Meeting the Drought Information Needs of Midwest Perennial Specialty Crop Producers

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ABSTRACT: Agricultural production in the U.S. Midwest is vulnerable to drought, and specialty crop producers are an underserved audience for monitoring information and decision-support tools. We investigate the decision-making needs of apple, grape, and cranberry growers using a participatory process to develop crop-specific decision calendars. The process highlights growers' decisions and information needs during the winter dormant, growing, harvest, and postharvest seasons. Apple, grape, and cranberry growers tend to be concerned with the effects of short-term drought on current crop quality and quantity, while also considering the long-term drought effect on the health of perennial plants and future years' production. We find gaps in drought information particularly for tactical and strategic decision-making. We describe the use of decision calendars to identify points of entry for existing drought monitoring resources and tools, and to highlight where additional research and tool development is needed.

SIGNIFICANCE STATEMENT: While drought causes agricultural losses in the U.S. Midwest, more is known about the impacts and decision-support needs of commodity row crop growers in the region than those of perennial specialty crop growers. We find opportunities for climate information providers to tailor drought information delivery to perennial fruit growers according to the season, the parameters that are relevant to their decisions, and the timeframe of information needed for operational, tactical, and strategic decision-making.

KEYWORDS: Social Science; North America; Adaptation; Agriculture; Climate services; Communications/decision-making; Decision-making

1. Introduction

Midwestern U.S. agricultural producers are experiencing rising temperatures, changes in the seasonality of precipitation, and increased heavy rain event frequency and severity (Angel et al. 2018). While climate projections indicate a generally wetter region in the future, flash drought events are also likely to occur more frequently (Kistner et al. 2018). When drought does occur, agricultural losses are significant. Between 1989 and 2016, drought was the primary driver of crop loss in the Midwest (Reyes and Elias 2019). The 2012 drought alone contributed to the largest financial losses seen by Midwestern agricultural growers in the last 30 years (Kistner et al. 2018). Agricultural producers in the region suffered drought losses again as recently as 2018 and 2020 (Guinan 2018; Eller 2020).

Drought early warning is a critical need of agricultural producers in the region. Dominated by corn and soybean production systems, commodity row crops tend to be the focus of regional monitoring and impact information and resources, while other cropping systems may receive less attention. For example, U.S. Department of Agriculture (USDA) National Agriculture Statistics Service (NASS) crop updates and media generally center on major commodity crops in their reporting (https://www.nass.usda.gov/Publications/National_Crop_Progress/), and substantial investments have been made in the public and private sectors to develop climate-related decision-support tools and resources to meet the needs of corn and soybean growers (Fox 2013; Haigh et al. 2018; Prokopy et al. 2017).

Midwest specialty crops, such as tree fruits and nuts, vegetables, and perennial vines (Johnson 2017), are less often considered when documenting drought impacts or developing monitoring and decision-support tools. Yet specialty crops are produced by approximately 42 000 Midwest farms on almost 650 000 ha of agricultural land, accounting for over 7% of farm operations in the region though only about 1% of the agricultural land (USDA NASS 2019). Specialty crop growers manage multiple sources of risk, including substantial climate risk (Han et al. 2022). Specialty crops are especially vulnerable to weather variations, pests, and diseases. Production is labor intensive and time and weather sensitive, and traditional risk management tools (i.e., insurance) are less commonly used than by commodity crop growers (Belasco et al. 2013; Andresen and Baule 2018; Zhao and Yue 2020).

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While many growers depend upon irrigation to manage risk related to drought, approximately 36% of Midwest specialty crop acreage is nonirrigated (USDA NASS 2019). Even for specialty crop acres that are irrigated, crop water demand may not be matched by water availability at critical times of the year (Kistner et al. 2018). Perennial crops' growth, temperature regulation, and evaporative cooling needs can result in daily water requirements that exceed that of annual row crops (Andresen and Baule 2018). A recent study indicates that water demands and weather/climate impacts, and their associated effects of amplifying variability in produce quantity and quality, are priority areas of concern for specialty crop production in the Midwest (Johnson and Morton 2015).

To improve specialty crop growers' capacity for managing climate risks such as drought, they need access to climate monitoring and prediction information that informs and supports their specific concerns and needs (Kistner et al. 2018). If information is not tailored to specialty crop growers' decision-making contexts, it will likely not be perceived as relevant or salient (Lemos et al. 2012; Mase and Prokopy 2014; Haigh et al. 2015). For example, specialty crop growers may struggle to use drought early warning information because of the spatial scale of the information. Specialty crop production systems tend to include multiple crops grown on relatively small size fields (Zhao and Yue 2020), making county- or watershed-level monitoring and prediction data potentially too coarse for their decision-making purposes.

A larger question is how drought early warning information fits into the decisions that specialty crop growers must make. Specialty crop production can differ from commodity row crop production in terms of both the type and timing of decisions needed to achieve success, and the metrics of crop success themselves. Yield parameters and a few general quality characteristics may be of primary interest for commodity crop production. For specialty crops, timing of crop maturity and harvest and quality factors such as sugar content, color, visual appearance, flavor, and texture may be as critical to growers' financial success as yield. Accounting for these parameters requires different management considerations with more complex relationships with climate (Walthall et al. 2013; Ahmed et al. 2016). Dry conditions may have beneficial effects on crop quality while having differing effects on current and future yield, which adds complexity to drought impact prediction. In addition, the management of perennial specialty crops must consider the crops' plant physiology and lifespan. Whereas annual row crop producers focus on a 1-yr yield, perennial crop producers make decisions that affect plant productivity for up to 20–30 years or more (Andresen and Baule 2018).

Knowledge about the usability of drought early warning information within the decision-making parameters of specialty crop production is limited, and Kistner et al. (2018) calls for additional research to fill this gap. This paper seeks to inform climate information providers and tool developers about decision-making processes and drought risk related to three important Midwestern perennial specialty crops. We take an exploratory approach to identify opportunities where the climate information scientific community might partner with specialty crop growers to dig deeper into specific needs and codevelop usable tools that support this important industry. We examine where current sources of information are available to meet growers' decision-making needs to highlight where gaps might be found. Our research questions include the following:

- What are the key decision points of selected perennial specialty crop growers in the Midwest, and what are the risks presented by drought to the success of their decisions?
- What are their associated needs for drought and climate information to manage risk?
- Which existing drought monitoring tools align with specialty crop growers' needs? Are there gaps?

This study focuses on specialty cropping systems producing cranberries grown for commercial markets, and apples and grapes primarily grown for local processing and consumption. These examples, while not exhaustive of economically important specialty crops in the region, provide a look at the potential diversity in perennial specialty crop producer decisions and information needs, and the associated seasonality of decisions and information needs.

We approach these questions through the development of crop-specific decision calendars. A decision calendar depicts management decisions made in specific months and the climate factors that affect those decisions throughout the year (Takle et al. 2014). Recognizing that many decisions are made on a cyclical, annual time frame, decision calendars incorporate agricultural decisions that take place at multiple time scales, including operational decisions (i.e., actions that will be carried out in the next few days) and tactical decisions (i.e., actions carried out in future weeks or months) (Hollinger 2009). Some decision calendars, including Takle et al.'s (2014), also address strategic decisions (i.e., actions carried out in future seasons or years). Strategic decision-making is more difficult to depict in the traditional circular annual calendar, but the decision calendar building process itself is useful for delineating strategic from tactical and operational decisions.

