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Assessing stakeholder climate data needs for farm-level decision-making in the U.S. Corn Belt

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Abstract. Across the Midwest region of the United States, agriculturalists make decisions on a variety of time scales, ranging from daily to weekly, monthly, and seasonally. Ever improving forecasts and decision support tools could assist the decision-making process, particularly in the context of a changing and increasingly variable climate. To be usable, however, the information produced by these forecasts and tools should be salient, credible, legitimate, and iterative, qualities which are achieved through deliberate co-production with stakeholders. This study uses a document analysis approach to explore stakeholder climate information needs and priorities in the U.S. Corn Belt. Through the analysis of 50 documents, we find that stakeholders are primarily concerned with practical and tactical decision making, including from whom they get their information, the application of information to agricultural, water, and risk management, and desired economic outcomes. The information that stakeholders desire is less focused on social issues, environmental issues, or long-term climate resilience. This study can inform the development of future decision support tools, identify known gaps in climate information services to reduce stakeholder fatigue, and serve as an example to scientists trying to understand stakeholder needs in other regions and specialties.

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1 Introduction

Across the Midwest region of the United States, agriculturalists make decisions on a variety of time scales, from weekly to seasonal to interannual and decadal (Haigh et al., 2015b). These decisions can be classified as either operational or strategic (Haigh et al., 2015b; Prokopy et al., 2013), and farmers have been found to rely on both proprietary information obtained through a subscription service or free information from a company or university to inform their management decisions (Haigh et al., 2018). However, climate change across the Midwest is projected to lead to higher temperatures, a longer frost-free season, increased springtime rainfall, higher humidity, and an increased risk of flooding, and to alter the timing and variability of seasons (Angel et al., 2018 and references therein). Combined, these changes may make the information upon which agriculturalists rely obsolete, necessitating a new process for decision making.

In the context of a changing climate, it has been proposed that farmers could benefit from continuously improving climate models and decision support tools that incorporate environmental and climate information and forecasts (Klemm and McPherson, 2017). Forecasts can indicate the likelihood of an El Niño year (Ghil and Jiang, 1998; Jones et al., 2006), project temperature and precipitation extremes for the season (Andrys et al., 2015) or forecast impending events such as extreme storms (Chawla et al., 2018; Moya-álvarez et al., 2018). Many decision support tools developed by public and private for-profit entities already exist for agriculture that assist agriculturalists in deciding, for example, whether or not to use cover crops or till the fields, when and how much nutrients to apply, and whether to purchase crop insurance (Palutikof et al., 2019 and references therein; Haigh et al., 2018). The structure of these tools varies, with some guiding users step-by-step through necessary decision processes and trade-off choices, and others providing information or indicators that are relevant to a range of decisions but not customized to a single decision context (Kenney et al., 2016; Rose, 2015; Wiggins et al., 2018). To ensure that decision support tools and products are usable, their information needs to be shared at a time that is relevant to farmers' decision-making processes, and it should be informed by existing stakeholder needs and engagement with agriculturalists and agricultural advisors (Haigh et al., 2015b).

The gap between the information that scientists produce and the information that end users find usable is well documented (Dewulf et al., 2020; Kirchhoff et al., 2013; Lemos et al., 2012). To be

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useful and usable, science should be salient, credible, legitimate (Cash et al., 2003), and iterative (Dilling and Lemos, 2011; Sarkki et al., 2015), and scientists should consider both the information's potential use and the process by which it was created (Dilling and Lemos, 2011). Many researchers increasingly turn to stakeholder engagement and knowledge co-production (Stumpf et al., 2016) to achieve these goals. One example of this effort is the Useful 2 Usable project, a multi-institutional effort to transform existing climate data into usable agricultural products that incorporated stakeholder feedback through user surveys and data use statistics (Angel et al., 2017). Other stakeholder-led projects have led to usable science in regions as far reaching as California (Baker et al., 2020), Argentina (Podestá et al., 2013), Zambia (Arslan et al., 2015), the UK (Rose, 2015), and Australia (Hochman and Carberry, 2011).

To explore stakeholder climate and environmental information needs and priorities in the U.S. Corn Belt, this study uses a document analysis approach (Bowen, 2009) modeled after the methods in Dilling and Berggren (2015) and Molino et al. (2020). Existing documents are categorized and coded from a predetermined coding schema to allow for an easy inter-documental comparison of stakeholder needs. Through this approach we can recognize both data needs that are commonly expressed and expected data needs that have not been prioritized. Because much has already been published on the information needs of agriculturalists in the region, we use this document analysis approach to understand the existing stakeholder need landscape. This reduces stakeholder fatigue and focuses future engagements on *advancing* the understanding of information translation.

Information collected from this study will be used to develop the Dashboard for Agricultural Water use and Nutrient management (DAWN). The DAWN project is co-creating sub-seasonal to seasonal forecasts that will be organized as decision-task-focused indicators and a decision support tool dashboard to support water and nutrient management decisions for food and energy crop production in the U.S. Midwest Corn Belt region. In addition, operationalized, predictive and downscaled seasonal climate outlooks present an opportunity to build open-access decision support systems that allow for more equitable access to relevant information.

The methods section of this paper outlines the study's design, including the methods and criteria for document retrieval and selection, the creation of a coding schema for the U.S. Corn Belt, and subsequent analysis of coded documents. The results section focuses on several main themes that were identified throughout the document coding, which relate to the climate and environmental

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information practitioners need, where they get their information, the decisions they focus on, and their desired outcomes. The discussion section focuses on the implications of this work for the DAWN project and scientists in other regions or sectors who are planning to conduct similar user-driven research and decision-support tool development.

2 Methods

Document analysis was used to assess stakeholders' perspectives without directly engaging with them (Saldana, 2013; Bowen, 2009). While this method is limited in its scope and relies on information and ideas that have already been shared, it benefits from being "stable, unobtrusive, exact, and available over a long span of time" (Yin, 2009; Dilling and Berggren, 2015). This method has also been used to identify stakeholder needs in other regions and with a variety of foci, such as to explore stakeholder needs with respect to climate change in the Mountain West (Dilling and Berggren, 2015) and the Northeastern United States (Molino et al., 2020). The following section outlines how documents were chosen, coded, and analyzed. The purpose of this study was to apply an existing schema to a new study period of interest, rather than to develop new methods.

2.1 Document Selection

Documents were found via a web search and "snowball sampling" (Goodman, 1961), beginning with recent research on Decision Calendars in the Midwest (e.g., Haigh et al., 2015). The search was considered complete when no new documents were found. Papers were included if they met four criteria: (1) geographic scope, (2) date of publication, (3) input from stakeholders, and (4) focus on agricultural and natural resource management. Review papers were not included in document coding, because they do not include original information, but they were used to identify other studies.

The first criterion for inclusion was geographic scope, which was motivated by the scope of the DAWN project (Figure 1). To be included, documents needed to focus on part or all of the following "Corn Belt" states: Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin (Hunt et al., 2020). Documents that stated a "Corn Belt" focus without specifying the state were also included in the initial identification and coded for specific states later (see Sect. 2.3). Papers for which

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approximately 10% of the study area or less was made up by a Corn Belt state were *not* included because their primary focus was outside the region of interest.

