carbon market includes the University of Maryland Extension, Maryland Soil Conservation Districts, chemical dealers, and Maryland Farm Bureau (Figure 6). To have a successful program where farmers are willing to participate, interviewees explicitly suggested there should be an unbiased party available for farmers to utilize for program options, contract resources, and overall questions. Often the Maryland Department of Agriculture was cited as a potential organization to guide the deployment of the carbon market.

Table 5: Illustrative quotes of farmers' carbon market concerns	
Limited payment	"We don't know the value [of our carbon]" (MD18) "They're not willing to pay enough" (MD29) "We'd probably entertain it if the money was right, but I don't know. It'd be a tough one in that situation to sign up that long term and be in this box that you're working with." (MD12)
Rented ground and inflexible contracts	"What happens if the situation changes and I need to get out of the contract?" (MD28) "Hard to do on rented ground when you don't know if you'll have it for two or twenty years" (MD20) "The weather dictates your practices, so how can you commit to something when you don't know what's going to happen next year?"
The need for more science/data	"Some folks that are leading this movement are not based in science and reality but heavily rely on emotion and perception" (MD37) "I'm not sure the science is there yet" (MD34) "How do we measure it?" (MD34)
Ethics of addressing environmental issues	"I think for me, if it helps the environment I would be interested. But if it's just to trade a credit so someone else can pollute, no." (MD25) "And just like nutrient trading, you cut back on your nutrients so this person that buys them doesn't have to. What does that solve? That's my big issue" (MD09) "So it's hard to follow that and think that we're all really doing something great for the environment. I mean, the airline company is still going to do the same thing they're doing, they're not changing anything" (MD01).
Unbiased structuring organizations/agency	"Yeah, I think it would be helpful if someone could, there's so many carbon markets and there's so much uncertainty and no one's vetting them. So I think whether it's the federal government or some type of state government that could help kind of filter through the noise and say, "This is what you've got, here's the risk that you're taking on." And then the farmer can make a better decision" (MD04).



IMPLICATIONS FOR FUTURE WORK

1. ***Survey research to determine generalizability***: Qualitative interviews are ideally suited to develop a baseline understanding of farmers' views, behaviors, and the complex set of factors that shape these outcomes. The emergent set of results we document here should be followed up with a large scale research effort to assess the generalizability of farmer and advisors' documented climate change views and adaptive management behaviors. *Intended* adaptation behaviors are commonly seen as proxies for future behavior, and thus measured in past surveys. However, empirical research suggest behavioral intentions are potentially poor predictors of actual adaptation behavior (Niles et al. 2016). Instead, *it may be more telling to invest time and money into a longitudinal, socio-ecological survey and analysis effort. Gathering detailed records of baseline management, as well as past behavioral responses to perceived climate impacts, is initially key.* Past behavior may be a better predictor than intentions of future behavior (Prokopy et al. 2019; Denny et al. 2019). *Future follow-up "panel surveys" can be used to assess absolute (i.e., new practices) or relative (i.e., increased or decreased spatial) use of certain practices overtime*. By incorporating downscaled annual weather data, along with other contextual data and individual-level data, multi-level structural equation modeling could enable

researchers to determine the role of climatic and non-climatic factors in shaping farmers' adaptive management overtime. This, coupled with on the ground interviews with a select group of representative farmers, could offer ground-breaking new insight into how, why, and to what extent Maryland farmers' are adapting management overtime.

2. ***What is sufficient to be resilient to climate change?*** Farmers in Maryland, and in this sample, are notably progressive in terms of their existing practice adoption. Our research suggests that in many cases farmers have adopted these conservation practices due to the economic or agronomic benefits. Climate impacts may be accelerating the use of some of these practices, but in general Maryland farmers appear to be taking a business-as-usual approach to addressing weather related challenges. *Consequently, we face the key question: Is our current level of practice use sufficient to be agronomically and environmentally resilient to climate change? And is an incremental adoption approach sufficient to meet the challenges of tomorrow?* Future biophysical research is key to answering these questions, and with providing agricultural stakeholders with potential solutions. Should we need to push management practice use to a new level of resiliency, farmers and farm advisors are likely to need guidance on what this next frontier is. These joint concerns are illustrated well by one comment from an advisor: "What's the next BMP? I can say on all of our farms […] we all have all these BMPs, but what's the next thing that we can do?" (MD24).