Crop development and management calendars have been applied to various decision-making contexts, including a USDA Foreign Agriculture Service series of monthly crop stage calendars for major global commodity crops, highlighting general regions where crops may be sensitive to precipitation or temperature stresses at specific times of the year (https://ipad.fas.usda.gov/ogamaps/cropmapsandcalendars.aspx). In the U.S. Corn Belt region, the Takle et al. (2014) decision calendar helped to guide development of a number of publicly available climate tools (Prokopy et al. 2017). Cropping-system decision calendars may also inform management approaches to future conditions under specific climate change scenarios (Ahmed et al. 2016; Janowiak et al. 2016) and link traditional and cultural knowledge and practices with climate data to facilitate education and knowledge coproduction (Chambers et al. 2020). In the present study, we use the development of decision calendars to identify entry points for climate information providers to deliver tools that are relevant and usable for growers.

TABLE 1. Two peer-reviewed processes for decision calendar development.

Ray and Webb (2016)	Takle et al. (2014)
Identify decision-makers and stakeholders	Identify who is making the decisions
	Identify what types of decisions and when
Document decisions, climate information needs, and timing	Identify when a weather condition is of concern and when impacts might occur
	Identify which meteorological variable(s) relate to the consequences of the decision
Organize the information into a decision calendar	Identify which applications are highly site specific vs regional or global
	Identify which other factors or types of information may affect the decision besides climate
Continue engagement with stakeholders to confirm and refine	Identify what level of accuracy is necessary to improve decision-making
	Identify how uncertainty metrics are interpreted and used by decision-makers

2. Methods

a. Study region

The project targets three distinct regions of the midwestern United States: central Iowa, central Missouri, and central Wisconsin, to investigate the decision-making timelines and drought monitoring needs of perennial specialty cropping systems.

While the state of Iowa is geographically and economically dominated by corn and soybean crop production, an increasing number of farmers are growing specialty crops including apples for on-farm marketing and grapes for wine production ("Iowa commercial horticulture survey results"; A. Enderton et al. 2017, unpublished material; contact author at arlene@iastate.edu for source). Historically, the state was a significant producer of both grapes and apples, though land devoted to these crops declined by the mid-1900s (A. Enderton et al. 2017, unpublished material). Iowa apple acres have grown recently along with consumer interest in locally produced fresh produce as well as value-added products such as hard cider (Kolbe 2019). Iowa grape and wine production also saw a resurgence in the early 2000s (Iowa Wine Growers Association 2020). The 2017 Census of Agriculture shows 2761 acres (1 acre ≈ 0.4 ha) of land in all orchards in Iowa, with only 294 acres irrigated (USDA NASS 2019). The economic impact of Iowa grape production was calculated at $420 million in 2012 (Frank, Rimmerman, and Co. 2014) and $1.6 billion in 2017 (https://wineamerica.org/impact/). Whereas grape and apple crops are less likely than many other specialty crops to be grown under irrigation, fruit quality in both crops is highly dependent upon precipitation (Kistner et al. 2018).

Grapes and apples are commonly grown in Missouri as well, along with a wide variety of mixed vegetables and fruit for commercial production and/or farmers markets (Roach et al. 2017). The 2017 Census of Agriculture shows 14 739 acres of land in orchard crops in Missouri, with only 2966 acres irrigated (USDA NASS 2019). The wine grape wine industry is larger in Missouri than Iowa, with an estimated annual economic impact of $1.76 billion in 2013 (Frank, Rimmerman, and Co. 2015) and $3.2 billion in 2017 (https://wineamerica.org/impact/). Missouri was included in the study partly because of recent experience with extreme drought in 2018. Missouri specialty crop growers were able to reflect upon their recent experience and information needs from that summer.

Wisconsin is a major production region for several specialty crops, including cranberries. The state produces approximately 60% of the nation's cranberry crop (Kashian and Peterson 2013). Cranberries are Wisconsin's leading fruit crop in terms of both acreage and economic value, with an annual economic impact to the state of nearly $1 billion (Wagener 2018). The 2017 Census of Agriculture shows 23 172 acres of berry production in Wisconsin (USDA NASS 2019), and these acres are largely in cranberry production (Kashian and Peterson 2013). Central Wisconsin's sandy, acidic soils support the needs of cranberries, which are grown largely in engineered bogs that require heavy use of water (flooding) of cropland for harvesting and management (McCoy 2020).

b. Approach and methods

Our approach draws on two methods for decision calendar development offered by both Takle et al. (2014) and Ray and Webb (2016) (Table 1). First, the decision-makers and the nature and timing of necessary decisions are defined. When and where drought is expected to occur must be identified next, in addition to relevant meteorological variable(s) and climate information needs. The information is then organized into draft decision calendars, refined iteratively with stakeholders representing the decision-makers as well as cropping-system specialists and climate scientists.

We used an interdisciplinary approach to data collection, analysis, and interpretation. The project team consisted of social scientists, engagement specialists, agricultural systems experts, and climate researchers and information providers. Data used to build the decision calendars were gathered through reviews of literature on perennial crop production and climate concerns, engagement of an expert advisory committee, and individual and focus group interviews with growers and cropping-systems experts. The crop production literature reviewed for the project included production guides, university extension publications, and other relevant agronomic resources identified in online searches and by the stakeholder advisory group. Crop-specific guides were reviewed for Midwest apple production (Hinman and Ames 2011; Warmund 2002; Morton et al. 2017b), grape production (Byers et al. 2003; Dami et al. 2005; Fiola 2020; Morton et al. 2017a; Read and Gamet 2017), and cranberry production in Wisconsin and eastern U.S. growing regions (Roper 2007, 2006; Sandler and DeMoranville 2008).

Project investigators recruited an expert advisory committee of 10 university extension educators and industry leaders to represent a variety of specialty crop systems in the three geographic locations. The advisory committee met virtually four times prior to the focus group interviews to discuss drought-related concerns of the specialty cropping systems, clarify the purpose of the project to identify grower needs for drought early warning detection, discuss use of decision calendars to gather information, develop focus group interview protocols, and identify and recruit participants for the focus group interviews. After the focus group interviews, the expert advisory committee was again essential in helping project investigators interpret and verify the data that had been collected.

Individual and focus group interviews were used to gather data from growers and advisors who work closely with growers. We used focus group interviews as our primary data collection method to allow growers to talk with each other about what they are seeing and doing in terms of weather and climate challenges (Cameron 2005). The objectives of the focus group interviews were 1) to identify important decisions and the timing of these decisions that could lead to producers' desired production outcomes during drought and 2) to investigate the spatial and temporal resolutions of drought information required by specialty crop growers to make more informed management decisions. Focus group interviews were conducted with small groups of growers and advisors in Ankeny, Iowa; Hancock, Wisconsin; and Columbia, Missouri in February and March of 2019. These in-person sessions were supplemented with telephone and email interviews to gather additional data and clarify data gathered in person. Through these two processes, we interviewed four perennial fruit extension educators who work with grape and tree fruit production, six wine grape growers, four apple/tree fruit growers, and three individuals who worked in cranberry production and industry. The wine grape growers and apple/tree fruit representatives were small-scale growers producing for local or direct markets. The cranberry production representatives worked with growers who produce for national processing companies.

To establish shared expectations of the focus group interviews, investigators began each session by presenting example decision calendars that had been developed for other crops such as commodity corn production and describing how the process had resulted in better understanding of needs and development of new climate information tools and resources. Investigators then facilitated interactive group interviews according to seasonal concerns and decisions, with the following open-ended guiding questions:

- What were your concerns during this season?
- How do drought conditions play a role in these concerns?
- What decisions are you making related to your concerns?
- What are the best and worst possible outcomes of managing this concern?

Participants were encouraged to respond to, and build upon, each other's comments, providing a sense of consensus and/or caveats to the comments (Cameron 2005).