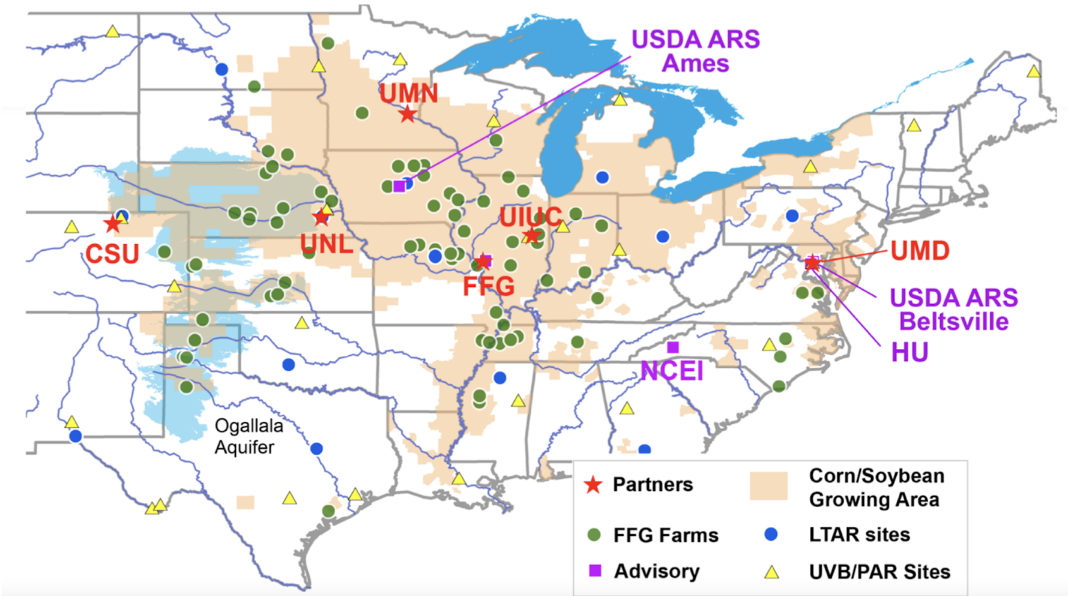

Figure 1: The geographic scope of the DAWN project, showing the 11 states chosen for the study focus (dawn.umd.edu). CSU = Colorado State University; UNL = University of Nebraska, Lincoln; UMN = University of Minnesota; FFG = Family Farm Group; UIUC = University of Illinois - Urbana Champaign; UMD = University of Maryland; USDA ARS = U.S. Department of Agriculture - Agricultural Research Service; NECI = National Centers for Environmental Information; HU = Howard University; LTAR = Long-Term Agroecosystem Research; UVB = Ultraviolet-B; PAR = Photosynthetically active radiation.

Only papers that have been published since 2010 were included, to focus the analysis on the most recent data possible. A ten-year time span ensured that enough papers were available to choose from and analyze, but also that the stated stakeholder perspectives were recent and reflective of the current social, political, and meteorological contexts in which decisions are being made. Note that, while the documents were constrained with respect to geography and publication year, documents were not constrained with regards to the kind of agriculture or the information time scale that they discussed.

The third and fourth criteria for inclusion were input from stakeholders and a focus on agricultural and natural resource management. "Input" could refer to quotes, survey results, product feedback, or the authors' interpretation of stakeholder needs. The topics of interest were chosen inductively after a precursory literature search, resulting in crops and livestock as the two primary topical foci. Some papers were also found that discussed water resource management, which were added to the

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document set to increase the scope of potential applications of this study. They comprised about 10% of the final document set.

2.2 Coding

Document analysis (Saldana, 2013) was conducted in MAXQDA, a software for qualitative data analysis. Documents were analyzed and coded deductively to the extent possible, meaning that the coding schema was pre-determined based on a prior understanding of stakeholder needs, rather than inductively, in which codes are created in response to the specific document set. The deductive approach was chosen both to create a coding schema that could be applied to other studies and to allow for analysis of expected needs that *are not* stated in addition to those that are. Some codes were added inductively during the coding process if they showed up repeatedly and had not been included in the original coding schema. This is a common approach in qualitative analysis, whereby study design is modified inductively until most of the research is complete (Bickman and Rog, 2009).

In accordance with the study's goal of applying an existing coding schema to a new region, the coding schema was adapted from (Molino et al., 2020) and (Dilling and Berggren, 2015; Dilling and Lemos, 2011), with changes made to account for different geographic regions and stakeholders and to make the schema more intuitive. The final schema consisted of 6 nodes, each with 4-6 sub-nodes: (1) Coordination, Collaboration, and Communication; (2) Monitoring and Data Collection; (3) Policies, Programs, and Law; (4) Research Topics; (5) Social Issues; and (6) Case attributes (e.g., year published, author affiliation, funding source, etc.). Most sub-nodes included their own sub-sub-nodes, with a fourth layer of codes including in instances where specificity was necessary. An overview of the final code is illustrated in Figure 2, and the reader is referred to the Supplementary Material for the complete coding schema.

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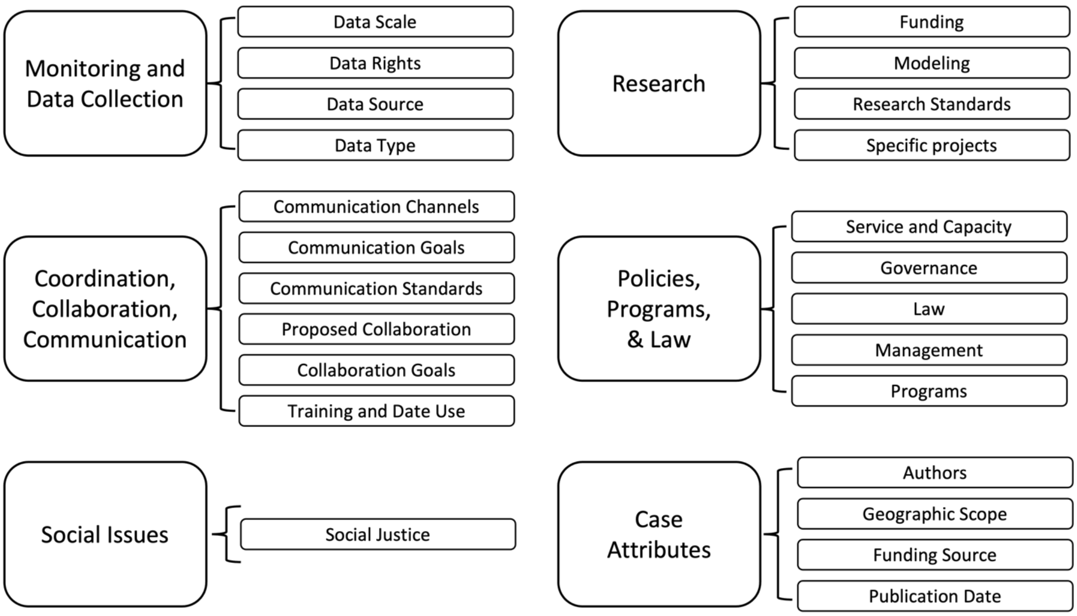

Figure 2: The main nodes and associated sub-nodes of the coding schema. The order of nodes/sub-nodes does not suggest ranking.