3. ***Understanding the social and ecological dimensions of the carbon market:*** There is a recognized need to better quantify the carbon benefits of agricultural practices, especially those that sequester carbon, such as reduced tillage and cover crops (Davidson 2022). Based on our interviews with Maryland producers, this need is not only seen by scientists, but also by the potential implementors of the carbon practices. Interviewed farmers expressed concern about the lack of established science on the emissions benefits of these practices and felt more detailed, and site-specific information was needed to build trust and encourage their participation. Some of this research is already ongoing in the state and across the nation. *Moving forward, studies of carbon sequestration potential must effectively engage producers to ensure their work builds farmers' understanding of how future quantifications of practices' carbon potentials were determined.*

   While better data and more participatory research practices are needed to facilitate understanding of the potential effectiveness of the carbon market, our findings suggest this is not sufficient in itself for Maryland commodity producers. Farmers expressed serious concerns around existing payment levels, that high levels of conservation practice use limited their potential for participation (should payments ever increase), and that the carbon offset approach of some potential market players is largely an unethical and ineffective way to address the problem. This latter concern suggest that interviewees primarily viewed the market through the lens of carbon offsets. It is also possible for firms to apply a market approach to address indirect emissions associated with their downstream production activities (i.e., scope 3 emissions). Farmers did not widely view

the market from this perspective, and it is worth considering in future work if this model may address some of the raised ethical concerns.

Overall, our work suggests there is a need to structure the emerging carbon market more systematically and inclusively if we want farmers to feel secure and able to fairly participate. Some farmers felt that a neutral party, potentially the State, could play this role in developing a framework. Moving forward, the potential for a collaborative approach to defining the future of the agricultural carbon market for Maryland agriculture should be explored.

4. ***Advancing nitrogen management in the face of climate change:*** Farmers reported using a suite of progressive, resilience enhancing nitrogen (N) management practices primarily for non-climate reasons. However, fertilizer and especially N fertilizer management will likely need to further progress in terms of efficiency if we are to meet regional water quality goals and maintain profitable crop production in the face of climate change. Despite having a high-level of N best management practice adoption, farmers still had room for improvement. Farmers and advisors in this sample, however, were not widely considering more advanced N management as a resilience-enhancing strategy (nor did our interviews suggest they were considering these strategies for other reasons). *Given the climate risks to and from N management, more research needs to consider what factors contributed to farmer and advisors limited consideration of this area of management.*

   Our interviews can begin to point to why further improvements to N management were not commonly explored. Farm advisors' lack of focus on this topic likely contributes, as does the existing high use of some best management practices (see above). Another potential barrier is the existing structure of required nutrient management plans in Maryland. Farmers, in discussing their nutrient management practices, tended to emphasize to degree to which these plans had structured the decision-making process (see table 4). As one farmer simply stated when asked to describe his N management decision-making: "We just follow the nutrient management plan" (MD44). Others offered similar statements:

   > "And then just rate is just based on our nutrient management plan" (MD07).
   >
   > "So for corn, obviously we'll use our nutrient management plan" (MD14).
   >
   > "I have a nutrient management plan, so I follow my nutrient management plan" (MD20).
   >
   > "And then just rate is just based on our nutrient management plan" (MD01)

   Farmers certainly, in part, offered these statements to illustrate that they were following the "rules" of nutrient management in the state. However, while the planning requirement likely contributed to the overall progressiveness of this sample (and

Maryland agriculture in general), *it may be that management plans are at the same time contributing to a routinization of nitrogen fertilizer management, where farmers feel as if they have met the "standard" and therefore are not actively exploring new boundaries or options.* In this way, the plan may be a social-psychological factor limiting adaptability or innovate approaches to nitrogen management. That general achievement standards can have this type of cognitive effect has been shown in other social research (Busch 2013). Beyond the social-psychological dimensions of decision-making, some farmers emphasized how the plan itself structured their capacity to be innovative. As one farmer put it, "Well, first and foremost, always going off of nutrient management plan, following that to a T. But with that said, [it can tie your hands]"(MD39), going on to discuss how he felt limited in his capacity to push for higher yield potentials through trialing new N management techniques.