Focus group interview participants were also invited to reflect upon a few currently available drought early warning tools and maps [including the U.S. Drought Monitor (USDM; https://droughtmonitor.unl.edu), evaporative stress index (ESI; https://hrsl.ba.ars.usda.gov/drought/index.php), and QuickDRI (https://quickdri.unl.edu)], as well as experimental field-scale ESI maps (30-m resolution) capable of depicting moisture stress at the subfield-scale. Participants were asked to reflect on how the resolution of information might affect their ability to make decisions. We did not discuss specific forecast or outlook products or ask participants to describe their needs with such products in terms of forecast skill. The focus group interviews were semistructured and followed participant interests, so not every question received the same level of attention in each session. The Missouri focus group interview spent more time discussing participants' experiences with the recent 2018 drought was categorized as "extreme" by the USDM category in late July, whereas the Iowa and Wisconsin focus groups tapped participants' memories of the 2012 drought, which was categorized as "extreme" by the USDM in mid-July, to address research questions.

Project team members captured the discussion in notes and tables. We used multiple note takers (project investigators and collaborators) at the group interviews to ensure that any disparities in how comments were interpreted could be identified and discussed after the interviews. Interview data related to drought concerns, impacts, and the timing of management decisions and crop development were summarized and organized into tables and categorized by the relevant month or season. The data tables were reviewed, classified, and interpreted through an iterative, participatory process involving project investigators, stakeholder advisory committee members, and additional experts interviewed as mentioned above (Jackson 2008). Follow-up interviews with cropping-system experts did not follow one specific script, but rather were guided by questions that emerged throughout the classification and interpretation stages of data analysis. The expert advisory committee reviewed the findings and provided additional information as needed to clarify and verify the data. The discussion section of this paper consists of the authors' reflections, rather than interview participants' input, on information and tools that are currently available and where needs appear to be unmet.

3. Results

At the time of the focus group interviews (early 2019), specialty crop growers were more concerned with wet conditions than dry. Only the Missouri growers had experienced recent drought. However, as each focus group interview proceeded, growers were able to identify concerns related to drought

TABLE 2. Apple growers' drought concerns, decisions, types of decisions, and information needs by season.

Month	Drought concern	Operational decisions	Tactical decisions	Strategic decisions	Information sought
Dec–Jan	New tree establishment; long-term tree genetics		Ordering new trees	Choosing varieties	Will this year be dry? What are the long-term trends?
Mar	Young tree health and susceptibility to disease		Planting new trees, staking, and trellising		Will this spring and summer be too dry to support young trees?
Mar–May	Pollination; decrease pest and disease pressure	Timing of pollination, pest and disease treatments, and fertilizing			When will conditions be optimal for field work?
Jun	Current crop fruit size and number;		Thinning flower clusters and/or irrigating		Will this spring and summer be too dry to support full crop?
Jun–Aug	Risk of fungal disease; susceptibility to borers	Pest control			Do current conditions indicate problems?
Jun–Jul	Next year's crop and tree/root size; access to irrigation water, and expense			Pruning young trees, thinning fruit, and irrigating	Will drought continue? Do I need to irrigate? Is water available?
Aug	Fruit quality		Harvest and marketing decisions		Is drought severe? Will it continue?
Sep–Nov	Grass/cover, crop germination, and fertilizer uptake	Timing of tillage, seeding, and nutrient and pH management	Cover crop/grass varieties; fertilizer amount		When are conditions optimal for field work? Will autumn and winter be dry?
Oct–Nov	Extreme cold during drought may damage tree roots		Irrigating and/or mulching prior to the ground freezing		Are soils dry going into winter? Is it going to be a snowy winter? Cold?

impacts and decision-making. Their comments underscored the risk of drought to specialty crop production and opportunities for tailoring monitoring information to their specific needs. Crop-specific decision calendars highlighting growers' drought concerns, decisions, and questions or information sought are summarized in Tables 2–4. Figures 1–3 visualize the cyclical nature of the annual decision calendar and the entry points for drought/climate information. For reporting purposes, growers' drought concerns, key decision points and emergent information needs are categorized by season: dormant, growing, ripening/harvest, and postharvest seasons, as well as longer-term decisions and needs. Study results and a discussion of implications for climate service delivery are described below.

a. *Dormant season*

For perennial specialty crops, the dormant season between leaf drop in the autumn and bud break in the spring is a time for making tactical and strategic decisions. Growers are making decisions about ordering new fruit trees or grape/cranberry vines, planning annual budgets, and repairing and maintaining equipment. These decisions require growers to make assumptions about the climate over the upcoming growing season and beyond.

The success of many decisions at this time depends upon climate conditions over the upcoming growing season. For example, growers may over or underspend on fungicides, miss a window to make irrigation equipment improvements, or find that newly planted trees or vines suffer, if their expectations of the year ahead do not match reality. Without guidance, growers' expectations of upcoming seasons may be influenced by what they experience during the dormant season, though there is little climatological evidence that a dry winter will linger into spring or summer in this region (Hoell et al. 2021). Therefore, growers' decisions could be improved using information that helps them look ahead over the full season.

The outcomes of budgeting, equipment, and planting decisions may also be affected by multiyear to decadal climate patterns. For example, decadal trends in precipitation affect the cost–benefit trade-off of new irrigation equipment or how well specific fruit varieties will perform for years to come.

TABLE 3. Grape growers' drought concerns, decisions, types of decisions, and information needs by season.

Month(s)	Drought concern	Operational decisions	Tactical decisions	Strategic decisions	Information sought
Jan	Budgets for disease control and irrigation		Planning annual budget	Investments that affect long-term success	Will this year be wet/dry? What are the long-term trends?
Mar	Young vine health/survival		Planting new vines		Will spring and summer be too dry to support young vines?
Apr	Lowered risk of fungal disease	Timing of disease/weed control.	Strategy for disease control		When will conditions be optimal for field work? Will summer be wet or dry?
May	Plants support fewer fruit clusters		Thinning fruit clusters		Will this summer be too dry to support full crop?
May–Jun	Restricted vegetative growth (good); harm to buds of next year's crop		Thinning leaves; irrigation as necessary		Are soil moisture conditions adequate? Changing?
Jun–Jul	Lessens disease and weed pressure	Timing of disease/weed control	Planning for harvest and labor needs		When are conditions optimal for field work? How hot and dry will it be over the coming month(s)?
Aug	Fruit quality; pests from neighboring crop fields; harvest timing	Timing of harvest			How are heat/dryness affecting sugar-to-acid ratio?
Sept–Nov	Getting autumn weed control and planting done; cover crop establishment	Timing of weed control and planting	Choice of cover crops		When are conditions optimal for field work? Will autumn/winter be wet or dry?
Oct–Nov	Extreme cold during drought may damage vines and roots		Irrigating and/or mulching prior to the ground freezing		Are soils dry going into winter? Is it going to be a snowy winter? Cold?

Such strategic decisions could be improved with information that helps growers consider the likelihood of best-case and worst-case scenarios in the future.

b. *Growing season*

The occurrence of drought during the growing season affects pests and diseases, fruit size and quality, how quickly fruit ripens, and also the development of the following year's fruit crops. Drought conditions can develop very quickly during the spring and summer when the atmospheric evaporative demand is higher than normal due to a prolonged period of hot temperatures, sunny skies, low relative humidity, and strong winds. When this weather pattern is accompanied by little to no rainfall, it can lead to flash drought development where vegetation health rapidly deteriorates over several weeks (Otkin et al. 2013, 2018). Flash droughts have been common within the central United States during the past several decades (Christian et al. 2019 2021), while multiyear droughts have not recently been as common as in other regions of the United States (Hoell et al. 2021). Growers may benefit from monitoring quickly emerging drought conditions and vegetation stress for decisions to alleviate drought impacts on new plantings, thinning, crop management, and irrigation.