Coding was guided by several principles to ensure consistency across all coders and documents. First, a code was applied wherever it appeared, regardless of how frequently (or infrequently). Second, only stakeholder input was coded, whether it appeared as (1) a direct quote, (2) in the analysis from the paper authors, or (3) as a quotation from another paper when used as context for the study's analysis. Information from other papers was not coded if the geographic scope of the cited study was beyond the Corn Belt (Sect. 2.2). Finally, all codes were weighted evenly, with no added judgment about the code's perceived importance by the stakeholder.

Two team members initially coded several documents simultaneously and discussed their results until a consensus about coding was reached. Thereafter, for efficiency, documents were split between the two coders without double-coding. Document codes were inductively adjusted as necessary to ensure intercoder consistency.

2.3 Analysis

Codes were analyzed for code occurrence and code co-occurrence. Code occurrence was counted by the number of documents in which a code appeared, rather than the number of times a code itself was used, to avoid biasing toward longer documents. To establish themes across the

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document set, the frequency of sub-nodes was analyzed first, followed by sub-sub-nodes and specific codes, as needed, to analyze details. The document set was analyzed for basic statistics, including the number of documents published in each year, the number of documents published in each state, and the distribution of funding from grants, universities, private donors, or government budget.

To analyze code occurrence in such a large coding schema, the document set was analyzed node by node, rather than for all codes simultaneously. This method was appropriate because three nodes - Monitoring and Data Collection; Coordination, Collaboration, and Communication; and Policies, Programs, & Law - were used across the same total number of documents (45), while the node Research appeared in two thirds of the total documents (34 documents), so sub-nodes within these four nodes were analyzed with equal weight. Codes under the same node were analyzed for co-occurrence, defined as occurring together within the same document. The node Social Issues was not used in any documents and was therefore not included in this analysis.

3 Results

3.1 Summary Statistics

Fifty (50) documents in total were found for analysis that met the criteria defined in Sect. 2.2. All but two of the documents had two or more authors, and most documents had at least one author from an academic institution (Figure 3). Among those academic institutions, the most frequently coded were the University of Nebraska - Lincoln (18 documents), Purdue University (17 documents), University of Wisconsin - Madison (12 documents), and Iowa State University (12 documents). Forty-five (45) out of the 50 documents were co-authored by an author from an institution (academic or otherwise) within the U.S. Corn Belt, and 25 documents were co-authored by an author from an institution outside of the geographic scope. Grants were the most dominant funding source (30 documents), followed by university programs (13 documents), government budgets (5 documents), and unlisted sources (2 documents). Eight (8) documents were funded as part of the Useful to Usable project.

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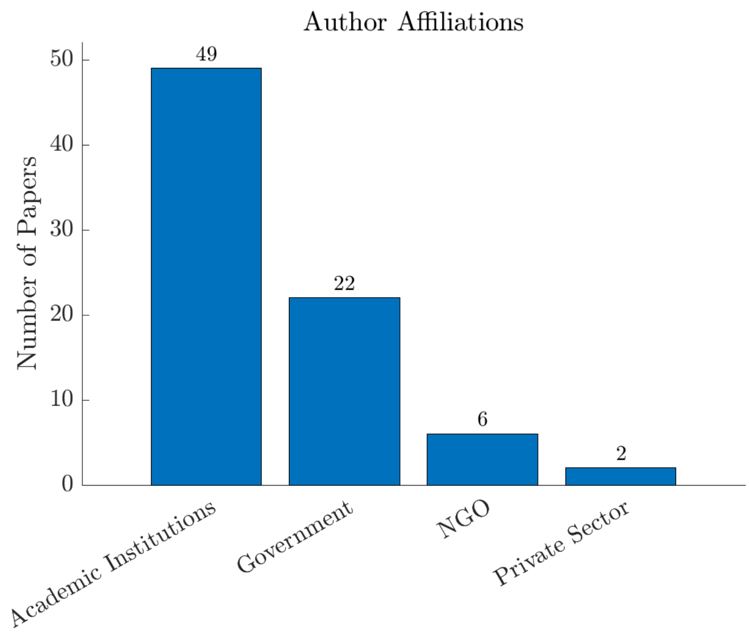

Figure 3: Number of documents with at least one author affiliated with an organization or institution from an NGO, the private sector, the government, or an academic institution. Note that the sum of the documents is greater than 50, because most documents had multiple authors, who may be affiliated with different institutions.

All of the states in the Corn Belt were mentioned in at least one paper, but their frequency varied widely. Kentucky was mentioned the least, in only 2 documents, while Iowa was mentioned in 28 documents (Figure 4). Most studies spanned state lines, with their geographic scope determined by natural features such as watersheds or anthropogenic boundaries such as individual farms and government jurisdictions. Some documents also included regions beyond the study's geographic scope, in other states and provinces, but those states and provinces are not discussed here.

More documents were published in the second half of the time period, from 2016 to 2021, than in the first half, from 2010-2016 (Figure 4). There was a peak in publications in 2017, but no apparent long-term trend.

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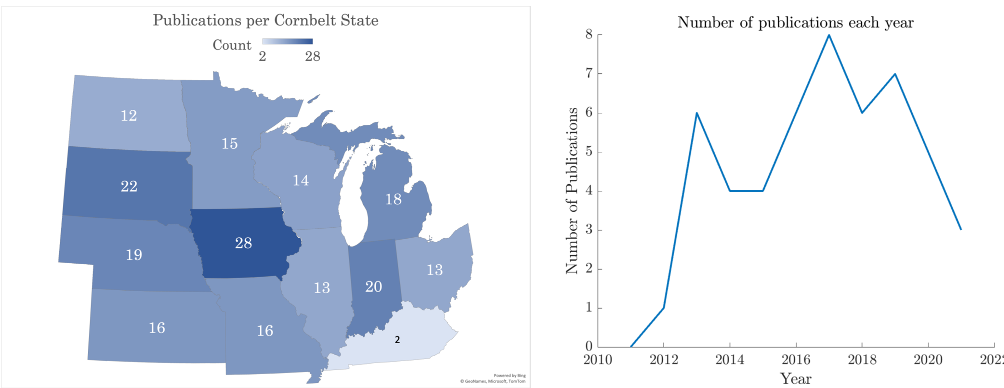

Figure 4: (left) States in the Corn Belt color-coded by the number of documents that included that state in their study area. (right) Number of publications per year

3.2 Common Themes

The most common codes fell under five overarching themes: where practitioners get their climate and environmental information; what information practitioners need; capacity and barriers that affect decision-making; which decisions practitioners can control; and the desired outcomes of information gathering and decision-making (Figure 5). Together, these themes indicate that the most frequently mentioned concerns were those related to practical decision-making. Themes such as social issues, research standards, and collaboration standards were mentioned less frequently, or not at all.