It is possible that farmers and advisors would benefit from a more adaptive, innovative approach to nutrient management planning. *Metrics for economically and environmentally sustainable N management are already being proposed for US agriculture (e.g., Zhang et al. 2015). To improve our planning process, collaborative efforts—including scientists, farmers, advisors, and other actors—that consider the applicability of these metrics to our state/region and explore what enabling conditions farmers and advisors see as key to supporting their effort to achieve N management advancements is a critical next step.*

With that said, our research cannot definitively point to what factors are limiting farmers' consideration or concern about nitrogen management related to climate impacts, though the data offered here is suggestive for future research to examine. This work should specifically consider the role of nutrient management planning.

5. ***Climate impact modeling that accounts for adaptation responses scenarios:*** Emerging research is attempting to better understand the expected, localized impact of climate change on Maryland and Maryland agriculture. While climate modeling often considers the potential human impacts of climate risks, the environmental and risk outcomes based on realistic human adaptation scenarios are rarely included in models (c.f., Zhang et al. 2022). Our research suggests that farmers are actively adapting to climate impacts, and though these practices do not represent a transformation shift in agricultural management, they may play a role in the risks and consequences of climate change broadly. Many adaptation practices farmers reported using can mitigate climate related production risks *while also* reducing environmental harm—sometimes called "strong resilience" (Reynolds et al. 2022). These include pursuing no till, edge of field practices such as vegetative buffers, and adding additional acres of cover crops, all of which can reduce nutrient and sediment loss to extreme events. As has been shown in prior studies, some agricultural management responses to climate impacts can reduce production risks to farmers but accelerate contributions to environmental challenges—sometimes called "maladaptive" or "weak resilience" (Houser and Stuart 2020; Kerr 2023; ibid). The reported practice of adding additional drainage to fields will reduce flood/saturation risks to crops, but likely enable increased fertilizer loss to waterways. Similarly, increasing use

of conventional tillage can mitigate field compaction caused by heavy rainfalls, but will release carbon and enable more sediment and nutrient loss to waterways.

How these diverse adaptation approaches will play out in future climate scenarios, regarding both risks to agriculture from climate change, but also the expected impact of agriculture on the environment given climate change, should be more fully considered in both field-level research and in modeling to suggest divergent potential future scenarios based on a diverse mix of adaptation approaches.

6. ***Information use in agricultural decision-making:*** Who farmers get their management information from has long been a consideration in the social sciences literature (e.g., Prokopy et al. 2015; Prokopy et al. 2019). While most of the past literature suggests commodity farmers' primarily use the private sector (Beethem et al. 2022), our findings build on prior research showing that who farmers turn to for management information varies by farm characteristics, such as farm size (Houser et al. 2018, 2019). Small farmers primarily used Extension, whereas larger farmers primarily used private sector sources. There is a recognized need for future farmer social science research and engagement efforts to consider farm segments more fully—accounting for how farmer, farm, and regional characteristics lead to distinct and significant "groupings" that may influence management decision-making (Pannell et al. 2014; Teixeira et al. 2018; Ranjan et al. 2019; Medina et al. 2020). *In line with this thinking, our research continues to indicate that engagement efforts cannot be a one size fits all approach, and different information source types may be more effective than others at providing new information to certain producers.*

   Relatedly, farmers' preference for information source varies by the type of information they are seeking (Arbuckle 2012). Here, farmers primarily trusted Extension to provide them with information related to climate change. However, like most of the advisors in our sample, Extension educators were not widely discussing climate change and adaptation practices with the farmers they advised. *This suggests a potential, moving forward, to increase Extension Agents' and University Extension's focus on climate adaptation outreach.* While private sector advisors did not widely trust Extension/University sources, integrated training models could be a means to connect these advisors with one another, helping to build trust in information and foster long-term relationships that support information sharing to distinct farmer groups.

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