1) CARE OF NEW PLANTINGS, THINNING

Early in the growing season, growers' decisions about planting and care of new trees or vines and thinning flowers, leaves, and fruits become more operational and tactical. While established fruit trees and grapevines are fairly resilient to drought, newly planted trees or vines may not survive an extremely dry year or may be susceptible to diseases that affect their productivity for years. If current conditions and forecasts indicate worsening drought, growers may adjust planting plans or plan to irrigate extensively to establish the plants. Cranberry growers are concerned about desiccation of young vines as well as established

TABLE 4. Cranberry growers' drought concerns, decisions, types of decisions, and information needs by season.

Month(s)	Drought concerns	Operational decisions	Tactical decisions	Strategic decisions	Information sought
March–May	Vine desiccation risk	Remove winter flood, but short flood to protect plants			Is there a risk from dry, windy weather? Do I have adequate water?
June	Preferable for pollination	Timing of pollination			When are temperature and precipitation optimal for pollination?
Jul–Aug	Scald on berries and other quality issues	Sprinkler irrigation before onset of heat			What is temperature and precipitation short-term forecast? (e.g., daily to weekly forecasts)
Jul–Aug	Pathogens, insects, disease pressure, and size of berries	Irrigation to cool vines	Irrigation to maintain water table within bog		Are soil moisture conditions adequate? When should irrigation begin and end?
Aug–Oct	Decreased water reserves available for harvest; harm to buds of next year's crop		Planning harvest strategy	Irrigation for vine/ bud health	Do I have adequate water for irrigation and harvest? What is hydrologic outlook?
Oct–Nov	Vine stress from warm water	Speed and timing of wet harvest			What is water volume and water temperature?
Nov–Dec	Adequacy of reservoirs for winter flooding		Applying winter flood once temperatures are consistently cold		Are water stores adequate? What is temperature outlook?

plantings early in the spring when dry, windy weather is prevalent. They may irrigate or reflood bogs to protect plants. These decisions indicate a need for information about the adequacy of soil moisture, short-term precipitation and wind forecasts (e.g., daily to weekly forecasts), flash drought monitoring to indicate quickly changing conditions, and seasonal drought outlooks tailored to the requirements of young perennial tree/vine establishment.

Apple and grape growers thin new growth on new and established vines/trees at multiple points throughout the season. Grape growers begin thinning clusters in the spring as the plants go through flower formation and fruit set. Severe drought may cause plants to support fewer fruit clusters, in which case growers would want to thin more heavily than normal at this point in the season. Apple growers also prune young trees and thin flower clusters and fruit in part according to moisture expectations, since drought conditions can affect the size and number of fruits in the current crop. Later in the season, grape growers also thin leaves to improve air circulation and light penetration to fruit clusters. Moderately dry conditions are desirable for restricting vegetative growth of plants while still supporting fruit yield and quality, lessening the labor associated with thinning and increasing confidence of a successful crop. Current conditions, along with expectations of summer precipitation, may guide decisions about the extent of thinning flowers, fruits, and leaves in these crops.

In the short term, thinning leaves and/or fruits influences the size and quality of the fruit produced, but in the long run it also strategically protects the health of vines and trees. The fruit buds of next year's crop begin to develop over the summer, so growers' decisions have ramifications for multiple years. One grape grower said,

> In the vineyard this can help keep vines healthy, keep balanced, not over-crop, [and] promote long term health of the vines if our goal is to make them be healthy for 40 years. It will improve our quality if we don't ask the vines to overproduce based on climate.

Growers of perennial crops are concerned not only with the current growing and harvest season, but are also hoping for success in future years, and would benefit from information that helped them make those decisions.

2) POLLINATION AND PEST/DISEASE CONTROL

Growers are not too concerned with drought conditions affecting their pollination and pest and disease control strategies.

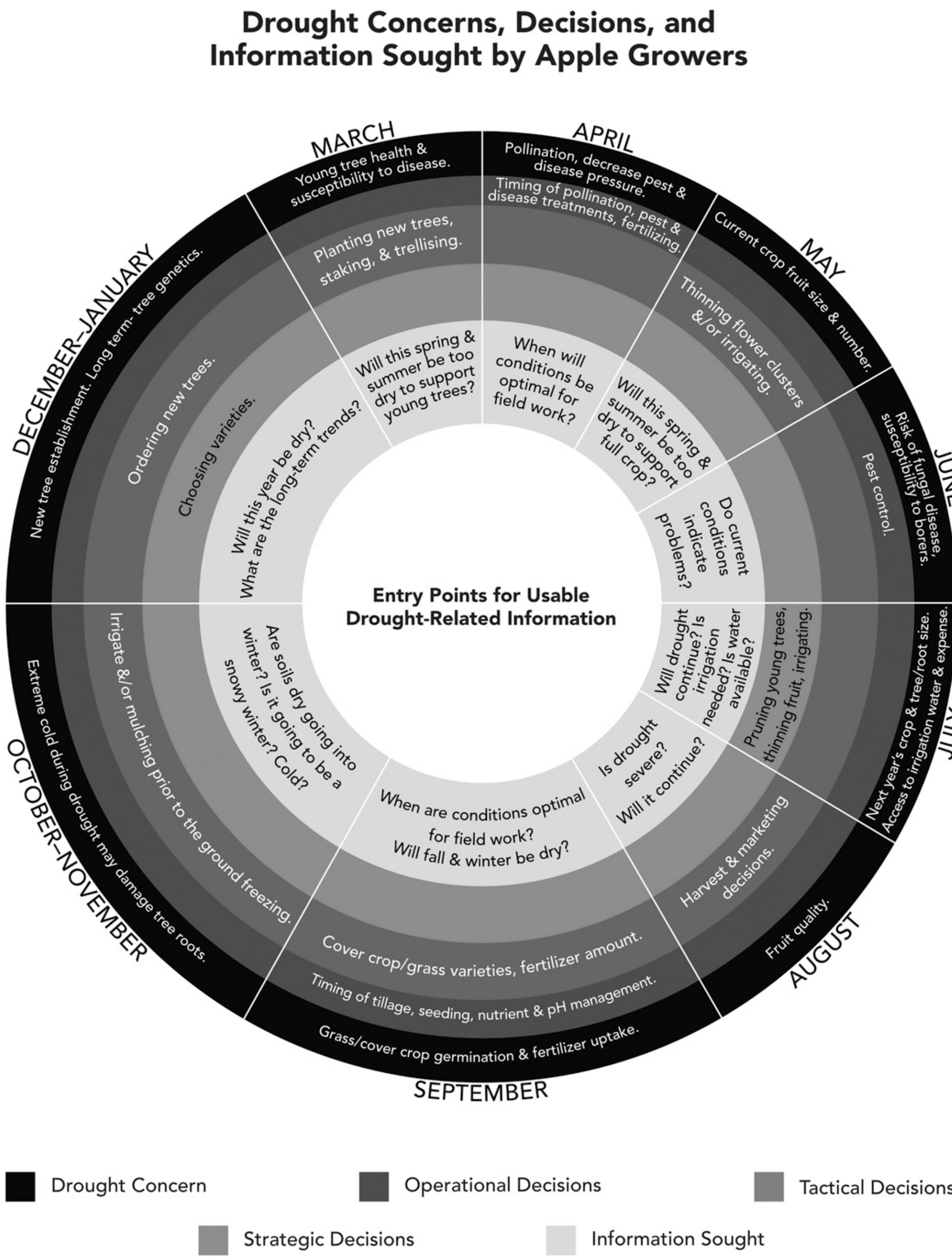

FIG. 1. Graphical decision calendar of Midwest apple production during a drought year.