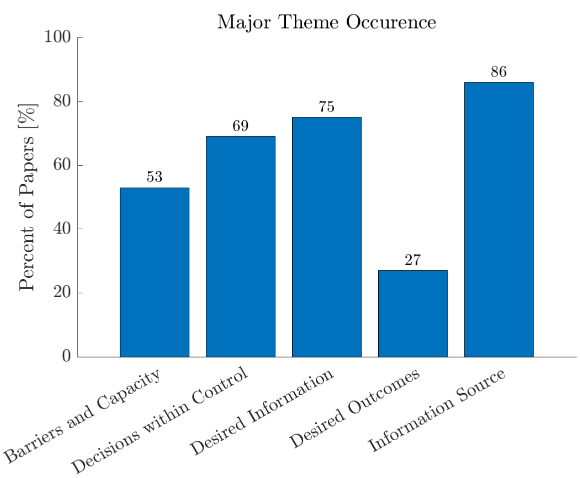

Figure 5: The relative frequency (percent of papers) with which each major theme occurs throughout the document set.

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3.2.1 Where practitioners get their information

The most frequently coded sub-nodes under "Coordination, Collaboration, and Communication" (Figure 2) were "Communication Channels" and "Training and Date Use". Codes related to communication/collaboration goals, proposed collaborations, and communication standards were used in fewer than five papers, if at all. Rather, when communication was mentioned, most papers discussed where practitioners get their climate and environmental information: from research agencies, other communities, private companies (e.g., seed and fertilizer suppliers), consultants, mass media, and Extension/boundary organizations. Most of the information sources mentioned were existing contacts. Communication channels between the government and private industry were mentioned about half as frequently as those between private companies and practitioners.

There was little discussion of lines of communication between different organizations, companies, or agencies, because the most common focus was the relationship between those who supply the information and those who use it. In addition to a focus on *who* shares data with practitioners, there was frequent discussion of *how* the data are shared, i.e., whether they are usable. There was overall agreement that climate and environmental information should be readily available and easy to download (accessible), and that stakeholders will not use information that they are not aware of (available). There was little discussion, however, of whether information should be proprietary/paid or open source/free.

As most of the focus was on data delivery through personal contacts, there was little discussion of developing an online "clearinghouse" of information. There were, however, several documents that mentioned evaluating current decision aids. This topic was often mentioned in the context of drought monitors such as the U.S. Drought Monitor (Derner and Augustine, 2016; Haigh et al., 2021, 2019), the Natural Resources Conservation Service drought tool (Beeton and McNeeley, 2020), the South Dakota Drought Tool (Knutson and Haigh, 2013), and the National Integrated Drought Information System (Otkin et al., 2015), which were particularly prevalent in papers set in the western half of the Corn Belt, where drought is more common. There were also several agricultural tools that were mentioned, such as the Useful 2 Usable Growing Degree Day tool (Haigh et al., 2015b, a) and the USDA GrassCast Tool (Haigh et al., 2018). However, some papers mentioned that these tools go underutilized, and that their utility cannot replace the experience of

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a consultant (Ranjan et al., 2019), which echoes the emphasis on communication channels and personal communication.

3.2.2 Information practitioners need

Documents primarily discussed two data sources: forecast and observations. There was less mention of climatological data, historical data, or remote sensing (i.e., satellite) data. Forecast data were often mentioned on the timescale of days to months, with little mention of longer timescales. Observational data overwhelmingly mentioned collecting and using new field data, rather than gathering or analyzing existing historical data.

The most frequently mentioned data types were all related - even if peripherally - to water resources: precipitation, drought, soil moisture, and soil erosion. Note that, in this coding schema, water resource codes were focused upstream, on how practitioners use water. Several papers were found related to water quality, but they were beyond the scope of the project because they focused on downstream effects rather than information use. Precipitation and drought data were mentioned most frequently, followed by soil moisture and erosion data. Soil health existed in the coding schema in a variety of forms, including soil temperature and compaction, but only moisture and erosion were coded in more than 10 documents, often in the context of rain-induced changes. In addition, although the coding schema included a variety of codes related to weather and climate, such as air temperature, air humidity, extreme heat, snow cover, hail, and wind, none of these codes were mentioned in more than 10% of documents. Similarly, codes related to pests and diseases were mentioned in fewer than 10% of documents, and codes related to air quality or land use were not used at all.

3.2.3 Decision Making

To keep their businesses running, practitioners - agriculturalists, water managers, and rangeland managers - make countless decisions on a variety of time scales, from daily to weekly, seasonally, and annually (Haigh et al., 2015). Not all factors to decision-making are within practitioners' control (see Sect. 3.2.4), but among those that are, the most frequently mentioned management decisions were in one of three categories: agricultural management, water management, or risk management.

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Certain agricultural management decisions were mentioned more than others, particularly whether to use cover crops, and whether or not to till the fields. No-till agriculture and cover crops both reduce soil erosion, increase soil biological activity, reduce nutrient leaching, and improve overall soil health (Agriculture, 2022; Creech, 2021), and several studies directly inquired whether stakeholders planned to adopt them. Nutrient application and efficiency were also often discussed in the context of *when* nutrients should be applied, i.e., the timing of nutrient application. The primary focus was on Nitrogen, with little discussion of Phosphorus, Potassium, Sulfur, or other nutrients.

Water management decisions most often related to irrigation, with some additional consideration for runoff/drainage, storage, and drought response timing. Irrigation was most often mentioned as a risk reduction or impact mitigation measure. Nationwide, less than 20% of croplands are irrigated, and in most Corn Belt states, less than 10% of corn is irrigated (Hrozencik and Aillery, 2021). Installing irrigation requires up-front costs that will only be recouped if weather becomes unpredictable enough to necessitate its use. Thus, only practitioners who thought water supply could become unstable were likely to utilize irrigation (Church et al., 2018), while others filed it away as a practice they would never adopt (Bitterman et al., 2019). Many of the agriculture and water management decisions mentioned in the documents overlapped with risk management, which appeared frequently. Practitioners mentioned both reducing the risk of natural events and making management decisions that are the least risky. Church et al. (2018) documented a subtle shift towards greater risk management over time.

Just because the decisions discussed above are within a practitioner's control does not mean that the decisions are without influence. Stakeholders mentioned multiple factors that affect their decision-making, whether by encouraging or discouraging a particular course of action. Crop insurance was mentioned frequently as a factor that could discourage adopting new crops or farming strategies.

The other factors to decision-making that were mentioned most often were factors related to capacity, i.e., funding and infrastructure. Funding referred both to a practitioner's liquid funds and to the availability of financial assistance from the government and private entities. "Infrastructure" in the document set most typically referred to physical infrastructure, such as irrigation or machinery. Several other "Service and Capacity" codes were mentioned, but less often than

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funding and infrastructure, e.g., the ability to make decisions autonomously and flexibly, and structural barriers such as cover crop seed availability and limited market access (Roesch-Mcnally et al., 2018), which prevent the adoption of sustainable practices. Human capacity, such as staff time, training opportunities, leadership, and familiarity with decision support tools, was mentioned rarely.

3.2.4 Desired outcomes

The primary desired outcomes that were discussed were economic: increased crop yields and available markets to sell products. There was no mention of desired social outcomes, and environmental motivations were typically mentioned as either contrary to economic outcomes or as less important. Several documents emphasized that, to promote particular environmental outcomes, governing bodies would have to provide significant incentive to offset potential economic losses.

4 Discussion

4.1 The Decision-Making Process

The themes mentioned in Sect. 3.2 guide the decision-making process and provide important context for when practitioners need climate and environmental information, what information they need and why they need it, how they prefer to receive information, and from whom. Kuehne et al. (2017) created a model to predict the adoption and diffusion of new agricultural practices and grouped the different factors to adoption into those that affect the *time to peak adoption* and those that affect *peak adoption level.* Within these two categories, a variety of factors can affect the decision-making process. The main themes of the document set (see Sect. 3.2) are discussed in the context of Kuehne et al.'s model below.

The most frequently mentioned codes in the node "Coordination, Collaboration, and Communication" were related to communication channels, indicating that most practitioners are concerned about who delivers their information and through what means. In addition, most practitioners indicated that they get their information from a human source such as a trusted advisor, Extension agent, private company, or consultant, although this is highly variable by farm scale and type, because very large farms might have data scientists on staff. There was little discussion of communication and collaboration standards or of creating new information sources,

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which suggests that practitioners place their trust in their information source, not the original creator of the information. It also emphasizes the need for translation of data and information to specific on-farm decisions, such that information is ready to use once it is passed from its creator to the practitioner's trusted source. Practitioners need to receive translated and contextualized information from people who can help describe why something matters and what information is especially relevant to their particular farm.

Data usability, availability, and accessibility were coded frequently, in the context of how practitioners will find and use existing data. Data are deemed usable when they are salient, credible, and legitimate, but the value placed on each of these characteristics varied (Haigh et al., 2018). In some contexts, "usable" environmental and climate information referred to information that "[is] updated on a regular basis and [is] available on a grid that provides continuous coverage over large geographic domains with horizontal resolutions sufficient to capture local and regional differences in drought severity" (Otkin et al., 2018). In other contexts, stakeholders deemed information to be usable when it was trustworthy/reliable (Church et al., 2018; Lemos et al., 2014), familiar (Easton et al., 2017), transparent (Easton et al., 2017), and timely (Stuart et al., 2018).

In addition to a focus on who delivers their information, practitioners were focused on several kinds of climate and environmental information in particular. "Precipitation" was the most frequently coded data type, and it often co-occurred with "Forecast." Precipitation was often discussed in the context of extreme events, particularly drought and extreme rain events, suggesting that practitioners have either experienced these events in the recent past, or are wary of their increased frequency in the future. The other two frequently mentioned data types - soil moisture and soil erosion - are both closely related to precipitation, illustrating one application of precipitation data to practitioners' decision-making. The documents coded in this study rarely mentioned a forecast time scale, but Haigh et al. (2015) found that management decisions are often made on seasonal time scales, in the fall and winter preceding planting season. Weekly and monthly forecasts may also be relevant for decisions related to the timing of fertilizer application (see below) (Easton et al., 2017; Haigh et al., 2015b; Kusunose et al., 2019; Mehta et al., 2010). Interestingly, "Air Temperature" was coded more than 50% less frequently than "Precipitation", despite the typical association of these two data types with weather. This does not necessarily indicate that air temperature is unimportant, however. Rather, practitioners might care about

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derived temperature products such as first and last frost, extreme heat days, or temperature variability in the spring, that are more directly applicable to decision-making.

Another frequently mentioned code related to precipitation was "Drought". It was most often coded in the context of learning about a certain event, which is likely a result of the flash drought of 2016 and suggests that practitioners want a better warning system in place (including communication) to let them know of an impending event. "Drought" was often coded in the context of having a drought response plan, or in the context of monitoring the event's progression.

Whether practitioners incorporate their desired climate and environmental information is influenced by upfront costs such as advisory support, group involvement, and relevant existing skills and knowledge (Kuehne et al., 2017). Upfront costs can also refer to financial, human, and physical *capacity,* as defined in our coding schema. These different forms of capacity affect the ability of a practitioner to implement a decision once it has been made, and their existence (or lack thereof) could persuade or dissuade a practitioner from using the requested information in the first place. The most mentioned forms of capacity in this document set were infrastructure and funding support. There was less of a focus on human resources such as staff time, staff members' existing skill sets, or time to develop new skills and stay up to date on available data. This does not necessarily suggest that such resources are not a priority; instead, these human resources, which are more focused on a project's continuation, could be secondary to the financial and infrastructural resources that enable a project's implementation.

In contrast, while capacity might enable a practitioner to make a decision, structural barriers prevent it. Challenges such as the structure of seed markets, laws governing water management, and uncooperative landlords were all given as reasons for why practitioners either could not or would not change their practices, even considering improved information or improved management strategies. Insurance can insulate against risk, allowing farmers to continue with "business as usual" and resist the adoption of conservation measures such as cover crops (Upadhaya and Arbuckle, 2021) or efficient nitrogen application (Stuart et al., 2014). Insurance regulations can also discourage trying new methods if the regulations are not flexible (Roesch-Mcnally et al., 2018).

Regardless of capacity or structural barriers, risk could ultimately affect how practitioners use information and make decisions. The relative advantage of using information or adopting a practice depends on both the practitioner's tolerance and understanding of risk and the risk of implementing the practice itself (Kuehne et al., 2017). Because this study was focused on information use but not the implementation of new conservation practices, it is difficult to assess the risk of the conservation practices themselves, and most of this discussion is centered on practitioners' perception of risk. Risk management took several forms in the document set: risk versus benefits of adopting new sustainable practices; reducing the risk associated with extreme events such as drought; perception of climate change risk; risk tolerance; using climate and environmental information in risk management; and financial risk. In many cases, a practitioner's perception of risk and existing risk reduction strategies affected their willingness to incorporate new information into decision-making.

Agricultural management and water management were both mentioned frequently in the context of risk management. Water management decisions, for example, might make a field or rangeland more resilient to drought risk, and the decision to implement irrigation was often mentioned simultaneously with practitioners' perceived risk of water shortages. Deciding when to apply nutrients is influenced by the balance between weather-induced and economic-induced risk, such that practitioners can maximize their yield. Stakeholders' willingness to adopt existing management strategies (irrigation, cover crops, etc.) and their interest in innovative strategies were affected by their perception of risk, but the reverse was also true - their perception of climate and weather risk was reduced if they already utilized risk management strategies. Most of the stakeholders interviewed were concerned with near-term agricultural and water management decisions, such as cover crops, when/how to till, nitrogen application, etc. Their concerns were less focused on long-term trends, and historical/climatological data was only relevant in the context that it informed current decision-making.

As mentioned in Sect. 3.2.4, the information that practitioners need, who they get it from, and the decisions that they make were overwhelmingly motivated by desired economic outcomes. In the context of Kuehne et al.'s framework, the code "economic" could refer to profit orientation, profit benefit in the future, profit benefit in the years a practice is used, the time for profit benefits to be realized, or upfront costs (Kuehne et al., 2017). Overwhelmingly, when the code "economic" was used in our coding schema, the document discussed profit orientation and profit benefit in the year a practice was used. Practitioners were primarily concerned with maximizing their yield and utilizing available markets, buyers, and contracts to profit off their crop. Economic opportunities

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and markets were a concern for farmers considering adopting new crops or participating in government sustainable management programs.