Warm and dry conditions are better for pollination than cool and wet, so growers may monitor precipitation and temperature when timing the use of bee colonies for pollination. Dry conditions are also generally desirable during the growing season from a pest, disease, and weed pressure perspective, though in some cases, drought stress may predispose plants to insects or disease. Growers using integrated pest management and in states with more intense fruit production may currently have fairly sophisticated weather and climate decision-support resources [e.g., Michigan's Enviroweather (https://legacy.enviroweather.msu.edu/about.php) resources], though growers outside of those areas may not.

3) Crop management and irrigation

For cranberry growers, irrigation is an integral aspect of production. Growers set irrigation pipes in spring and begin

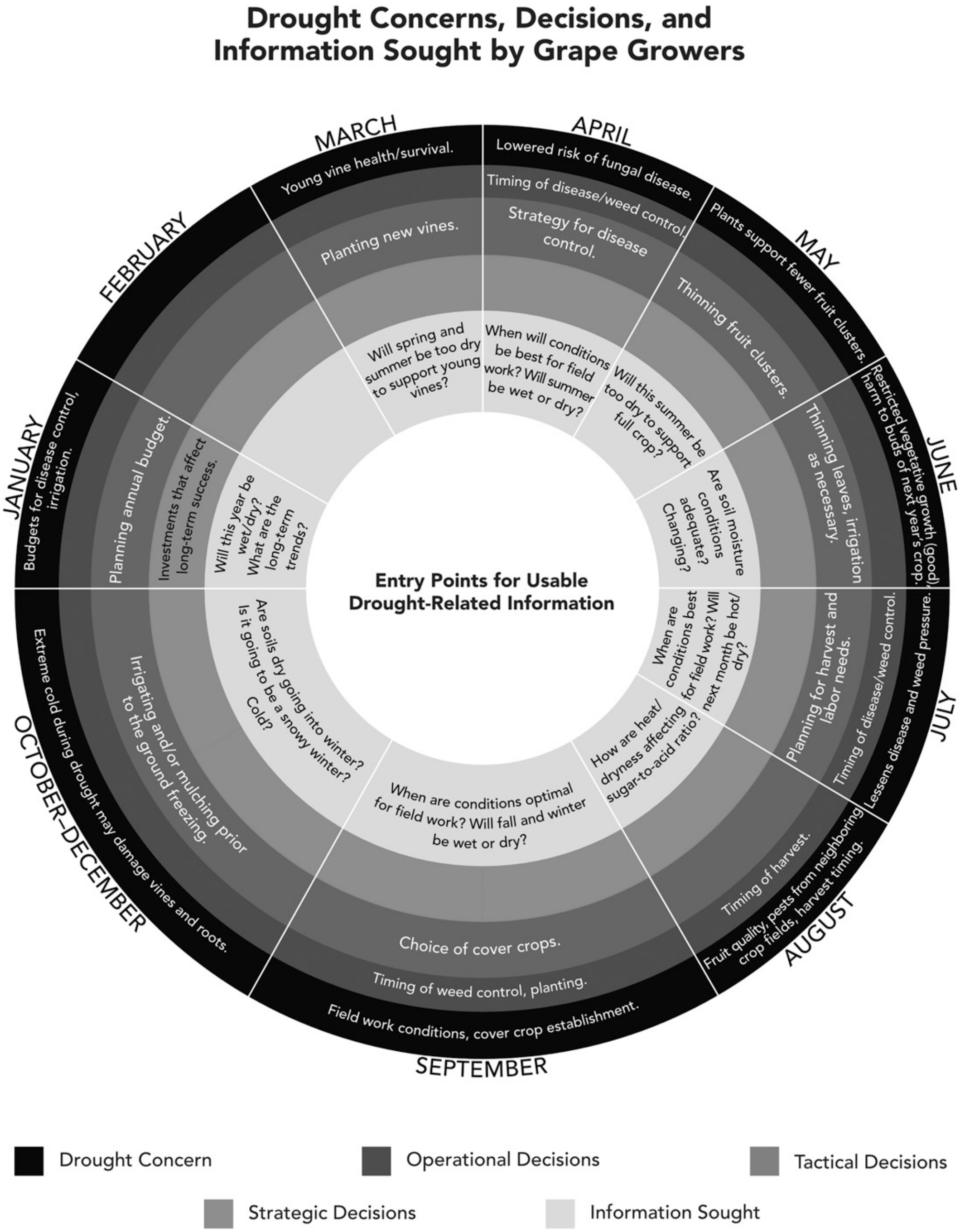

FIG. 2. Graphical decision calendar of Midwest grape production during a drought year.

using irrigation early to protect the crop from frost damage and support young vine establishment. Berry yield is highly sensitive to soil moisture availability, and hot and dry conditions lead to scald on cranberries and other quality issues. In addition, drought-stressed vines are vulnerable to pathogens, insects, disease pressure, and damage to the buds that are developing for the following year's cranberry crop. Cranberry beds are not flooded during the growing season (except as short floods for pest control); rather, growers rely upon precipitation, irrigation, and water table manipulation to support vine health and fruit productivity and quality. Growers use drainage ditches and tile to maintain an optimal water table, and also rely upon sprinkle irrigation to water and cool the cranberry vines and prevent berry scald. To prevent scald, water must be applied to beds before the onset of heat, so short-term temperature forecasts (e.g., daily to weekly