Desired outcomes were rarely environmental or societal in this document set, except for when the researchers were investigating environmental issues directly, and even in those scenarios the practitioners indicated that it was not their primary concern. In some instances, economic factors motivated decisions that could lead to a synergistic environmental benefit, such as cover crops or contour farming.

4.2 Themes that were not discussed

Several topics were defined in the coding schema that were not discussed in the document set. This does not mean that the topic is unimportant, but rather that it did not arise given how the code was defined; stakeholders could define it differently or assign it a different indicator than what was named in the schema. In some instances, stakeholders approach management decisions qualitatively and experientially rather than quantitatively or with data. For example, interviews with Extension agents on the DAWN project have revealed that farmers might determine soil moisture by kicking it, not by instrument-based measurements. The missing codes discussed below should be interpreted in this context, with the understanding that all of this study's available information is dependent on studies that have already been conducted.

First, collaboration goals were only mentioned in 6 documents, which could suggest that practitioners are more focused on data delivery than data creation. Given the prevalence of the code "Communication Channels", however, collaborations might occur in ways that are not explicitly mentioned by practitioners. For example, several documents discussed proposed collaborations, such as between government agencies and between research agencies, which could suggest a desire for improved efficiency in collaboration and data delivery.

Another topic that was expected but mentioned infrequently was the geospatial scale of information (6 documents), which contrasts with information from Extension specialists on the DAWN team that says that people often request field-scale information. This could be because the types of data most often discussed are already available at the scale that practitioners need. It could also be because information sources are already localized: as exemplified under the sub-node

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"Communication Channels", most practitioners get their information from trusted (local) sources such as consultants or crop advisors.

Finally, the node "Social Issues" was not used at all in the document set. This is not uncommon: social science and social issues are not often mentioned in stakeholder needs analysis papers (e.g. Dilling et al. 2015; Molino et al. 2020). This could be because most people do not link social and environmental issues when asked about climate information. In general, the themes that were not mentioned in the document set emphasize our conclusion that practitioners mentioned standards of practice far less often than they mentioned usable data, management challenges, and desired outcomes.

4.3 Research Gaps, Implications, and Future Work

Because only peer-reviewed academic literature was publicly available for the study, the focus of the document set was on what researchers found important to ask; as a result, some topics might have been missed that are important to stakeholders but are not frequently discussed in research. In addition, authors' affiliations were primarily academic institutions, and research funding was primarily grant-based. As a result, the documents were skewed towards those states and institutions which readily fund stakeholder and agriculture research.

The results outlined here have implications for both the DAWN project and further research. First, the fact that practitioners get their information from personal sources highlights the need to promote and explain the DAWN dashboard through existing channels, because potential users are not likely to find a new online dashboard otherwise. Second, for forecasts to be relevant, the DAWN dashboard and other decision support tools should seek to provide information on weekly and seasonal time scales that can directly inform management decisions. Third, the focus on risk management but not long-term forecasts or climatological data highlights an opportunity for education: some risk management decisions, such as infrastructure investments, must be made on time scales longer than annual. It is therefore important to communicate which factors contribute to potential risk and on which time scales.

Future research should include public fora with stakeholders where questions are more open-ended and less guided by existing research interests. It might also prove useful to conduct follow-up surveys with stakeholders who have already provided input to learn about changes in priority over

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time, in the context of new weather events and updated environmental information. If stakeholders are unavailable for follow-up research, similar goals can be achieved by interviewing organizations or Extension staff that work with stakeholders; valuable information can be gleaned this way without the need to interview practitioners directly.

5 Conclusion

This paper analyzed 50 documents about stakeholder climate data needs in the U.S. Corn Belt. The most common themes considered practitioners' decision-making process: from whom they get their information, what information they need, the decisions they can control, what affects their decision-making, and what their desired outcomes are. Collaboration goals, social issues, and data geospatial scale were mentioned less often, indicating a lower priority, a knowledge gap, insufficient research methods, or some combination of these three. The conclusions presented here can inform the future development of decision support tools both within and beyond the DAWN project. Future research should seek to collect information that is motivated as much as possible by stakeholders' needs, rather than by scientists' research priorities. This study identifies the starting point for future studies, such that they are efficient and reduce stakeholder fatigue. It also serves as an example for the background research that scientists can and should do when initiating a project that requires stakeholder engagement: the method presented here can easily be applied to other geographies and sectors.

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Author Contributions

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Felix Wolfinger – data curation, formal analysis, investigation, writing – review & editing

Melissa Kenney – conceptualization, funding acquisition, methodology, supervision, writing – review & editing

Michael Gerst – conceptualization, writing – review & editing

Heidi Roop – conceptualization, writing – review & editing

Competing Interests

Some authors are members of the editorial board of Geoscience Communication. The peer-review process was guided by an independent editor, and the authors have also no other competing interests to declare.

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https://doi.org/10.5194/egusphere-2022-308
Preprint. Discussion started: 12 May 2022

6 References

Agriculture, U.S. Department of. 2022. Cover crops - keeping soil in place while providing other benefits

Andrys, J., Lyons, T. J., and Kala, J.: Multidecadal evaluation of WRF downscaling capabilities over Western Australia in simulating rainfall and temperature extremes, J. Appl. Meteorol. Climatol., 54, 370–394, https://doi.org/10.1175/JAMC-D-14-0212.1, 2015.

Angel, J. R., Widhalm, M., Todey, D., Massey, R., and Biehl, L.: The U2U Corn Growing Degree Day tool: tracking corn growth across the U.S. Corn Belt, Clim. Risk Manag., 15, 73–81, https://doi.org/10.1016/j.crm.2016.10.002, 2017.

Angel, J. R., Swanson, C., Boustead, B. M., Conlon, K., Hall, K. R., Jorns, J. L., Kunkel, K. E., Lemos, M. C., Lofgren, B. M., Ontl, T., Posey, J., Stone, K., Takle, E., and Todey, D.: Chapter 21: Midwest. Impacts, risks, and adaptation in the United States: the fourth national climate assessment, volume II, 872–940 pp., https://doi.org/10.7930/NCA4.2018.CH21, 2018.

Arslan, A., Mccarthy, N., Lipper, L., Asfaw, S., Cattaneo, A., and Kokwe, M.: Climate smart agriculture? Assessing the adaptation implications in Zambia, J. Agric. Econ., 66, 753–780, https://doi.org/10.1111/1477-9552.12107, 2015.

Baker, Z., Ekstrom, J. A., Meagher, K. D., Preston, B. L., and Bedsworth, L.: The social structure of climate change research and practitioner engagement: evidence from California, Glob. Environ. Chang., 63, 102074, https://doi.org/10.1016/j.gloenvcha.2020.102074, 2020.

Beeton, T. A. and McNeeley, S. M.: Who, what, where, when, and how? A typology of drought decision-making on public and tribal lands in the north-central united states, Weather. Clim. Soc., 12, 611–627, https://doi.org/10.1175/WCAS-D-19-0137.1, 2020.