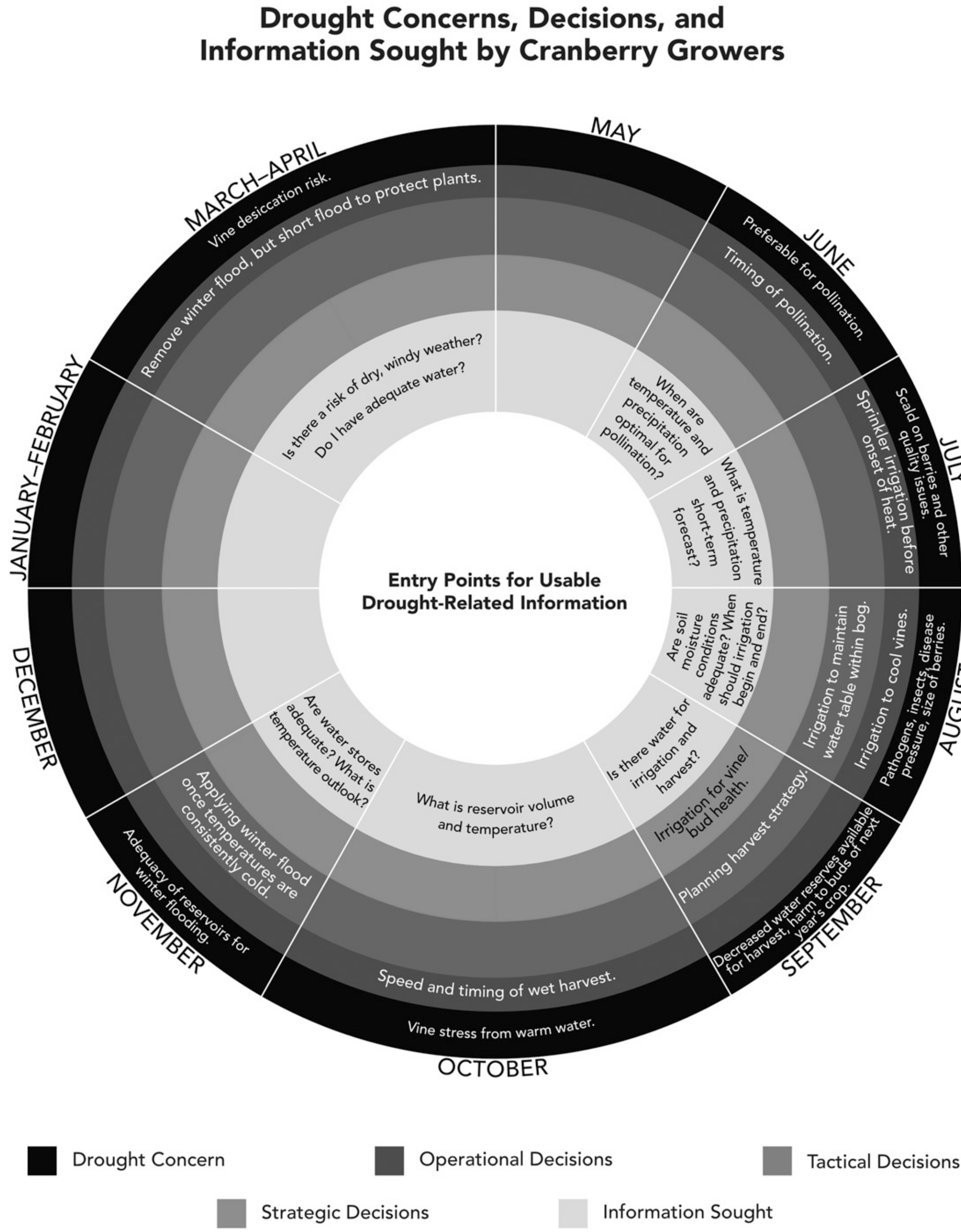

FIG. 3. Graphical decision calendar of Midwest cranberry production during a drought year.

forecasts) can help growers act proactively. In situ soil moisture monitors are used to maintain optimal soil moisture or water tables in the beds. Evapotranspiration monitoring could also alert growers to potential problems. During severe or prolonged drought, growers may also need to monitor irrigation water availability.

Apple and grape growers use irrigation in a strategic way to support long-term tree and vine health. Young tree or vine plantings are more sensitive to drought than older plantings and require irrigation throughout a dry summer to become established. The growers we interviewed irrigated established trees/vines only enough to keep them alive and healthy, though others rely on irrigation to support fruit production targets. Soil moisture is important for apple tree and root system size. Young apple tree shoots grow throughout much of the growing season, while trunk enlargement and root growth happen later in the summer and autumn. In dry years, some smaller-scale growers may be forced to use city water for irrigation, adding significant expense to the year's budget. Growers in Missouri indicated that they were limited by pond water resources, which became depleted during the 2018 drought. Irrigation decisions may be based on soil moisture conditions, evapotranspiration rates, and stress, as well as irrigation water availability.

c. *Ripening and harvest season*

Flash drought, though less likely to develop during the autumn months than spring or summer (Christian et al. 2019), can affect grape and apple crop quality during ripening and harvest. In the weeks leading up to grape harvest, heat and precipitation quickly affect the sugar-to-acid ratio and fruit weight, and growers need to carefully time the fruit harvest to achieve their production targets. Further, during drought, pests from nearby conventional row crop fields may move into vineyards and become a problem for wine quality. Growers may make plans about the timing of harvest (including hiring the labor force to carry out the harvest) by midsummer, but they may have to adjust these plans quickly to respond to rapidly changing conditions. One producer said,

> fruit [grapes] starts ripening in July. If there's no chance of rain [over the coming weeks or month], our sugars will accumulate extremely fast. Harvest dates will be likely to be sooner. [That does] screw up the harvest parameter because of the sugar to acid ratio. Wine will be really alcoholic. [I have to decide], do I let it hang longer to hit certain parameters.

Growers are looking at quickly changing conditions related to heat and precipitation.

As apple growers begin planning harvest and marketing, they are concerned about the effects of drought during last two months before harvest on the quality of the fruit (e.g., starch accumulation, calcium deficiency, color development, and timing of fruit drop). In Missouri, the 2018 drought affected apple crop quality to the extent that one grower reported that their crop was unmarketable. Thus, apple growers may be watching for fast-developing drought conditions as well as effects on crop quality for making necessary adjustments to marketing plans.

Although cranberries are not harvested until later in the autumn (October–November), growers may be watching conditions throughout the late summer and early autumn as they look ahead to their harvest season. Prolonged hydrological drought may decrease the water reserves that are available for cranberry harvest. Fruit for processing is typically wet harvested in fields flooded with 8–10 in. (20–25 cm) of water. The speed and timing of wet harvest depends partially upon the temperature of water reserves, which may be affected by drought conditions. If water reserves are inadequate, growers must adjust their harvest plans. They may have to harvest smaller areas with available water and move from area to area, which can lead to lost production. In addition, warmer water temperatures can stress vines, and harvest may need to be moved to times of the day when water reserves are cooler. Thus, growers are interested in both volume and temperature of local water reserves.

d. *Postharvest season*

After harvest, grape, apple, and cranberry growers are concerned with replenishing soil moisture, recharging aquifers and reservoir levels, and protecting plants and roots from large temperature swings. First, however, they need to undertake autumn fieldwork.

1) FIELDWORK

Grape and apple growers are watching precipitation as they engage in autumn weed control and other field work such as tillage, seeding grass or cover crops, and nutrient and pH management. They may hope for dry weather to complete field work, but then for moisture to establish and maintain cover crops/grass as well as overall vineyard/orchard health. Climatologically in the autumn, soils tend to be dry, having been depleted by crop and plant growth during the summer; however, the region has seen trends for increasing autumn precipitation (Easterling et al. 2017).

2) PROTECTION OF DORMANT PLANTS AND PREPARATION FOR NEXT GROWING SEASON

After harvest, cranberry growers prune vines and clean ditches in preparation for winter flooding and sand application. For cranberry growers, extended severe drought can be a problem if water reserves are not sufficient for flooding the fields to protect the vines from extreme cold. Autumn precipitation is important for building water reserves that will be necessary for winter flooding of cranberry bogs. As noted above, growers can count on some degree of hydrologic recovery in most years, as climate trends show increases in autumn precipitation events. During an extended severe drought event, though, full recovery is less likely. Winter precipitation is another driver of hydrological system recovery, as snow accumulation runs off during the spring snowmelt, directly replenishing streams and reservoirs for the following year.

Late autumn/early winter is also an important time for ensuring that apple trees and grape vines overwinter successfully. Dry soils and cold temperatures allow frost to penetrate lower in the soil profile, injuring the roots of the plants. If autumn rains fail to recharge soil moisture profiles, growers might make decisions about irrigating extensively before the ground freezes, and/or adding mulch around plants to protect the roots over the winter. Precipitation has less effect on soil moisture after the ground is frozen, but snow cover provides crucial insulation to limit the depth of soil freezing. Growers need information about current soil moisture and soil temperature conditions to make decisions about irrigating, as well as winter snow and temperature forecasts to assess the potential severity of the situation. Information showing how soil moisture, soil temperature, and accumulated precipitation (including snowfall) are trending may be useful to growers. Trends in current conditions are not a substitute for forecasts or outlooks, but can help growers consider potential problems, particularly because drought conditions typically change more slowly during the dormant season than during the growing season.

e. *Decadal and longer-term timeframes*

Perennial crop growers make decisions that exist outside of the annual decision calendar. Decisions such as which apple or grape varieties to invest in and where to plant them could be made by the grower at any point in the year (e.g., when new research comes out, during a farm tour, or when they receive advertising or catalogs). And the success of these strategic decisions, which will affect their operations for many years to come, ultimately depends upon future water availability and climate trends. In this way, perennial specialty crop growers may consider longer-term drought and climate expectations in ways that annual row crop growers do not. Their interests may extend beyond the timeframe of seasonal or annual outlooks, to historical trends and patterns and decadal and longer-term climate prediction.

f. Scale of information

Focus group interview participants were specifically asked about the potential usefulness of subfield scale information. Many specialty crops are grown in small fields (tens of acres or less) so data at that resolution would more accurately capture their condition. Coarse-resolution information (tens of kilometers to county scale), such as that provided by typical climate-related drought indices, is unable to capture small-scale differences across a field that can be very important for producing a high-quality crop with good yields. We found that perennial specialty crop growers who also grow commodity crops (e.g., corn) said they had access to commercial climate resources and tools that are easier for them to use and more spatially relevant to their operations. Smaller-scale specialty crop growers who do not also raise commodities were interested in subfield scale information, but currently have to rely on more generic data or tools that are less tailored to their specific locations and needs.

4. Discussion

A synthesis of drought-related decisions and questions illuminates some common information needs of perennial specialty crop growers in the Midwest. Growers of perennial specialty crops expressed the need for drought information that supports short-term, or operational decision-making, as well as information that supports longer-term tactical and strategic decision-making. This section describes existing tools and resources that could be used to inform decisions and reduce gaps in information availability or relevance for meeting growers' needs. This section is summarized in Table 5.

a. Operational decisions

From the perspective of weather and climate information provision, operational decision-making requires information that provides current conditions as well as short-term forecasts that predict hourly or daily conditions (Hollinger 2009). Operational decisions include decisions about the timing of pesticide and fungicide application, irrigation rates, and timing of harvest and postharvest activities. Perennial specialty crop growers' needs are not significantly different from annual commodity crop growers needs at this time scale, depending upon current condition monitoring and hourly, daily, and multiday forecasts relative to precipitation, temperature, and wind. This information can be accessed from numerous private companies, the National Weather Service, state and regional climate centers, and other sources. Like other growers working in precision agriculture environments, Midwestern specialty crop growers' operational decisions would benefit from higher-resolution data to target management actions appropriately within fields. Questions of adequacy of forecast skill are beyond the scope of this study, but they are also important to ongoing efforts to improve the usability of such tools.

Operational decisions during the growing season may depend upon evaporative stress and topsoil moisture conditions, which can change quickly and be highly variable across fields. In situ evapotranspiration and soil moisture monitors can improve the efficiency of water use in irrigation and help the grower to conserve water when possible while also protecting plant health and yield. Evapotranspiration estimates from observed data at some mesonet stations and provided during the freeze-free season; however, these in situ observations can be very specific to conditions at the observing site. Producers expressed interest in using spatially continuous, high-resolution satellite- and model-based monitoring tools to monitor changes in vegetation health at the field scale. Advancements in satellite imaging of the land surface have led to the development of newer evapotranspiration-based monitoring tools with high spatial resolution including the ESI (Anderson et al. 2013) and QuickDRI (Brown et al. 2008; Tadesse et al. 2015) datasets containing 4- and 1-km resolution, respectively. Satellite-based monitoring tools track vegetation health with high spatial resolution, showing the cumulative impact of elevated evaporative demand and dry soils. The tools monitor relatively fast changes in vegetation conditions when plants are actively growing and can act as an "alarm" of rapidly developing drought (Otkin et al. 2016). Discussions with growers revealed that it could be very valuable to further develop the experimental 30-m evapotranspiration products to provide real-time monitoring of vegetation health and function. Future work could build upon studies related to commodity crop yield (Yang et al. 2021) and irrigation scheduling (Anderson et al. 2012) and further examine the usability of these products for specialty crop growers, for example, for grape growers as harvest approaches.

b. Tactical decisions

Tactical decision-making requires information with a lead time of weeks to months that communicates the likelihood of future conditions based on current conditions and probabilities associated with future weather patterns (Hollinger 2009). Like other types of growers, perennial crop growers may be making tactical decisions about irrigation, pest/disease control, cover crops and harvest. However, unlike annual crop growers, they are also making decisions such as thinning leaves and fruits and helping new trees and vines to get off to a good start, which affect the current year's crop, next year's crop, and long-term health of plants. Postharvest, annual crop growers may be done making decisions for the year, while perennial growers are planning how much autumn mulching or irrigation is done to protect plants and roots over the winter, and for cranberry growers, the timing of winter flooding and flood removal.

Drought monitoring information can inform both operational and tactical decision-making because current conditions not only represent what has happened in the near past and the present, but it may also be indicative of near future conditions.

TABLE 5. Summary of entry-points for drought-related weather and climate information in meeting the needs of Midwest perennial specialty crop operational, tactical, and strategic decisions by season, with gaps shown in italics.

	Operational decisions	Tactical decisions	Strategic decisions
Dormant season		Hydrologic monitoring, MRCC Climate Watch snowpack and soil temperature monitoring, and NOAA CPC seasonal outlooks	ENSO forecasts, National Climate Assessments, Climate Resilience Toolkit, and USDA Climate Toolbox
Gaps		*Outlook specific to upcoming growing season (6 months out)*	*Annual to multiyear climate outlooks; Midwest-specific Future Crop Suitability Tool*
Growing season	Hourly/daily/multiday forecasts for precipitation, temperature, wind, ET stress; soil moisture monitor, ESI, and QuickDRI	U.S. Drought Monitor, ESI/QuickDRI, CPC or GRACE soil moisture monitors; monthly/seasonal climate outlooks	USDA Climate Toolbox (precipitation and water demand under future climate scenarios); hydrologic trends
Gaps	*High-spatial-resolution data; irrigation scheduler specific to specialty crops*	*Field-scale soil moisture monitoring; probabilistic prediction of current and next year's crop yield*	*Probabilistic prediction of long-term tree/vine health based on current conditions and management; long-term models of irrigation water availability*
Ripening/harvest season	Short-term heat and precipitation forecasts (e.g., daily), ESI	USGS WaterWatch streamflow monitor, NWS River Forecast Center, and NOAA National Water Model	
Gaps		*Water temperature models/outlooks; more localized hydrologic data*	*Long-term hydrologic models of local streams, reservoirs, and aquifers*
Post–harvest season	Precipitation and temperature monitoring and forecasts	MRCC Climate Watch snowpack and soil temperature monitoring, NWS Frost Depth Map, CPC or GRACE soil moisture monitoring, reservoir/hydrologic monitoring, and CPC precipitation/temperature monthly/seasonal outlooks	USDA Climate Toolbox (first freeze under future climate scenarios)
Gaps		*High-spatial-resolution soil moisture and temperature; Snowpack forecast; threat of deep frost level throughout winter*	*Long term winter snowpack, temperature, and soil temperature models*

General monitoring tools such as the weekly USDM (Svoboda et al. 2002) may provide early cues of emerging dryness at any time of the year before it is noticeable in the landscape. Specific drought indicators such as evapotranspiration and soil moisture may be more useful to growers as indicators of vegetation health (Anderson et al. 2013; Otkin et al. 2013). Evapotranspiration monitoring tools are described above in the context of operational decisions but are also of interest for tactical decision-making. For soil moisture monitoring, growers can find potentially useful information from sources such as the NOAA Climate Prediction Center (CPC; https://www.cpc.ncep.noaa.gov/products/Soilmst_Monitoring/US/Soilmst/Soilmst.shtml) and National Aeronautics and Space Administration (NASA) Gravity Recovery and Climate Experiment (GRACE; https://nasagrace.unl.edu/.). However, these tools are not field scale, and accurate and spatially relevant depiction of soil moisture has been found to be a challenge (Ford and Quiring 2019). Efforts such as the National Coordinated Soil Moisture Monitoring Network (NCSMMN; https://drought.gov/drought-in-action/national-coordinated-soil-moisture-monitoring-network) to improve delivery of soil moisture products and tools, could be targeted to meet growers' needs in the future.