Bickman, L. and Rog, D. J.: Handbook of Applied Social Research Methods, 2nd ed., SAGE, 2009.

Bitterman, P., Bennett, D. A., and Secchi, S.: Constraints on farmer adaptability in the Iowa-Cedar River Basin, Environ. Sci. Policy, 92, 9–16, https://doi.org/10.1016/j.envsci.2018.11.004, 2019.

Bowen, G. A.: Document analysis as a qualitative research method, Qual. Res. J., 9, https://doi.org/https://doi.org/10.3316/QRJ0902027, 2009.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Jäger, J., and Mitchell, R. B.: Knowledge systems for sustainable development, Proc. Natl. Acad. Sci. U. S. A., 100, 8086–8091, https://doi.org/10.1073/pnas.1231332100, 2003.

Chawla, I., Osuri, K. K., Mujumdar, P. P., and Niyogi, D.: Assessment of the weather research and forecasting (WRF) model for simulation of extreme rainfall events in the upper Ganga Basin, Hydrol. Earth Syst. Sci., 22, 1095–1117, https://doi.org/10.5194/hess-22-1095-2018, 2018.

Church, S. P., Dunn, M., Babin, N., Mase, A. S., Haigh, T., and Prokopy, L. S.: Do advisors

https://doi.org/10.5194/egusphere-2022-308
Preprint. Discussion started: 12 May 2022

perceive climate change as an agricultural risk? An in-depth examination of Midwestern U.S. Ag advisors' views on drought, climate change, and risk management, Agric. Human Values, 35, 349–365, https://doi.org/10.1007/s10460-017-9827-3, 2018.

Saving money, time and soil: the economics of no-till farming:

Derner, J. D. and Augustine, D. J.: Adaptive management for drought on rangelands, 38, 211–215, https://doi.org/10.1016/j.rala.2016.05.002, 2016.

Dewulf, A., Klenk, N., Wyborn, C., and Lemos, M. C.: Usable environmental knowledge from the perspective of decision-making: the logics of consequentiality, appropriateness, and meaningfulness, Curr. Opin. Environ. Sustain., 42, 1–6, https://doi.org/10.1016/j.cosust.2019.10.003, 2020.

Dilling, L. and Berggren, J.: What do stakeholders need to manage for climate change and variability? A document-based analysis from three mountain states in the Western USA, Reg. Environ. Chang., 15, 657–667, https://doi.org/10.1007/s10113-014-0668-y, 2015.

Dilling, L. and Lemos, M. C.: Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy, Glob. Environ. Chang., 21, 680–689, https://doi.org/10.1016/j.gloenvcha.2010.11.006, 2011.

Easton, Z. M., Kleinman, P. J. A., Buda, A. R., Goering, D., Emberston, N., Reed, S., Drohan, P. J., Walter, M. T., Guinan, P., Lory, J. A., Sommerlot, A. R., and Sharpley, A.: Short-term forecasting tools for agricultural nutrient management, J. Environ. Qual., 46, 1257–1269, https://doi.org/10.2134/jeq2016.09.0377, 2017.

Ghil, M. and Jiang, N.: Recent forecast skill for the El Nino/Southern Oscillation, Geophys. Res. Lett., 25, 171–174, 1998.

Goodman, L. A.: Snowball sampling, Ann. Math. Stat., 32, 148–170, 1961.

Haigh, T., Morton, L. W., Lemos, M. C., Knutson, C., Prokopy, L. S., Lo, Y. J., and Angel, J.: Agricultural advisors as climate information intermediaries: exploring differences in capacity to communicate climate, Weather. Clim. Soc., 7, 83–93, https://doi.org/10.1175/WCAS-D-14-00015.1, 2015a.

Haigh, T., Takle, E., Andresen, J., Widhalm, M., Carlton, J. S., and Angel, J.: Mapping the decision points and climate information use of agricultural producers across the U.S. Corn Belt, Clim. Risk Manag., 7, 20–30, https://doi.org/10.1016/j.crm.2015.01.004, 2015b.

Haigh, T., Koundinya, V., Hart, C., Klink, J., Lemos, M., Mase, A. S., Prokopy, L., Singh, A., Todey, D., and Widhalm, M.: Provision of climate services for agriculture: public and private pathways to farm decision-making, Bull. Am. Meteorol. Soc., 99, 1781–1789, https://doi.org/10.1175/BAMS-D-17-0253.1, 2018.

Haigh, T., Hayes, M., Smyth, J., Prokopy, L., Francis, C., and Burbach, M.: Ranchers' use of drought contingency plans in protective action decision making, Rangel. Ecol. Manag., 74, 50–62,

https://doi.org/10.5194/egusphere-2022-308
Preprint. Discussion started: 12 May 2022

https://doi.org/10.1016/j.rama.2020.09.007, 2021.

Haigh, T. R., Otkin, J. A., Mucia, A., Hayes, M., and Burbach, M. E.: Drought early warning and the timing of range managers' drought response, Adv. Meteorol., 2019, https://doi.org/10.1155/2019/9461513, 2019.

Hochman, Z. and Carberry, P. S.: Emerging consensus on desirable characteristics of tools to support farmers' management of climate risk in Australia, Agric. Syst., 104, 441–450, https://doi.org/10.1016/j.agsy.2011.03.001, 2011.

Hrozencik, R. A. and Aillery, M.: Trends in U.S. irrigated agriculture: increasing resilience under water supply scarcity, U.S. Department of Agriculture, Economic Research Service, 1–55 pp., https://doi.org/10.2139/ssrn.3996325, 2021.

Hunt, E. D., Birge, H. E., Laingen, C., Licht, M. A., McMechan, J., Baule, W., and Connor, T.: A perspective on changes across the U.S. Corn Belt, Environ. Res. Lett., 15, https://doi.org/10.1088/1748-9326/ab9333, 2020.

Jones, R. N., Chiew, F. H. S., Boughton, W. C., and Zhang, L.: Estimating the sensitivity of mean annual runoff to climate change using selected hydrological models, Adv. Water Resour., 29, 1419–1429, https://doi.org/10.1016/j.advwatres.2005.11.001, 2006.

Kenney, M. A., Janetos, A. C., and Lough, G. C.: Building an integrated U.S. National Climate Indicators System, Clim. Change, 135, 85–96, https://doi.org/10.1007/s10584-016-1609-1, 2016.

Kirchhoff, C. J., Lemos, M. C., and Dessai, S.: Actionable knowledge for environmental decision making: broadening the usability of climate science, Annu. Rev. Environ. Resour., 38, 393–414, https://doi.org/10.1146/annurev-environ-022112-112828, 2013.

Klemm, T. and McPherson, R. A.: The development of seasonal climate forecasting for agricultural producers, Agric. For. Meteorol., 232, 384–399, https://doi.org/10.1016/j.agrformet.2016.09.005, 2017.

Knutson, C. and Haigh, T.: A drought-planning methodology for ranchers in the great plains, 35, 27–33, https://doi.org/10.2111/RANGELANDS-D-12-00075.1, 2013.

Kuehne, G., Llewellyn, R., Pannell, D. J., Wilkinson, R., Dolling, P., Ouzman, J., and Ewing, M.: Predicting farmer uptake of new agricultural practices: a tool for research, extension and policy, Agric. Syst., 156, 115–125, https://doi.org/10.1016/j.agsy.2017.06.007, 2017.

Kusunose, Y., Ma, L., and VAN SANFORD, D.: User responses to imperfect forecasts: findings from an experiment with Kentucky wheat farmers, Weather. Clim. Soc., 11, 791–808, https://doi.org/10.1175/WCAS-D-18-0135.1, 2019.

Lemos, M. C., Kirchhoff, C. J., and Ramprasad, V.: Narrowing the climate information usability gap, Nat. Clim. Chang., 2, 789–794, https://doi.org/10.1038/nclimate1614, 2012.

Lemos, M. C., Kirchhoff, C. J., Kalafatis, S. E., Scavia, D., and Rood, R. B.: Moving climate

https://doi.org/10.5194/egusphere-2022-308
Preprint. Discussion started: 12 May 2022

information off the shelf: Boundary chains and the role of risas as adaptive organizations, Weather. Clim. Soc., 6, 273–285, https://doi.org/10.1175/WCAS-D-13-00044.1, 2014.

Mehta, V. K., Knutson, C. L., Rosenberg, N. J., Olsen, J. R., Wall, N. A., Bernadt, T. K., and Hayes, M. J.: An assessment of decadal drought information needs of stakeholders and policymakers in the Missouri River Basin for decision support, 1–15 pp., 2010.

Molino, G. D., Kenney, M. A., and Sutton-Grier, A. E.: Stakeholder-defined scientific needs for coastal resilience decisions in the northeast U.S., Mar. Policy, 118, 103987, https://doi.org/10.1016/j.marpol.2020.103987, 2020.

Moya-álvarez, A. S., Gálvez, J., Holguín, A., Estevan, R., Kumar, S., Villalobos, E., Martínez-Castro, D., and Silva, Y.: Extreme rainfall forecast with the WRF-ARW model in the Central Andes of Peru, Atmosphere (Basel)., 9, https://doi.org/10.3390/atmos9090362, 2018.

Otkin, J. A., Shafer, M., Svoboda, M., Wardlow, B., Anderson, M. C., Hain, C., and Basara, J.: Facilitating the use of drought early warning information through interactions with agricultural stakeholders, Bull. Am. Meteorol. Soc., 96, 1073–1078, https://doi.org/10.1175/BAMS-D-14-00219.1, 2015.

Otkin, J. A., Haigh, T., Mucia, A., Anderson, M. C., and Hain, C.: Comparison of agricultural stakeholder survey results and drought monitoring datasets during the 2016 U.S. Northern Plains flash drought, Weather. Clim. Soc., 10, 867–883, https://doi.org/10.1175/WCAS-D-18-0051.1, 2018.

Palutikof, J. P., Street, R. B., and Gardiner, E. P.: Decision support platforms for climate change adaptation: an overview and introduction, Clim. Change, 153, 459–476, https://doi.org/10.1007/s10584-019-02445-2, 2019.

Podestá, G. P., Natenzon, C. E., Hidalgo, C., and Ruiz Toranzo, F.: Interdisciplinary production of knowledge with participation of stakeholders: a case study of a collaborative project on climate variability, human decisions and agricultural ecosystems in the Argentine Pampas, Environ. Sci. Policy, 26, 40–48, https://doi.org/10.1016/j.envsci.2012.07.008, 2013.

Prokopy, L. S., Haigh, T., Mase, A. S., Angel, J., Hart, C., Knutson, C., Lemos, M. C., Lo, Y. J., McGuire, J., Morton, L. W., Perron, J., Todey, D., and Widhalm, M.: Agricultural advisors: a receptive audience for weather and climate information?, Weather. Clim. Soc., 5, 162–167, https://doi.org/10.1175/WCAS-D-12-00036.1, 2013.

Ranjan, P., Singh, A. S., Tomer, M. D., Lewandowski, A. M., and Prokopy, L. S.: Lessons learned from using a decision-support tool for precision placement of conservation practices in six agricultural watersheds in the US Midwest, J. Environ. Manage., 239, 57–65, https://doi.org/10.1016/j.jenvman.2019.03.031, 2019.

Roesch-Mcnally, G. E., Basche, A. D., Arbuckle, J. G., Tyndall, J. C., Miguez, F. E., Bowman, T., and Clay, R.: The trouble with cover crops: farmers' experiences with overcoming barriers to adoption, Renew. Agric. Food Syst., 33, 322–333, https://doi.org/10.1017/S1742170517000096, 2018.

https://doi.org/10.5194/egusphere-2022-308
Preprint. Discussion started: 12 May 2022

Rose, S.: The Inevitability of Climate Adaptation in U.S. Agriculture, Choices Mag. Food, Farm, Resour. Issues, 30, 1–5, https://doi.org/10.22004/ag.econ.206238, 2015.

Saldana, J.: The coding manual for qualitative researchers, https://doi.org/10.1108/qrom-08-2016-1408, 2013.

Sarkki, S., Tinch, R., Niemelä, J., Heink, U., Waylen, K., Timaeus, J., Young, J., Watt, A., Neßhöver, C., and van den Hove, S.: Adding "iterativity" to the credibility, relevance, legitimacy: a novel scheme to highlight dynamic aspects of science-policy interfaces, Environ. Sci. Policy, 54, 505–512, https://doi.org/10.1016/j.envsci.2015.02.016, 2015.

Stuart, D., Schewe, R. L., and McDermott, M.: Reducing nitrogen fertilizer application as a climate change mitigation strategy: understanding farmer decision-making and potential barriers to change in the US, Land use policy, 36, 210–218, https://doi.org/10.1016/j.landusepol.2013.08.011, 2014.

Stuart, D., Denny, R. C. H., Houser, M., Reimer, A. P., and Marquart-Pyatt, S.: Farmer selection of sources of information for nitrogen management in the US Midwest: Implications for environmental programs, Land use policy, 70, 289–297, https://doi.org/10.1016/j.landusepol.2017.10.047, 2018.

Stumpf, R. P., Johnson, L. T., Wynne, T. T., and Baker, D. B.: Forecasting annual cyanobacterial bloom biomass to inform management decisions in Lake Erie, J. Great Lakes Res., 42, 1174–1183, https://doi.org/10.1016/j.jglr.2016.08.006, 2016.

Upadhaya, S. and Arbuckle, J. G.: Examining factors associated with farmers' climate-adaptive and maladaptive actions in the U.S. Midwest, Front. Clim., 3, https://doi.org/10.3389/fclim.2021.677548, 2021.

Wiggins, A., Young, A., and Kenney, M. A.: Exploring visual representations to support data re-use for interdisciplinary science, Proc. Assoc. Inf. Sci. Technol., 55, 554–563, https://doi.org/10.1002/pra2.2018.14505501060, 2018.

Yin, R. K.: Case study research: design and methods, 5th ed., Thousand Oaks, CA, 2009.