Other tools may be needed to monitor long-term hydrological drought impacts such as depleted reservoirs or low-flow conditions in streams. Cranberry growers could use the U.S. Geological Survey's WaterWatch (https://waterwatch.usgs.gov/index.php), which provides hourly information about current streamflow at locations along major rivers and their tributaries, and how they compare with normal conditions. A limitation to the usability of the data, though, is that water levels within smaller streams and ponds for individual farms may differ in important ways from streamflow within the larger rivers. For forecasted information, cranberry growers could also use streamflow forecast products from the National Weather Service River Forecast Centers (https://water.weather.gov/ahps/rfc/rfc.php), as well as the National Water Model (experimental as of March 2022; https://water.noaa.gov/map).

During the dormant season, perennial fruit growers' tactical decisions consider drought mainly in relation to other climate variables such as snow cover and soil temperature. Growers may be able to use regional maps of snowfall and snow depth available publicly on websites such as the Midwestern Regional Climate Center's (MRCC) Midwest Climate Watch (https://mrcc.purdue.edu/cliwatch/watch.htm). Soil temperature data are typically measured by state mesonet sites, and MRCC provides an integrated map of individual stations through their Regional Mesonet Program (https://mrcc.purdue.edu/RMP/currentMaps.html). In addition, the NWS North Central River Forecast Center offers a frost depth map (https://www.weather.gov/ncrfc/LMI_FrostDepthmap), which may be useful for monitoring conditions during a dry, warm winter as well as the autumn and winter seasons. However, there are limitations to these monitoring datasets. For instance, the spatial resolution of observation data does not provide orchard-, vineyard-, or bog-scale information, and while gridded datasets are available, interpolation may cause inaccurate depiction of conditions on the ground. Spatial resolution of soil temperature is limited in some areas depending on available data from state mesonets, and this may reduce the value of this data resource for some growers. Therefore, growers may prefer to invest in on-site monitors to monitor conditions.

In addition to monitoring current conditions, tactical decision-making is highly dependent upon outlooks of conditions over the coming months and seasons. The NOAA CPC (https://www.cpc.ncep.noaa.gov/) provides 3–4-week, monthly, and seasonal outlooks for precipitation, temperature, and drought, including prediction of drought persistence, improvement, emergence, or removal at a broad scale across the United States. Forecasting precipitation, temperature, and/or drought far enough in advance to fully meet growers' tactical decision-making needs several weeks to months in advance is not possible with current technology and knowledge of predictability.

c. *Strategic decisions*

Strategic decision-making requires information with a lead time of many months, years, or decades that communicates the likelihood of future conditions using longer-term climate and agronomic models (Hollinger 2009). Perennial specialty crop growers' strategic decisions include choosing specific crops and varieties to plant, locating the crops for optimal health and productivity, and investing in new technologies and infrastructure such as irrigation. We found gaps in drought and climate information for meeting these specific needs, such as tools looking out over the coming year to two years. We found more information, and opportunities to adapt tools for Midwest growers, in the area of longer-term climate trends (e.g., decadal to multidecadal forecasts).

Climate decision support tools can inform long-term strategic decisions by demonstrating how precipitation, temperature, evapotranspiration, growing seasons, and hydrology might change in coming years and decades. Growers might look to National Climate Assessments (https://nca2018.globalchange.gov/) or to the Climate Explorer and related tools in the Climate Resilience Toolkit (https://toolkit.climate.gov) for general trends and expert interpretations of trends (Lipschultz et al. 2020). And more specific to agronomic concerns, growers may be able to use the USDA Climate Toolbox to explore contemporary and future cold hardiness zones (https://climatetoolbox.org/tool/Future-Cold-Hardiness-Zones) and changes in precipitation and temperatures using climate model projections and consider which trees, shrubs, or vines to plant that are most likely to thrive under future climate conditions (https://climatetoolbox.org/tool/future-climate-dashboard). The USDA toolbox includes a Future Crop Suitability tool (https://climatetoolbox.org/tool/future-crop-suitability) that predicts future climate suitability for several specialty crops in the northwest United States, based on an integration of agronomic and climate data. Growers in the Midwest would highly appreciate similar efforts for their region.

d. *General considerations for drought and climate information provision*

Many resources available for small-scale specialty crop growers' operational, tactical, or strategic decisions are not particularly user-friendly or clearly connected to their decision points. Many existing publicly available tools (including those referenced and footnoted above) require some level of technological sophistication on the part of the user. General users are unlikely to be able to discern times of year when a particular tool is more or less appropriate for their needs, or when and where to use particular datasets as indicators of drought for a particular location. This study did not extend to the investigation of specialty crop growers' feedback on each of the tools we highlight. Rather, for each of the tools highlighted, tool developers would benefit from more in-depth discussions with growers of their requirements for usability. Those discussions can be informed by an understanding of the timing and nature of critical decisions as described above. Growers too may benefit from discussions with climate communicators to help them understand and interpret all of the different variables they might be considering in their decisions. To a large degree, growers may be unaware of the many tools and resources that have been developed. Some growers or crop advisors may find it useful to participate in the North Central Climate and Drought monthly webinar series (https://www.climatehubs.usda.gov/hubs/midwest/climate-outlooks), developed in 2011 to distill and present relevant data and information at decision points throughout the year to a public audience that includes crop and livestock producers. The webinars do not currently address specialty crops to a large degree, but they could do so with demonstrated interest and involvement from stakeholders. Alternatively, similar services might be developed to specifically serve specialty crop audiences. Both the USDA Midwest Climate Hub (https://www.climatehubs.usda.gov/hubs/midwest) and the NOAA National Integrated Drought Information System (NIDIS; https://drought.gov/) Midwest Drought

Early Warning System (DEWS; https://drought.gov/about/drought-early-warning) aspire to make climate and drought science accessible and useful for decision-makers. These agencies might be considered potential partners in future efforts to align existing and newly developed drought and climate tools with specialty crop growers needs.

5. Conclusions

After developing and analyzing the specialty crop decision calendars, this project identified decision points where currently available monitoring and forecasting tools can be applied to support growers' management decisions. The project also gaps between what specialty crop growers need and what is available. The project sought to identify these gaps and research needs to improve drought monitoring and forecasting tools to better meet the needs of specialty crop growers. Further investigation of growers' perspectives on the usability of existing and potential tools is needed and should be considered a critical step in a process of tool codevelopment.

Identifying growers' information needs through a decision calendar process helps connect existing information to the specific decisions and times of year when it is most relevant. From this inventory of existing drought monitoring tools and resources, fact sheets were developed for several specialty crops to help advisors and growers see how existing tools and resources might generally meet their needs. These fact sheets can be accessed on the National Drought Mitigation Center's website (https://drought.unl.edu/OurWork/Detail.aspx?id=41; https://www.drought.gov/documents/midwest-crop-production-decision-calendars-and-fact-sheets). We suggest that even where data and tools exist and generally provide needed information, drought and climate monitoring tool providers would better serve specialty crop growers by linking the tools to growers' decisions and specific questions highlighted in Tables 2–4.

This process also highlights gaps where additional research is needed to better meet the decision-making needs of specialty crop growers, highlighted in Table 5 as well as in the questions listed in Tables 2–4. The findings open the door for climate scientists to codevelop monitoring and forecasting tools for a wider range of specialty crops and decisions. There is sufficient need and interest from specialty crop industries in the Midwest to support additional research on climate change scenarios, potential impacts, and adaptive decision-making. Future research focused more specifically on the specific needs of specialty crop growers has the potential to improve the information environment for these growers and support the growth of specialty crop industries as a means of diversifying the Midwest agricultural landscape and foodscape.

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